ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering

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BULLETIN OF ENGINEERING

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ACTA Technica CORVINIENSIS
BULLETIN OF ENGINEERING

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ACTA Technica CORVINIENSIS
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We are very pleased to inform that our international scientific journal ***ACTA TECHNICA CORVINIENSIS - Bulletin of Engineering*** *completed its six years of publication successfully [2008 - 2013, Tome I - VI].*

In a very short period it has acquired global presence and scholars from all over the world have taken it with great enthusiasm.

We are extremely grateful and heartily acknowledge the kind of support and encouragement from all contributors and all collaborators!

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Aims & Scope

General Aims

ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING is an international and interdisciplinary journal which reports on scientific and technical contributions. Every year, in four online issues (fascicules 1 - 4), ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering [e-ISSN: 2067-3809] publishes a series of reviews covering the most exciting and developing areas of engineering. Each issue contains papers reviewed by international researchers who are experts in their fields. The result is a journal that gives the scientists and engineers the opportunity to keep informed of all the current developments in their own, and related, areas of research, ensuring the new ideas across an increasingly the interdisciplinary field.

Topical reviews in materials science and engineering, each including:

- *surveys of work accomplished to date*
- *current trends in research and applications*
- *future prospects.*

As an open-access journal ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering will serve the whole engineering research community, offering a stimulating combination of the following:

- *Research Papers - concise, high impact original research articles,*
- *Scientific Papers - concise, high impact original theoretical articles,*
- *Perspectives - commissioned commentaries highlighting the impact and wider implications of research appearing in the journal.*

ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING encourages the submission of comments on papers published particularly in our journal. The journal publishes articles focused on topics of current interest within the scope of the journal and coordinated by invited guest editors. Interested authors are invited to contact one of the Editors for further details.

Mission

ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering is an international and interdisciplinary journal which reports on scientific and technical contributions. The ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering advances the understanding of both the fundamentals of engineering science and its application to the solution of challenges and problems in engineering and management, dedicated to the publication of high quality papers on all aspects of the engineering sciences and the management.

You are invited to contribute review or research papers as well as opinion in the fields of science and technology including engineering. We accept contributions (full papers) in the fields of applied sciences and technology including all branches of engineering and management.

Submission of a paper implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis) that it is not under consideration for publication elsewhere. It is not accepted to submit materials which in any way violate copyrights of third persons or law rights. An author is fully responsible ethically and legally for breaking given conditions or misleading the Editor or the Publisher.

The Editor reserves the right to return papers that do not conform to the instructions for paper preparation and template as well as papers that do not fit the scope of the journal, prior to refereeing. The Editor reserves the right not to accept the paper for print in the case of a negative review made by reviewers and also in the case of not paying the required fees if such will be fixed and in the case time of waiting for the publication of the paper would extend the period fixed by the Editor as a result of too big number of papers waiting for print. The decision of the Editor in that matter is irrevocable and their aim is care about the high content-related level of that journal.

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ENGINEERING
- ☐ Mechanical Engineering
- ☐ Metallurgical Engineering
- ☐ Agricultural Engineering
- ☐ Control Engineering
- ☐ Electrical Engineering
- ☐ Civil Engineering
- ☐ Biomedical Engineering
- ☐ Transport Engineering
- ☐ Nanoengineering

CHEMISTRY
- ☐ General Chemistry
- ☐ Analytical Chemistry
- ☐ Inorganic Chemistry
- ☐ Materials Science & Metallography
- ☐ Polymer Chemistry
- ☐ Spectroscopy
- ☐ Thermo-chemistry

ECONOMICS
- ☐ Agricultural Economics
- ☐ Development Economics
- ☐ Environmental Economics
- ☐ Industrial Organization
- ☐ Mathematical Economics
- ☐ Monetary Economics
- ☐ Resource Economics
- ☐ Transport Economics
- ☐ General Management
- ☐ Managerial Economics
- ☐ Logistics

AGRICULTURE
- ☐ Agricultural & Biological Engineering
- ☐ Food Science & Engineering
- ☐ Horticulture

COMPUTER & INFORMATION SCIENCES
- ☐ Computer Science
- ☐ Information Science

EARTH SCIENCES
- ☐ Geodesy
- ☐ Geology
- ☐ Hydrology
- ☐ Seismology
- ☐ Soil science

ENVIRONMENTAL
- ☐ Environmental Chemistry
- ☐ Environmental Science & Ecology
- ☐ Environmental Soil Science
- ☐ Environmental Health

BIOTECHNOLOGY
- ☐ Biomechanics
- ☐ Biotechnology
- ☐ Biomaterials

MATHEMATICS
- ☐ Applied mathematics
- ☐ Modeling & Optimization
- ☐ Foundations & methods

History

ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering has been published since 2008, as an online supplement of the ANNALS OF FACULTY ENGINEERING HUNEDOARA – INTERNATIONAL JOURNAL OF ENGINEERING. Now, the ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering is a free-access, online, international and multidisciplinary publication of the Faculty of Engineering Hunedoara.

ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING exchange similar publications with similar institutions of our country and from abroad.

Invitation

We are looking forward to a fruitful collaboration and we welcome you to publish in our ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering. You are invited to contribute review or research papers as well as opinion in the fields of science and technology including engineering. We accept contributions (full papers) in the fields of applied sciences and technology including all branches of engineering and management.

ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING publishes invited review papers covering the full spectrum of engineering and management. The reviews, both experimental and theoretical, provide general background information as well as a critical assessment on topics in a state of flux. We are primarily interested in those contributions which bring new insights, and papers will be selected on the basis of the importance of the new knowledge they provide.

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Advisory Board & Steering Committee & Scientific Reviewers

The Scientific Committee members and Reviewers do not receive any remuneration. These positions are voluntary.
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ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering accept for publication unpublished manuscripts on the understanding that the same manuscript is not under simultaneous consideration of other journals. Publication of a part of the data as the abstract of conference proceedings is exempted.

Manuscripts submitted (original articles, technical notes, brief communications and case studies) will be subject to peer review by the members of the Editorial Board or by qualified outside reviewers. Only papers of high scientific quality will be accepted for publication. Manuscripts are accepted for review only when they report unpublished work that is not being considered for publication elsewhere. The evaluated paper may be recommended for:

- *Acceptance without any changes – in that case the authors will be asked to send the paper electronically in the required .doc format according to authors' instructions;*
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The manuscript accepted for publication will be published in the next issue of ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering after the acceptance date.

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The Editor and editorial board members do not receive any remuneration. These positions are voluntary.
We are very pleased to inform that our journal ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING is going to complete its six years of publication successfully. In a very short period it has acquired global presence and scholars from all over the world have taken it with great enthusiasm. We are extremely grateful and heartily acknowledge the kind of support and encouragement from you.
The members of the Editorial Board may serve as scientific reviewers.
ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING is seeking qualified researchers as members of the editorial team. Like our other journals, ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING will serve as a great resource for researchers and students across the globe. We ask you to support this initiative by joining our editorial team. If you are interested in serving as a member of the editorial team, kindly send us your resume to redactie@fih.upt.ro.

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ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING
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CONTENTS of
Tome VII [2014]
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Abstract: *The momentary amount of the available solar energy and the demand usually are not equal during the usage of solar energy for heating and electric power supply. So it is necessary to store the heat energy. This article shows optimal design of a new construction, sensible heat store filled with solid heat storage material. The planned heat store has cascade system formed a spiral flow-path layout. This is a conceptual model, worked out in case of pipe-channelled construction. The aim of the special layout is to realize better overall efficiency than regular sensible heat stores have. The new construction would like to get higher overall efficiency by long flow-way, powerful thermal stratification and spiral flow-path layout which can ensure lower heat loss. The article shows the calculation method of the simulation of the charge and discharge and the calculation method of the overall efficiency using the results of the simulations. The geometric sizes and operating parameters of the thermal energy store with the best overall efficiency was calculated using genetic algorithm (GA). The results of the calculation tasks show that a thermal energy store with long flow-way, with cascade system formed spiral flow-path layout has much higher overall efficiency than an one-duct, short flow-way thermal energy store which has equal mass of solid heat storage material as the long flow-way one, mentioned before.*

Abstract: *The influence of cold rolling and solution heat-treatment on the corrosion behaviour of alumina reinforced Aluminium (6063) alloy composites in 0.3M H_2SO_4 solution was investigated. AA 6063 – Al_2O_3 particulate composites having 6, 9, and 12 volume percent of Al_2O_3 were produced using two step stir casting process. The composites were cold rolled to 20 and 35% deformation before solution heat-treating at 550°C for 1hour cooling rapidly in water. Mass loss and corrosion rate measurements were utilized as criteria for evaluating the corrosion behaviour of the composites. It is observed that AA (6063) – Al_2O_3 composites exhibited superior corrosion resistance in comparison to the unreinforced alloy in H_2SO_4 solution. Furthermore, the cold rolling – solution heat-treatment process resulted in significant improvement in corrosion resistance of the composites in comparison to the as-cast and solely solution heat-treated temper conditions.*

Abstract: *One of emission sources in the urban area have been identified as coming from the road traffic. Therefore, several simulation methods for traffic and pollution assessment are presented. There were analyzed the three main methods used for assessing the atmospheric air quality and the classification of air pollution models depending on multiple criteria. The mathematical models are used to describe the correlations between the meteorological conditions and the level of atmospheric concentrations of the pollutant emissions, analysis and interpretation of the experimental data. The primary objective of some specialised operational models is meant to supply a fast but still realistic assessment of the pollutant dispersion for the emissions due to the road traffic. The microscale numerical modelling offers the opportunity for a detailed simulation of the impact of various scenarios of urban planning, in order to establish and optimise the related strategic decisions.*

Abstract: *An experimental work was carried out to investigate some mechanical properties of Reactive Powder Concrete (RPC) which are particularly required as input data for structural design. These properties include* compressive strength, tensile strength (direct, splitting and flexural), flexural toughness, load-deflection capacity and static modulus of elasticity. The effects of three variable parameters on these properties were carefully studied which are the silica fume content SF (0%, 10%, 15%, 20%, 25%, and 30%) as a partial replacement by weight of cement, steel fibers volume fraction V_f (0%, 1%, 2% and 3%) and superplasticizer type (Sikament®-163N, PC200). The experimental results showed that as the silica fume content (SF) increases from 0% to 30% the compressive strength significantly increases, while the increase in tensile strength is relatively lower. The inclusion of steel fibers leads to a considerable increase in tensile strength, while the addition of steel fibers causes a slight increase in compressive strength of RPC as fiber volume fraction increases from 0% to 3%. The increase in the steel fibers volume fraction and silica fume content improved the load-deflection behavior and consequently gave larger ductility and fracture toughness of RPC.

Abstract: The paper reflects on development of new technologies and mentality of its developers. Authors have selected important technologies which shape future life style. Each of selected technologies has specific characteristics which require different mentality of own developers. New ways of thinking and acting are necessary for different type of education. Today we are living in the period when science strongly produces new knowledge that is simultaneously translated into in new technologies. The speed of creating new technologies increases permanently, whereas the speed of change management lags behind the technology development. Because of this, it is important that management is innovated, i.e. that management processes are reengineered. Development of new technologies has marked number of evolutionary steps that different industries have made. Once competitors have reached similar level of technological advancement, exploration of new drivers of differentiation and competitiveness entered a "soft orbit". Companies started paying additional attention to innovation and talents. Therefore authors underline the connection between selected technologies, new ways of thinking and development of more adequate organizational practice, and human resources management that support it.

Abstract: Material sustainability and efficiency in the different phases of the product life-cycle are relevant and necessary perspectives for improving the environmental and economic sustainability of products. Renewable energies need to be sustainable in all the aspects, particularly wind energy which gained the most renewable power capacity around the world in 2011. Sustainable production, maintenance and disposal of wind turbines support sustainability of the energy source. This paper identifies raw materials, auxiliary materials and operating supplies along the life-cycle of wind turbines. Furthermore, an overview of material requirements and potential improvement areas for sustainable material usage is developed and discussed.

Abstract: This paper is a review of papers with keywords Green Supply Chain Management, Lifecycle Assessment, Product Lifecycle Management, Product Life Cycle Management and Life Cycle Management. Number of articles and doctoral theses written with above mentioned concepts, methods and models were analyzed, leading to a summarized presentation of papers with their interrelated appearance. This paper is an extended article of paper published on 5th International Conference: Management of Technology - Step to Sustainable Production (MOTSP 2013).

Abstract: Due to its high resolution and the large measuring range, laser interferometer has been applied widely to the precision industrial measurement and calibration. Fabry-Perot interferometry was often used for the micro-displacement, because of its common optical path structure being insensitive to the environmental disturbances. In the past researches, some kinds of modified Fabry-Perot interferometers with corner-cube reflector have been proposed to enhance the measuring range. With such new optical structure, the Fabry-Perot interferometer can be used in the purpose of hundred milometer displacement measurement. This will be beneficial to realize the high precision displacement in the large measuring range and under the ordinary measuring environment. In this investigation, a novel folded Fabry-Perot interferometer has been proposed. With the optical design, the optical resolution is about 158.2 nm and the measurement range of the Fabry-Perot interferometer can be enhanced up to 200 mm without any tilt angle compensation system.

Abstract: 3D X-ray CT in metrological applications is the latest field of coordinate measuring technique. The first commercial measuring devices appeared on the market around 2005. Since then, gaining new market areas that previously were reserved for other devices of coordinate measuring technique. An important advantage of CT is the ability to control closed space and simultaneous verification of internal structure - for example, casting bubbles. The paper gives an overview of CT method and its potential applications as one of the newest measurement device.

Abstract: Today reusable containers, widely used in closed loops in production environments, are cleaned irrespective of their cleanliness-status and thus the actual necessity for being cleaned. This often leads to a considerable degree of technically superfluous container-cleaning, associated with high costs, transport efforts and resource utilization. This paper aims at investigating ways to harness the savings potential of a necessity based triggering of the cleaning process amid securing the quality of the container supply, controlling the uncertainty introduced into the container-loops through the status-dependent triggering of cleaning and establishing a process transparency enabling a reduction of the overall container inventory. A case study performed in an automotive supplier is included.

Abstract: Deep drawing process is a complex process of significant planar deformation. Deformation in the thickness direction is a critical phenomenon in most cases regarding possible crack creation. Therefore, it is necessary to pay a special attention to its measuring. Direct measurement of the sheet metal thickness of parts is limited by complexity of their geometry. So it is necessary to evaluate it indirectly, e.g. by optical measuring of true strain using deformation networks. The digital photography method has been proven as effective but limited to only planar strain. Multiple images stereo-photogrammetry enables digitalizing the part surface into the three-dimensional model including real texture of deformation network. Strain measurements of individual network elements are accomplished only on the virtual model with no geometry restrictions. This contribution presents the way of verifying simulation results by photogrammetric measurement of thickness changes of B-pillar drawn by Kuka Enco Werkzeugbau s.r.o.

Abstract: This paper presents the multipurpose service, emergency and rescue tracked mobile robot Hardy. The mechanical construction, technical solution, functions carried out by the robot and examples of potential applications are briefly explained in the beginning. Then follows description of the control system in the mobile robot and the operator's suitcase used for remote control. Presented are also experiences with modern electronic devices for control of hydraulic and electric motors in the robot based on the communication protocol SynqNET, implemented using technology from Robot System Integration (RSI). The next part of the paper deals with the user interface of the operator's application and some of the features that were designed to assist the operator, primarily the anti-collision system. The whole system is then critically evaluated using some experiences from practical use of the robot, even by a common user.

Abstract: Worldwide raising requirements for the heat and the energy have huge influence on decreasing amounts of the mineral resources and to increasing tendency of their prices. It is necessary to deal with them responsibly. One of these cases is using natural gas as an energy and heat source. Nowadays billions of normalized cubic meters of natural gas are transferred and used every day around the world. The most common flow measurement type, used in high-pressure pipelines, is measuring by pressure differential, which mainly uses orifice plates inserted in the pipelines. In this type of measurement it is very important to have a steady flow to avoid inaccuracies in the measurement. It could be difficult in the case of the measuring of the volumetric flow in the measuring stations, where one transit pipeline is dividing into the more pipelines of smaller diameters with lots of bendings in a small area. These bendings should have the impact on the stream field of the natural gas before the inlet to the orifice plate that could affect flowing of the gas behind the orifice plate and differential pressure measured on the orifice plate. The aim of this article is to show the magnitude of the impact of different pipeline bendings on the shape of the stream field in the high-pressure pipelines.

Abstract: Robotics is a field of modern technology that crosses traditional engineering boundaries. Understanding the complexity of robots and their applications requires knowledge of mechanical engineering, electrical engineering, systems and industrial engineering, computer science, economics, and mathematics. This paper gives survey of the position analysis, jacobian and singularity analysis, stiffness analysis, dynamics and applications of serial and parallel robots. Also a detailed comparison of the characteristics of serial and parallel robots and their advantages and disadvantages are presented.

Abstract: The later year's evolvement to a more commonly open innovation model [1] have laid a fundament for a rapid growth of Small and Medium Enterprises (SMEs). While large enterprises often have large production lines with low variation, the task for the industrial robot is predictable and highly repetitive, SMEs have more often small batch production with high variation. The SMEs have in the most recent years begun to adopt industrial robots in their production. While SMEs rarely have their own expertise on robotic installation the use has been made possible by more user friendly program editors and remote service and operations. To further enhance the flexibility and overcome the challenges of complex niche production, redundant industrial robots should be introduced to a larger extent. The challenges with redundant industrial robots have so far been the complexity related to solving the inverse kinematics with reasonable secondary tasks. This paper presents advantages of using redundant industrial robots, and aim to motivate more research on user friendly, "easy-to-use" redundancy resolutions for redundant industrial robots.

Abstract: The vehicle mass experienced a period of progressive increase. Nowadays as it is essential to decrease both the fuel consumption and the CO_2 production, lightweight design becomes a relevant target for car manufacturer. One of the considered strategy toward lightweight is the substitution of the material used for manufacturing the different parts of the car body. Together with the new developed HSS steels, aluminium and magnesium are considerded. Recently composite material solutions have gained a lot of attention due to their very interesting characteristic. The paper discusses some the relevant aspects when developing a new material solution from the material production to the end-of-life. The paper includes one example of results that can be achieved with properly oriented light weight design procedure.

Abstract: Technological production systems within food processing industry use machines which have specific requirements regarding the lubrication of particular components that come into contact with raw processing material. To satisfy stringent requirements, different types of lubricants have been developed. The problem of lubricating components and assemblies in the processing and packaging machines lies in the fact that the lubricant must possess qualities which allow it to come into contact with tobacco without compromising its safety. This paper gives an example of a synthetic ester-based gear oil used in tobacco industry. This paper reviews an example of gear reducer oil in a circulation system used for lubrication of working components of a cigarette filter making machine - Filter Maker.

Abstract: The article is aimed to clarify issues of calculation and illustrate the course of compaction process of pellet press PLG 2010. Construction of machine and its main parts are described in introduction to form image of the issue. Introduction also describes the basic principle of machine functioning. Next chapters are devoted to the principle of the finding out course of compaction ratio of the press. At the first 3D model of pressing space was created to find out of compression ratio. Next step was to divide the pressing space to smaller precisely defined parts, and measure its volume. The measured values were used to calculate exact values of compression ratio. And finally the calculated values were added to diagram, which describes illustrative course of compaction ratio the pellet press. Finally we must mention that the determined compaction ratio is not real but only idealized.

The ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, Fascicule 1/2014 [January-March/2014] includes scientific papers presented in the sections of Conference on:

- *The 5th INTERNATIONAL CONFERENCE "MANAGEMENT OF TECHNOLOGY – STEP TO SUSTAINABLE PRODUCTION" – MOTSP 2013 (29 – 31 May, 2013), in Novi Vinodolski, CROATIA, as a joint project organized by the Faculty of Mechanical Engineering and Naval Architecture in Zagreb, CROATIA. The new current identification numbers of the papers are # 6 – 10, according to the present contents list.*
- *The 7th INTERNATIONAL CONFERENCE for YOUNG RESEARCHERS and Ph.D. STUDENTS – Education, Research, INnovation 2013 – ERIN 2013 (15 – 17 May, 2013), hosted by Slovak University of Technology in Bratislava, in Častá-Papiernička, SLOVAKIA. The new current identification numbers of the papers are # 11 – 17 and # 23 – 24, according to the present contents list.*
- *The 11th INTERNATIONAL CONFERENCE on ACCOMPLISHMENTS in ELECTRICAL and MECHANICAL ENGINEERING and INFORMATION TECHNOLOGY – DEMI 2013, organized in Banja Luka, BOSNIA & HERZEGOVINA (30 May – 1 June, 2013), jointly by the Faculty of Mechanical Engineering, University of East Sarajevo. The new current identification number of the papers are # 20 – 22, according to the present contents list.*
- *The INTERNATIONAL CONFERENCE MOTOR VEHICLE & TRANSPORTATION – MVT 2012, organized in Timisoara, ROMANIA (7 – 9 November, 2012), hosted by the University "Politehnica" of Timisoara, Mechanical Engineering Faculty, Road Vehicles and Transportation Department, under support of SIAR (Society of Automotive Engineers of Romania).*

Also, the ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, Fascicule 1/2014 [January-March/2014] includes, also, original papers submitted to the Editorial Board, directly by authors or by the regional collaborators of the Journal.

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[1.] Tibor BORBÉLY

OPTIMAL DESIGN OF SEASONAL PIPE-CHANNELLED THERMAL ENERGY STORE WITH GAS HEAT TRANSPORT MEDIUM

[1.] University of Pannonia, Institute of Mechanical Engineering, Veszprém, HUNGARY

Abstract: *The momentary amount of the available solar energy and the demand usually are not equal during the usage of solar energy for heating and electric power supply. So it is necessary to store the heat energy. This article shows optimal design of a new construction, sensible heat store filled with solid heat storage material. The planned heat store has cascade system formed a spiral flow-path layout. This is a conceptual model, worked out in case of pipe-channelled construction. The aim of the special layout is to realize better overall efficiency than regular sensible heat stores have. The new construction would like to get higher overall efficiency by long flow-way, powerful thermal stratification and spiral flow-path layout which can ensure lower heat loss. The article shows the calculation method of the simulation of the charge and discharge and the calculation method of the overall efficiency using the results of the simulations. The geometric sizes and operating parameters of the thermal energy store with the best overall efficiency was calculated using genetic algorithm (GA). The results of the calculation tasks show that a thermal energy store with long flow-way, with cascade system formed spiral flow-path layout has much higher overall efficiency than an one-duct, short flow-way thermal energy store which has equal mass of solid heat storage material as the long flow-way one, mentioned before.*
Keywords: *solar energy, heat storage, solid charge, sensible heat, optimization*

INTRODUCTION

The possible thermal energy storing methods are: sensible heat storage, latent heat storage, sorption heat storage and chemical energy storage [1]- [8].

The simplest way is the storage of sensible heat, by heating a heat storage material without phase changing. The energy density of the sensible heat storage will be high if the specific heat and the density of the heat storage material are great as well [9].

Out of the materials which can be found in the environment in large quantity, the water has the greatest volumetric heat capacity (~4.18 MJ/m^{3}K), but water can be applied at atmospheric pressure up to 100 ^{o}C only. The heat transport media of the concentrated solar power systems can be used as heat storage liquids as well. The melt of the solar salt (60% $NaNO_3$ + 40% KNO_3) is used out of these materials in concentrated solar power plants as heat storage material (operating temperature range 260-550 ^{o}C, volumetric heat capacity ~2.84 MJ/m^{3}K [11]). It is not flammable, not toxic, and not too expensive.

The volumetric heat capacity of some solid materials (magnesite, corundum) –because of their higher density– come near to the volumetric heat capacity of the water with much higher upper temperature limits (magnesite 3.77 MJ/m^{3}K, corundum 3.3 MJ/m^{3}K, cast iron 4.1 MJ/m^{3}K [10]).

Screened pebble stone, cracked stone (1.5-2.5 MJ/m^{3}K), concrete (0.8-1.8 MJ/m^{3}K), wet soil (3.56 MJ/m^{3}K) [10] are used as sensible heat storage materials, because they are inexpensive.

The sensible heat stores are typical regenerative heat-exchangers. These are instationary thermal state heat-exchangers. The regenerators are long ago applied, great heat capacity heat stores with solid fill and with short charge-discharge cycle time (10-7200 s). My aims were to study the possible interior structure of the long-term heat stores, the charge-discharge process, to calculate the optimal geometric sizes and operating parameters of those.

COMPARISON OF SHORT (L/D<10) AND LONG (10<L/D) HEAT STORES

The temperature-place function of the heat transport medium is similar to the temperature-place function of the solid heat storage material at a moment (the temperature of the heat transport medium t_f is higher at charge, lower at discharge than the temperature of the solid heat storage material t_s), so it is enough to show the temperature-place functions of the solid heat storage material.

Charge

The hot heat transport medium gives a part of its heat content to the solid heat storage material by flowing through the heat store, which is cold at the beginning of the charge period.

In case of short heat store the outlet temperature of the heat transport medium and the solid heat storage material are increasing soon after the beginning of the charging (Figure 1), in case of long heat store they start to increase only at the end of the charge period (Figure 2).

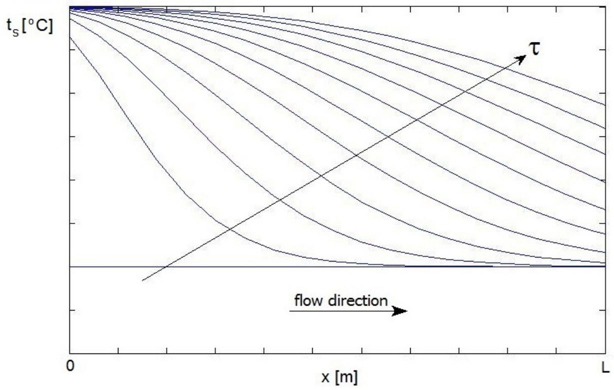

Figure 1. The temperature-place functions of the solid heat storage material during charge, in case of short heat store

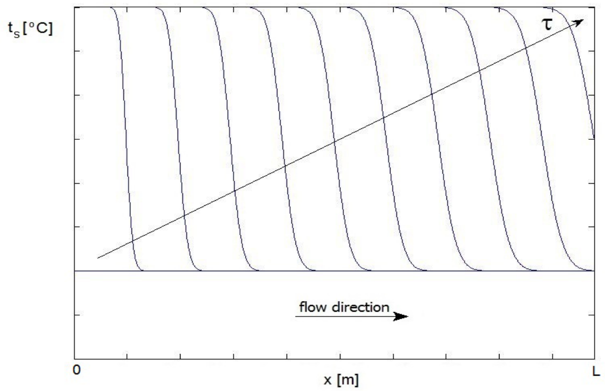

Figure 2. The temperature-place functions of the solid heat storage material during charge, in case of long heat store

Discharge

In the discharge period the cold heat transport medium flows through the hot heat store in opposite flow direction of the charge.

In case of short heat store the outlet temperatures of the heat transport medium and the solid heat storage material are decreasing soon after the beginning of the discharging (Figure 3), in case of long heat store they start to decrease only at the end of the discharge period (Figure 4).

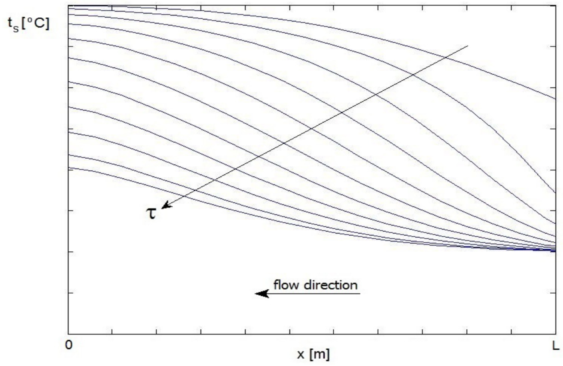

Figure 3. The temperature-place functions of the solid heat storage material during discharge, in case of short heat store

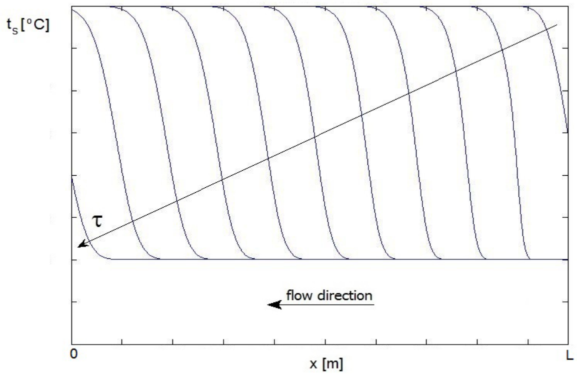

Figure 4. The temperature-place functions of the solid heat storage material during discharge, in case of long heat store

BASIC IDEA OF THE CASCADE SYSTEM HEAT STORE

During the charging and discharging of the long heat store the thermocline zone is located only in a part of the length of the heat store. It is plausible solution to divide to sections the heat store and allow knocking-off the sections from the flow-path of the heat transport medium. Let's call these sections as ducts. In case of the cascade system heat store the heat transport medium must flow through only the ducts where the thermocline zone is going along. The transport power demand of the heat transport medium can be reduced by this solution.

The heat-loss of the heat store into the environment will be small if the heat store has small specific surface. From the prismatic bodies the cylinder with H/D=1 ratio has the smallest specific surface, followed by the regular n-sided prism with H/S=1 ratio (assuming that the heat-loss flux is approximately equal in all sides of the body).

The higher heat-loss of the long heat store (because of its greater specific surface) can be reduced by using cascade system of the ducts formed a spiral flow-path layout (see later on Figure 5).

Out of the regular n-sided prisms the three-sided, four-sided and six-sided are suitable to build from them regular n-sided prisms without gaps.

THE GEOMETRY AND OPERATING OF THE HEAT STORE MADE FROM PIPE-CHANNELLED BRICKS

The pipe-channelled ducts of the heat store are regular hexagonal prisms with metal shell and outer thermal insulation. The metal shell holds the heat transport medium in. The thermal insulation supports the thermal stratification in radial direction.

The heat store is built up from pipe-channelled ducts. The outer geometry of the heat store is of regular hexagonal prism with $H/S_t \approx 1$ ratio and cascade system of the ducts formed a spiral flow-path layout.

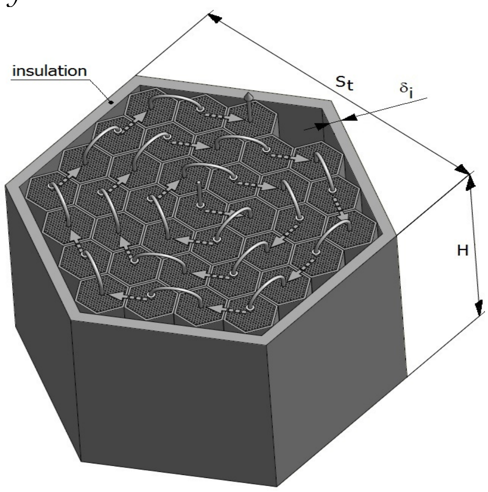

Figure 5. The constructional layout of the pipe-channelled heat store and arrangement in the cascade system with spiral connection
S_t – side distance of the heat store, H – bed height of a duct, δ_i – thickness of the outer thermal insulation

The number of ducts N_j is an odd one in case of full filling, but leaving out the last duct we get an even number, so it is possible to lock out or join in the heat transport medium flow into any duct-pairs (duct-pair means a pair of ducts, one downwards and another upwards). This way the place of the last duct could be used e.g. for service purpose.

The hot heat transport medium is put in at the top of the middle duct at the beginning of charge and it flows downwards, it turns in the return band flows into the next duct (the lower connecting of the ducts is signed with dashed arrow) and flows trough that upwards. The heat transport medium coming out from the second duct can be led to the next pair of ducts. The heat transport medium must flow through only the ducts where the thermocline zone is going along. In the discharge period the cold heat transport medium flows through the hot heat store opposite to the flow-direction of the charge (from outside to middle).

The main sizes of a duct of the heat store can be seen in Figure 6.

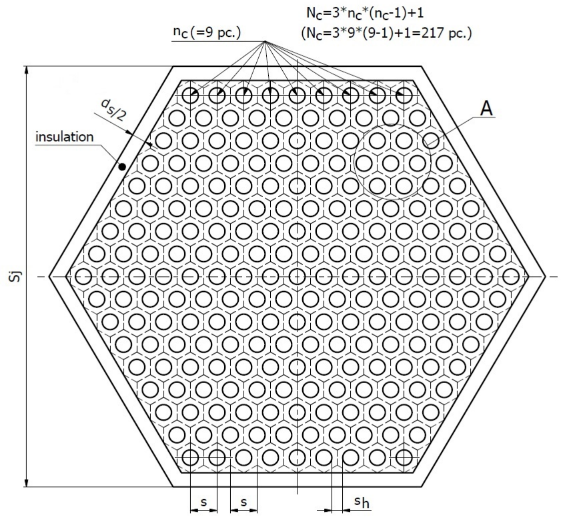

Figure 6. Top view of a pipe-channelled duct with the main sizes
S_j – side-distance of the insulated duct, d_s – whole thickness of the thermal insulation between two ducts, n_c – number of channels along a side-length of a duct, N_c – total number of channels of a duct, s – distance between the center of two pipe-channels, s_h – minimal material-thickness between two pipe-channels.

The centres of the pipe-channels form an equal-sided triange shape. The heat storage material which belongs to a pipe-channel can be replaced by a pipe of equal solid volume (drawn with dashed line in Figure 7).

The pipe-channels of the bricks of a duct are arranged so that they make the pipe-channels connected along the whole duct. The whole cross-

section of a duct can not be made from a single brick – because of the cross-sectional size of the duct.

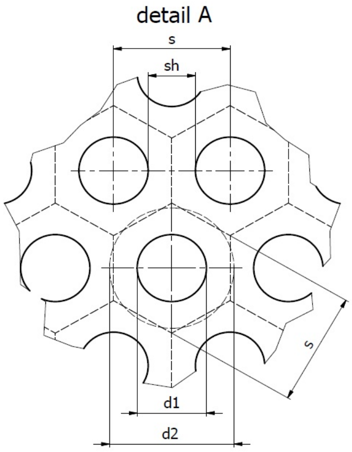

Figure 7. The part of the heat storage medium which belongs to a pipe-channel and approximation principle of it
d_1 – inside diameter of a pipe-channel, d_2 – equivalent outside diameter of the substitutional heat storage pipe.

BASIC DIFFERENTIAL EQUATIONS OF THE HEAT TRANSPORT IN THE PIPE-CHANNELLED HEAT STORE

Ismail, K. A. R. and Stuginsky Jr., R. [12] have reported an excellent comparative analysis of several models for description of the heat transfer in the heat transport medium and the solid heat storage material.

For both media I have chosen a bit simpler model than the general, one-dimensional model and then I have converted it to be suitable for the case of the pipe-channelled model. The heat-loss boundary condition is not included in the differential equations, because it takes effect only at the outer ducts, the effect of it will be calculated separately from the calculation of the temperature-place functions.

The differential equation for the description of the heat transfer in the heat transport medium is

$$\varepsilon\ \rho_f\ c_f\left(\frac{\partial t_f}{\partial \tau}+w_f\frac{\partial t_f}{\partial x}\right)=\alpha_f\ a_p(t_s-t_f), \quad (1)$$

where t_f is temperature of the flowing heat transport medium, t_s is temperature of the solid heat storage material, ρ_f is density of the heat transport medium, c_f is specific heat of the heat transport medium, w_f is average velocity of the heat transport medium in the flow-channels, a_p is superficial heat transfer surface area per unit bed volume, α_f is heat transfer coefficient between the flowing heat transport medium and the solid heat storage material, ε is void fraction.

The void fraction ε in case of pipe-channelled heat store (see Figure 7) is

$$\varepsilon=\frac{\frac{d_1^2\pi}{4}}{\frac{\sqrt{3}}{2}s^2}=\frac{\frac{d_1^2\pi}{4}}{\frac{d_2^2\pi}{4}}=\left(\frac{d_1}{d_2}\right)^2. \quad (2)$$

The superficial heat transfer surface area per unit bed volume a_p in case of pipe-channelled heat store is (see Figure 7)

$$a_p=\frac{d_1\pi}{\frac{\sqrt{3}}{2}s^2}=\frac{d_1\pi}{\frac{d_2^2\pi}{4}}=\frac{4d_1}{d_2^2}. \quad (3)$$

The differential equation of the heat transfer in the heat transport medium was discretized by applying explicit forward difference scheme in time and upwind difference scheme in space [13], [14].

The differential equation for the description of the heat transfer in the solid heat storage material is

$$(1-\varepsilon)\ \rho_s\ c_s\frac{\partial t_s}{\partial \tau}=\lambda_{seffx}\frac{\partial^2 t_s}{\partial x^2}+\alpha_f\ a_p(t_f-t_s), \quad (4)$$

where ρ_s is density of the solid heat storage material, c_s is specific heat of the solid heat storage material, λ_{seffx} is effective axial thermal conductivity of the solid heat storage material.

The effective axial thermal conductivity of the solid heat storage material λ_{seffx} is

$$\lambda_{seffx}=(1-\varepsilon)\ \lambda_s, \quad (5)$$

where λ_s is thermal conductivity of the solid heat storage material.

The differential equation of the heat transfer in the solid heat storage material was discretized by applying explicit forward difference scheme in time and centred difference scheme in space (FTCS) [13], [14].

The heat transfer coefficient between the flowing heat transport medium and the solid heat storage material was calculated according to [16].

THE DESIGN VARIABLES

The velocity of the flowing heat transport medium w_f has the most influence on the charge and discharge. Out of sizes in Figure 7. d_1 and s or s_h are the most important geometrical sizes which can be chosen in order to be optimization variables together with the velocity of the heat transport

medium w_f. In the w_f-d_1-s or the w_f-d_1-s_h groups there are only two independent design variables.
The economical flow velocity in pipelines (nonlinearly) depends on the inside diameter of the pipe [15], but there is such a k exhibitor, with that w_{fmax}/d_1^k and w_{fmin}/d_1^k are nearly constant against to d_1. This value for the exhibitor is k=0.6. The w_{fmax}/d_1^k and w_{fmin}/d_1^k can be used as restriction limits. The design variables are the following

$$x_1 = \frac{w_f}{d_1^{0.6}},\ x_2 = s_h. \tag{6}$$

DEFINITION OF THE RESTRICTIONS

Geometric restrictions

In case of a pipeline the upper limit of the variable x_1 would be restricted by the operation cost, the lower limit would be restricted by the investment cost. In case of the pipe-channelled heat store there is not such lower limit, so I have decreased the lower limit.
Limits for design variable x_1 are given by

$$1\frac{m^{0.4}}{s} \le x_1 \le 110\frac{m^{0.4}}{s}. \tag{7}$$

Lower limit of the size s_h is restricted by the manufacturing technology, and the upper limit is also restricted by the minimal way-length of the heat transfer in the heat storage material.
Limits for design variable x_2 are are given by

$$0.01\ \text{m} \le x_2 \le 0.1\ \text{m}. \tag{8}$$

The lower limit of the diameter of the pipe-channel d_1 is restricted by the manufacturing technology and the mountability

$$0.01\ m \le d_1. \tag{9}$$

For the minimal specific surface the best value of the geometric ratio could be

$$\frac{H}{S_t} \approx 1. \tag{10}$$

Integral restriction

The number of channels along a side-length of a duct n_c must be integer.

Pressure drop restriction

The pressure drop of the heat transport medium flowing through the pipe-channels in case of incompressible medium is

$$\Delta p' = \lambda_{fr}\frac{L}{d_1}\frac{\rho_f}{2}w_f^{\,2}, \tag{11}$$

where λ_{fr} is friction factor.

In case of compressible medium and if the pressure drop is lower than 10 percent of the entire pressure this equation could be used [17].
The pressure drop of the heat transport medium must be restricted in order not to be necessary to install pressure resistant shell, not to get high transport work demand, can be negligible the compressibility of the gas and may be sufficient to use ventilator instead of blower or compressor in case of gas heat transport medium.
The upper pressure drop limit for L=2H flow-way length according to the previous requirements is

$$\Delta p'_{2H} \le 10000\ Pa = 0.1\ bar. \tag{12}$$

COMPOSITION OF THE OBJECTIVE FUNCTION

The objective function is the overall efficiency of the heat storage, which is suitable to compare the variants of the heat stores. The optimal sizes and operating parameters could be got from the maximum-point of the objective function.
In the calculation of the overall efficiency I relate the part of the extractable heat quantity which can be used for heating and electric power production to the sensible heat storage capacity of the heat store as it is here:

$$\eta_o = \frac{Q_{hid} - Q_l - Q_{tr}}{Q_{cap}}, \tag{13}$$

where Q_{hid} is extractable heat quantity from the heat store during a charge-discharge cycle without heat-loss, Q_l is heat-loss to the environment through the boundary surfaces during a charge-discharge cycle, Q_{tr} is heat-equivalent of the transport work demand during a charge-discharge cycle, Q_{cap} is sensible heat storage capacity of the heat store between the inlet and outlet temperature of the heat transport medium at the charge.
The optimal value of the design variable can be searched by optimization using the calculation of the temperature-place functions during the whole length of the charge-discharge cycle.

The heat quantity Q_{hid}

The heat quantity Q_{hid} is the difference between the heat-content of the heat store after charge and after discharge without heat-loss.
It is necessary to know the temperature-place functions of the heat store at the end of the charge and at the end of the discharge. The heat quantity Q_{hid} is

$$Q_{hid} = \int_0^{N_j H} c_s\ \rho_s\ N_c \left(\frac{\sqrt{3}}{2} s^2 - \frac{d_l^2\ \pi}{4} \right) \left(t_s(x,\tau_c) - t_s(x,\tau_c+\tau_d) \right) dx, \quad (14)$$

where τ_c is term of charge, τ_d is term of discharge.

The final temperature-place function of the charge of the heat store is the initial condition of the discharge. In the discharge period the heat transport medium flows through the heat store in opposite flow direction of the charge.

The heat quantity Q_l

The heat quantity Q_l is the heat-loss into the environment through the boundary surfaces during a charge-discharge cycle is

$$Q_l = Q_{lr} + Q_{ls} + Q_{lb}, \quad (15)$$

where Q_{lr} is heat-loss to the environment through the roof surface, Q_{ls} is heat-loss to the environment through the side surfaces, Q_{lb} is heat-loss to the environment through the bottom and the ambient ground.

The calculation of the heat-loss has taken into account the temperature of the heat store changing in place and time.

The heat quantity Q_{tr}

The heat quantity Q_{tr} is the heat-equivalent of the transport work demand during a charge-discharge cycle.

The heat quantity Q_{tr} is approximated

$$Q_{tr} = \frac{(N_{j2Hc}\ \tau_c + N_{j2Hd}\ \tau_d)\ \dot{m}_f\ \ \rho_f\ \ \Delta p'_{2H}}{\eta_{oh}}, \quad (16)$$

where N_{j2Hc} is average number of duct-pairs which are simultaneously used during the charge, N_{j2Hd} is average number of duct-pairs which are simultaneously used during the discharge, $\dot{m}_f$ is mass flow rate of the heat transport medium, $\Delta p'_{2H}$ is pressure drop of the heat transport medium on L=2H flow-way length, η_{oh} is overall efficiency of the electric power production in a heat power station.

The heat quantity Q_{cap}

The heat quantity Q_{cap} is the sensible heat storage capacity of the heat store between the inlet and outlet temperature of the heat transport medium at the charge (Eq.17).

$$Q_{cap} = \dot{Q}_f\ \tau_c = \dot{m}_f\ c_f (t_{f,ci} - t_{f,co})\ \tau_c = m_s\ c_s (t_{s,ce} - t_{s,cs}), \quad (17)$$

where $\dot{Q}_f$ is heat current during the charge, $t_{f,ci}$ is inlet temperature of the heat transport medium at charge, $t_{f,co}$ is outlet temperature of the heat transport medium at charge, m_s is mass of the heat storage material, $t_{s,cs}$ is (homogeneous) temperature of the solid heat storage material at the start of the charging, $t_{s,ce}$ is (homogeneous) temperature of the solid heat storage material at the end of the charging.

Basic data of the optimization task

We have made the calculations during the optimization with the following main data:

τ_c=63 day=1512 h=5 443 200 s, $\dot{Q}_f$=2 MW,

$t_{f,ci}$=400 °C, $t_{s,cs}$=100 °C, d_s=0.2 m.

τ_d=58 day=1392 h=5 011 200 s.

The solid heat storage material is magnesite, its physical properties are at $t_{s,mid}$ [10.]:

$t_{s,mid}=(t_{s,cs}+t_{s,ce})/2$=(100 °C+400 °C)/2=250 °C

λ_s=23.26 W/mK, ρ_s=3500 kg/m³, c_s=1077.5 J/kgK.

The required mass of the heat storage material for an ideal heat store: m_s=33 678 t.

The heat transport medium is nearly ambient pressure air, its physical properties are at $t_{f,mid}$ [10]:

$t_{f,mid}=(t_{f,ci}+t_{f,co})/2$=(400 °C+100 °C)/2=250 °C

λ_f=0.0425 W/mK, ρ_f=0.6715 kg/m³,

c_f=1038.5 J/kgK, $\nu_f=4.1525 \cdot 10^{-5}$ m²/s.

The final temperature-place function of the charge of the heat store is the initial condition of the discharge.

The mass flow rate of the heat transport medium is constant during the charge-discharge process.

The inlet temperature of the heat transport medium during discharge is: $t_{f,di}$=100 °C.

Data of the outer thermal insulation:

λ_i=0.0468 W/mK, δ_i=1 m. η_{oh}=0.3.

I have applied the genetic optimization algorithm of the Matlab software in order to find the optimal geometric sizes and operating parameters of the thermal energy store with the best overall efficiency.

OPTIMAL SIZES AND OPERATING PARAMETERS OF THE PIPE-CHANNELLED THERMAL ENERGY STORE WITH THE BEST OVERALL EFFICIENCY

The optimization process has been executed with number of ducts N_j=1, 6, 18, 36, 60, 90, 126, 168. The results are summarized in Table 1. and Figure 8.

Table 1. Optimal sizes and overall efficiencies with several number of ducts

N_j [-]	1	6	18	36
x_1 [$m^{0.4}$/s]	1	5	8	10
x_2 [m]	0.01	0.01	0.01	0.01
H [m]	25.7	29.6	29.8	31.1
L [m]	25.7	177.7	536.1	1121.3
S_j [m]	24.5	9.74	6.12	4.62
S_t [m]	26.5	30.1	30.3	31.3
N_c [-]	1230721	155269	37969	13669
d_1 [mm]	11.9	14.2	20.4	27.7
d_2 [mm]	23.0	25.4	31.9	39.6
s [mm]	21.9	24.2	30.4	37.7
s_h [mm]	10.0	10.0	10.0	10.0
w_f [m/s]	0.07	0.39	0.77	1.16
Q_{cap} [PJ]	10.89	10.89	10.89	10.89
Q_{hid} [PJ]	7.09	9.28	9.89	10.07
Q_l [PJ]	0.94	1.12	1.08	1.11
Q_{tr} [PJ]	0.004	0.09	0.13	0.16
η_o [-]	0.5644	0.7417	0.7970	0.8083
N_j [-]	60	90	126	168
x_1 [$m^{0.4}$/s]	11	15	9	7
x_2 [m]	0.01	0.01	0.01	0.01
H [m]	32.4	33.2	36.4	41.6
L [m]	1945.8	2990.7	4591.8	6988.4
S_j [m]	3.82	3.18	3.09	2.90
S_t [m]	32.9	33.2	37.7	40.6
N_c [-]	5941	3571	1141	397
d_1 [mm]	36.8	39.7	74.9	123.8
d_2 [mm]	49.1	52.2	89.2	140.5
s [mm]	46.8	49.7	84.9	133.8
s_h [mm]	10.0	10.0	10.0	10.0
w_f [m/s]	1.52	2.16	1.90	2.00
Q_{cap} [PJ]	10.89	10.89	10.89	10.89
Q_{hid} [PJ]	10.12	10.15	10.19	10.25
Q_l [PJ]	1.17	1.18	1.40	1.57
Q_{tr} [PJ]	0.19	0.32	0.29	0.23
η_o [-]	0.8049	0.7951	0.7808	0.7764

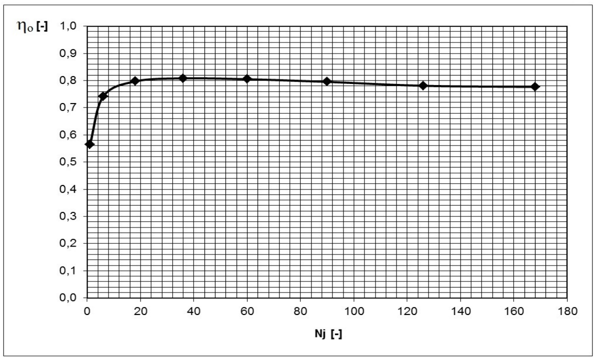

Figure 8. The optimal overall efficiency against the number of ducts

MAIN RESULTS

The best overall efficiency can be reached with 36 ducts. This is much better than the overall efficiency of one-duct type and six-duct type, it is slightly better than the overall efficiency of 18-, 60-, 90-, 126-, 168-duct types. The reason of the decrease of the overall efficiency in case of larger number of ducts is the increasing transport work demand of the heat transport medium and the increasing heat-loss.

The advantage of the multi-duct type against the one-duct type is the smaller cross-section of a duct. It is easier to distribute the stream of the heat transport medium along a smaller flowing cross-section than along a larger one.

The location of the optimal combination of the design variables can be seen in Figure 9: a version N_j=1; b version N_j=6, N_j=18, N_j=36, N_j=60; c version N_j=90, N_j=126, N_j=168. The grey area is the available range of the design variables.

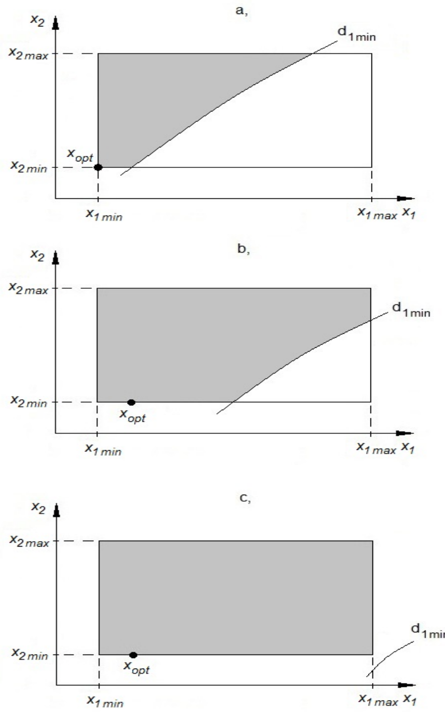

Figure 9. The location of the optimal combination of the design variables

In case of technical tasks the location of the optimal combination of the design variables is often at the border of the available territory. The location of the opimum may move by changing the basic data. In this case it is easy to get general design principles which are suitable to design nearly optimal construction without any optimization process.

The results show that the small minimal material-thickness between two pipe-channels s_h is advantageous.

Greater flow velocity of the gas heat transport medium w_f coluld make shorter thermocline zone, but the optimal flow velocity is lower than 20 percent of the economic flow velocity in pipelines w_{fmin} – because of the greater transport work demand of the greater flow velocity w_f.

The diamaters of the pipe-channel d_1 of the optimal solutions are greater than the lower limit restricted by the manufacturing technology and the mountability.

CONCLUSIONS

I have worked out the constructional and the mathematical model of the long flow-way, pipe-channelled sensible heat store with cascade system. The temperature-place functions and the overall efficiency can be calculated using the mathematical model.

I have used genetic optimization algorithm in order to find the optimal variant of the thermal energy store with the best overall efficiency.

The chargeable and the dischargeable heat quantity of the multi-duct, long flow-way heat store is more than of the one-duct, short flow-way thermal energy store with equal mass of solid heat storage material. The temperature level of the outgoing heat transport medium is more advantageous in case of the multi-duct heat store than in case of the one-duct type during the whole charge-discharge cycle.

The heat-loss can be reduced by using heat store with small specific surface and by allowing charge from middle to outside and discharge from outside to middle.

The transport power demand of the heat transport medium can be reduced by making the flow of the transport medium only through the ducts where the thermocline zone is going along.

According to the results of the optimization much higher overall efficiency can be reached in case of 36-duct type than in case of one-duct type pipe-channelled heat store.

The overall efficiency decreases with further increasing of the number of ducts – because of the increasing of the transport work demand.

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CORROSION BEHAVIOUR OF COLD DEFORMED AND SOLUTION HEAT-TREATED ALUMINA REINFORCED ALUMINIUM MATRIX COMPOSITES IN 0.3M H_2SO_4 SOLUTION

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Abstract: *The influence of cold rolling and solution heat-treatment on the corrosion behaviour of alumina reinforced Aluminium (6063) alloy composites in 0.3M H_2SO_4 solution was investigated. AA 6063 – Al_2O_3 particulate composites having 6, 9, and 12 volume percent of Al_2O_3 were produced using two step stir casting process. The composites were cold rolled to 20 and 35% deformation before solution heat-treating at 550°C for 1hour cooling rapidly in water. Mass loss and corrosion rate measurements were utilized as criteria for evaluating the corrosion behaviour of the composites. It is observed that AA (6063) – Al_2O_3 composites exhibited superior corrosion resistance in comparison to the unreinforced alloy in H_2SO_4 solution. Furthermore, the cold rolling – solution heat-treatment process resulted in significant improvement in corrosion resistance of the composites in comparison to the as-cast and solely solution heat-treated temper conditions.*

Keywords: *Stir casting; Al (6063) – Al_2O_3 composite; solution heat-treatment; Corrosion rate; mass loss*

INTRODUCTION

Improving the performance of Aluminium matrix composites (AMCs) in varied service applications is of paramount interest to Materials Engineers. This has contributed largely to the efforts in developing novel processing techniques for the production of AMCs [1-3]. Stir casting process has continued to attract patronage from researchers for the production of AMCs due to its low cost, simplicity of processing, and adaptability to mass production among others [4-5]. There have been sustained efforts to improve the properties of AMCs developed by stir casting through thermo-mechanical processing [6-7]. These secondary processing operations (extrusion, forging, rolling) have been observed to result in a marked improvement in mechanical properties [3, 7]; however conclusive information on its effect on the corrosion behaviour of AMCs is yet to be reported.

Understanding the corrosion behaviour of AMCs has been quite problematic – in some cases, reinforcements have been observed to improve corrosion resistance [8-10] while in some other reports, corrosion susceptibility was observed to increase [11]. The conflict in research observations has made it elusive for a comprehensive assessment of the corrosion behaviour of AMCs to be documented. This has created the necessity for corrosion studies to be carried out on specific aluminium alloy based composite systems. The present work is an effort to study the corrosion behaviour of cold rolled and solution heat-treated alumina particulate reinforced Aluminium alloy 6063 (AA 6063) composites in sulphuric acid medium. The cold deformation and solution heat-treatment processing has been reported to result in marked improvement in mechanical properties of the composite [12] but its impact on corrosion behaviour has not received considerable attention. The interest in studying the corrosion behaviour of the composite in sulphuric acid medium is informed by its potential applications in chemical industries where it could come in contact with acids during operations such as cleaning, pickling, *and de-scaling [13]. Aluminium alloys especially AA6063 are used extensively in developing countries for structural and architectural design due to their attractive mechanical properties, good extrusion properties, low cost and excellent corrosion resistance [4]*

MATERIAL AND METHOD

Composite Production

Aluminium alloy (6063) with composition as presented in Table 1 was utilized as the metal matrix while 100% chemically pure alumina with particle size of 28µm was used as the reinforcement. The composites having 6, 9 and 12 volume percent alumina were produced by adopting a two-step stir casting technique. The wettability of the composite was improved by preheating the alumina particles before introducing it into the liquid alloy. The two step stirring technique was adopted to improve the distribution of particles in the matrix. It entails melting the aluminium alloy in a gas fired crucible furnace, the melt was allowed to solidify to a semi-solid state after which the preheated alumina was introduced and stirred manually for 5 minutes to break the surface gas layers. This was then followed by heating the mix to a temperature of 720°C accompanied with mechanical stirring at 300rpm for 10 minutes before pouring into prepared sand moulds. Monolithic aluminium alloy was also prepared for control experimentation.

Table 1: Chemical Composition of the Aluminium Alloy 6063 (AA 6063)

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
0.45	0.22	0.02	0.03	0.50	0.02	0.03	0.02	Bal.

Mechanical and Thermal Processing

Four different temper conditions were utilized in this present study, the as cast condition and three others namely, solution heat-treated only, 20% cold rolled and solution heat-treated; and 35% cold rolled and solution heat-treated. The solution heat-treatment was carried out by heating the samples to 550°C, holding for 1 hour and then quenching rapidly in water.

Immersion Testing

The corrosion tests were carried out in 0.3 M H_2SO_4 (pH 0.3) which was prepared following standard procedures. The specimens for the test were cut to sizes 20 × 20 × 5 mm, after which the sample surfaces were mechanically polished with emery papers starting from 120 grit down to 640 grit size. The samples were degreased in acetone and then rinsed with distilled water before immersion in still solutions which were exposed to atmospheric air. The solution-to-specimen surface area ratio was about 150 ml cm^{-2}. The result of the corrosion test was evaluated using mass loss and corrosion rate measurement and the experiment was monitored on forty-eight hours interval for 648 hours. Mass loss (g/cm^2) was determined by dividing the cumulative weight loss (measured using a four decimal digit electronic weighing balance) by its total surface area in accordance with ASTM G31 standard recommended practices [14]. The corrosion rate in millimetre per year (mmy) was determined from the weight loss following standard procedures.

RESULTS AND DISCUSSION

Corrosion Behaviour of the AA 6063 Composites in 0.3M H_2SO_4 Solution

Figures 1 – 4 show the variation of mass loss and corrosion rate with volume percent alumina for the composites in as-cast, solution heat-treated, 20 % and 35 % cold rolled and solution heat-treated conditions. Figure 1 shows the mass loss and corrosion rate plots for the as-cast composites. The mass loss does not show any apparent difference in corrosion susceptibility of the composites but the corrosion rate plot (Figure 1b) indicates that the 12vol.% alumina reinforced AA 6063 composite exhibited the best resistance to corrosion in comparison with the unreinforced alloy and the lower vol.% alumina reinforced AA 6063 composites. In the case of the solution heat-treated condition, it is observed from the mass loss plot (Figure 2a) that corrosion resistance increases with increase in alumina volume percent with the unreinforced alloy showing the greatest susceptibility to corrosion. This trend is supported by the corrosion rate plots (Figure 2b) in which it is observed that peak corrosion rate was obtained after 72 hours of exposure in the sulphuric acid solution but stable corrosion rate was obtained for the remaining days of immersion. For the 20% cold rolled and solution heat-treated condition (Figure 3), it is also observed from the mass loss plots that the corrosion resistance of the composites was *superior to that of the unreinforced alloy. However, there was no particular trend observed with respect to volume percent alumina. In the case of the 35% cold rolled and solution heat-treated samples (Figure 4), again the composites exhibited superior corrosion resistance in comparison to the unreinforced alloy. The superior corrosion resistance of the composites over the unreinforced AA 6063 alloy indicates the composites will be suitable for use in mild H_2SO_4 environments.*

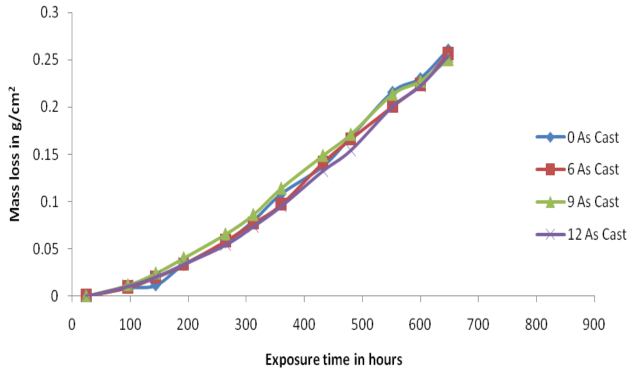

Figure 1(a): Variation of mass loss against exposure time for as cast alloy and composites

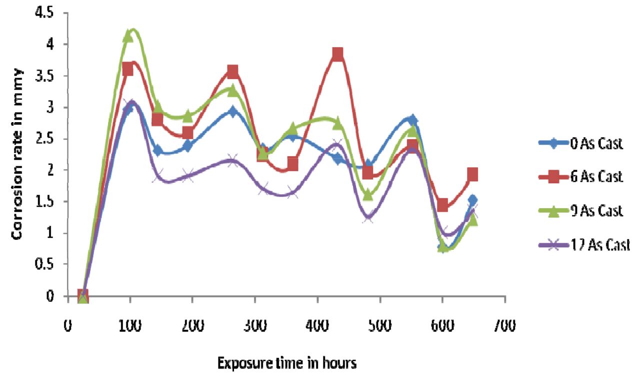

Figure 1(b): Variation of Corrosion rate against exposure time of as cast alloy and composites

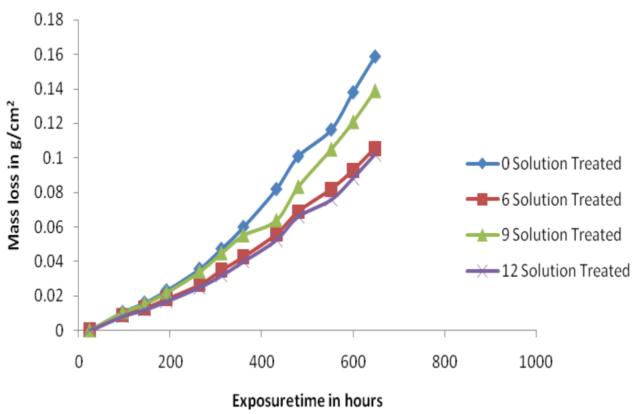

Figure 2(a): Variation of mass loss against explosion time of solution treated alloy and composites.

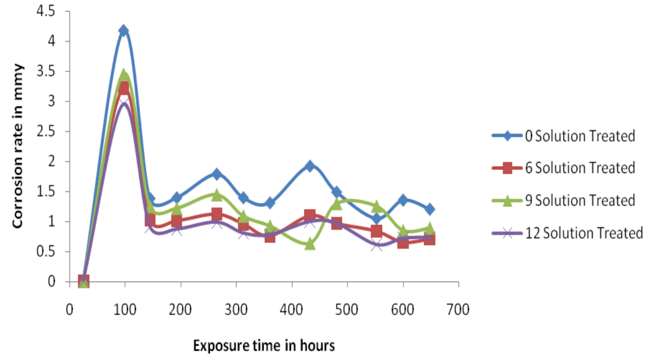

Figure 2(b): Variation of corrosion rate against exposure time of solution treated alloy and composites

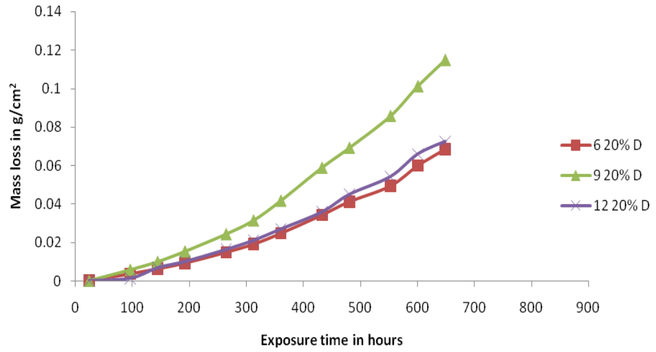

Figure 3(a): Variation of mass loss against exposure time of alloy and composites subjected to 20% deformation plus solution treatment.

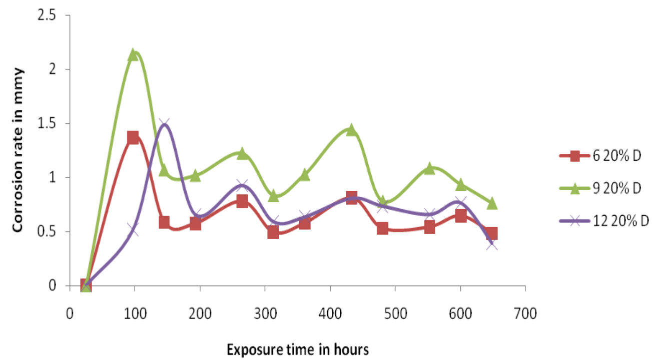

Figure 3(b): Variation of Corrosion rate against exposure time of alloy and composites subjected to 20% cold deformation plus solution treated

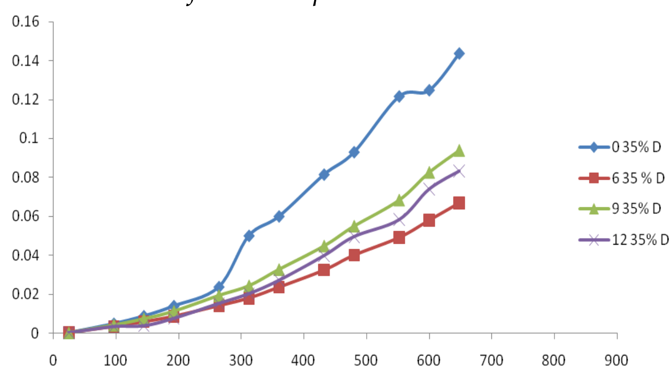

Figure 4(a): Variation of mass loss against exposure time of alloy and composites subjected to 35% deformation plus solution treatment.

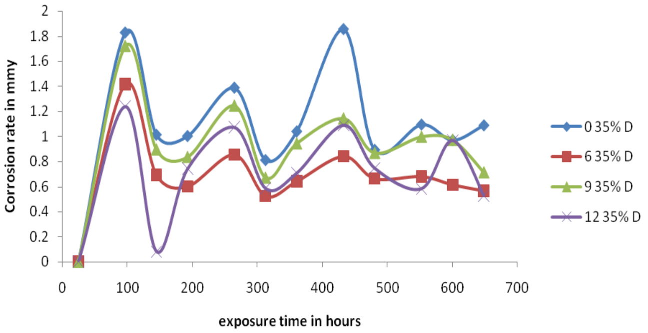

Figure 4(b): Variation of Corrosion rate against exposure time of alloy and composites subjected to 35% cold deformation plus solution treated

The superior corrosion resistance of the alumina reinforced AA 6063 composites is in agreement with observations of Alaneme and Bodunrin [15]. They reported that the improved corrosion resistance of the alumina reinforced AA 6063 composites over that of the unreinforced alloy is as a result of the inert nature of alumina. Hence the alumina particulates exhibits good resistance to corrosion attack. It has been stressed that galvanic corrosion that results from the formation of cathodic and anodic sites by the reinforcement and matrix as established in Al/SiC is unlikely in Al/Al_2O_3 composites [10]. The alumina particles are reported to have a very high resistivity (> 10^{14} Ohms) and thus functions as an insulator and as such do not have significant effect on the passive films formed on the aluminium matrix [16].

Corrosion behaviour of the Cold Rolled and Solution Heat-treated Composites in 0.3M H_2SO_4 Solution

Figures 5-7 show the influence of different temper conditions on the mass loss and corrosion rate of the alumina reinforced AA 6063 particulate composites. Figure 5 shows the variation of corrosion behaviour of the 6 vol. % alumina reinforced AA 6063 alloy with different temper treatment. It is observed from Figure 5(a) that the 20 % and 35 % cold rolled and solution heat-treated samples exhibited greater resistance to corrosion in comparison to the as-cast and solely solution heat-treated samples. For the exposure period of 720 hours in the H_2SO_4 solution, the 20% cold rolled and solution heat-treated sample for instance had mass loss of 0.06g/cm^2 which corresponds to 500% and 50% reduction in mass loss in comparison to the as-cast and solely solution heat-treated samples respectively. This indicates clearly that there is a significant improvement in corrosion resistance of the alumina reinforced AA 6063 composites with the adoption of the cold rolling and solution heat-treatment processing. Alaneme [12] reported that cold rolling treatment results in improved particulate distribution and reduction in the apparent porosity of the composites. The subsequent solution heat-treatment helps in the dissolution of the second-phase intermetallic compounds and elimination of dislocations and residual stresses developed during the cold rolling process [17]. The combined process results in a composite with improved material properties. Figure 5(b) the corrosion rate plots support the mass loss trend as it is observed that the as-cast samples had the highest corrosion rate for the entire exposure period. For the 9 vol. % alumina reinforced AA 6063 composites, it is observed from the mass loss plots (Figure 6a) that the cold rolled – solution heat-treated and solely solution heat-treated samples had corrosion resistance superior to that of the as-cast sample. Figure 6(b) shows that the 20% and 35% cold rolled – solution heat-treated samples exhibited a significant resistance to corrosion in comparison to the solely solution heat-treated sample at the early stages of exposure in the H_2SO_4 solution. For the 12 vol. % alumina reinforced AA 6063 composites (Figure 7), it is also observed that the cold rolled and solution heat-treated samples had the least corrosion susceptibility. The corrosion rate plots confirm that the cold rolled – solution heat-treated samples had the least corrosion rate in comparison with the as-cast and solely solution heat-treated samples.

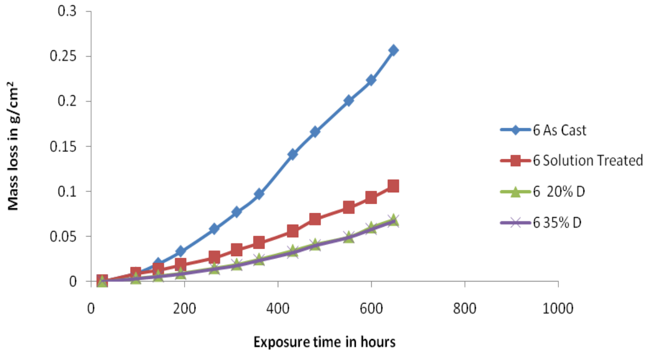

Figure 5(a): Variation of mass loss against exposure time of 6% alumina reinforced composite samples

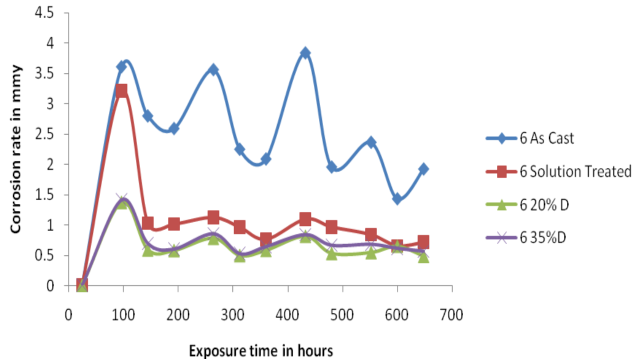

Figure 5(b): Variation of corrosion rate against exposure time of 6% alumina reinforced composite samples

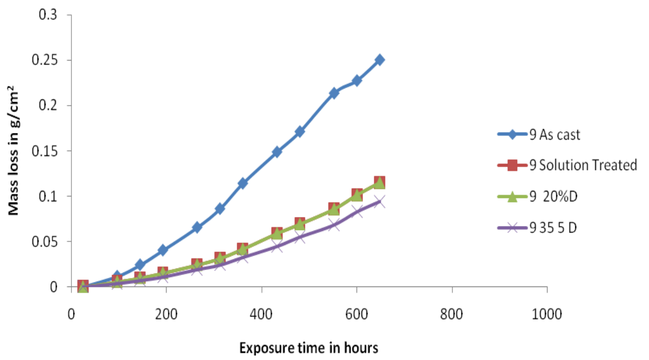

Figure 6(a): Variation of mass loss against exposure time of 9% alumina reinforced composite samples

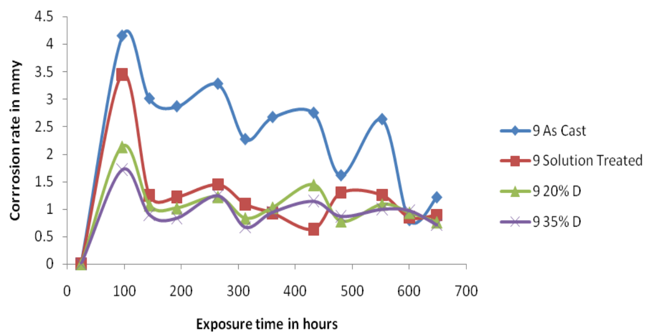

Figure 6(b): Variation of corrosion rate against exposure time of 9% alumina reinforced composite samples

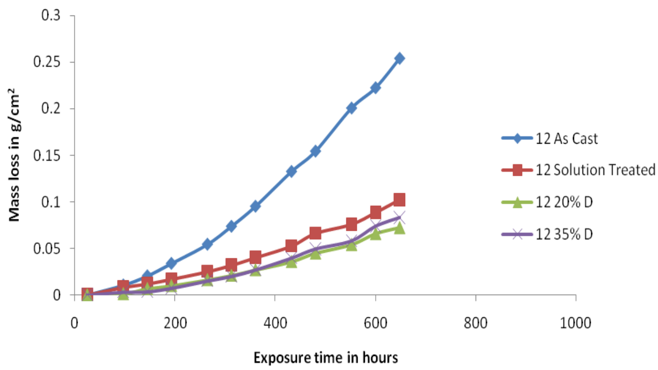

Figure 7(a):Variation of mass loss against exposure time of 12% alumina reinforced composite samples

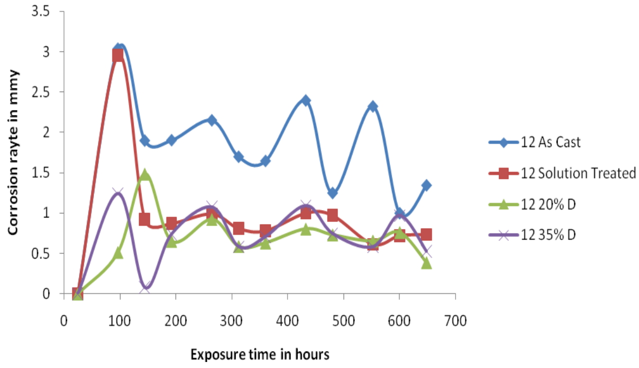

Figure 7(b): Variation of corrosion rate against exposure time of 12% alumina reinforced composite samples

CONCLUSION

The influence of cold rolling and solution heat-treatment on the corrosion behaviour of alumina reinforced Aluminium (6063) alloy composites in 0.3M H_2SO_4 solution was investigated. The results show that AA (6063) – Al_2O_3 composites exhibited superior corrosion resistance in comparison to the unreinforced alloy in H_2SO_4 solution. Also, the cold rolling – solution heat-treatment process resulted in significant improvement in corrosion resistance of the composites in comparison to the as-cast and solely solution heat-treated temper conditions.

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SIMULATION METHODS FOR TRAFFIC AND POLLUTION ASSESSMENT

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Abstract: *One of emission sources in the urban area have been identified as coming from the road traffic. Therefore, several simulation methods for traffic and pollution assessment are presented. There were analyzed the three main methods used for assessing the atmospheric air quality and the classification of air pollution models depending on multiple criteria. The mathematical models are used to describe the correlations between the meteorological conditions and the level of atmospheric concentrations of the pollutant emissions, analysis and interpretation of the experimental data. The primary objective of some specialised operational models is meant to supply a fast but still realistic assessment of the pollutant dispersion for the emissions due to the road traffic. The microscale numerical modelling offers the opportunity for a detailed simulation of the impact of various scenarios of urban planning, in order to establish and optimise the related strategic decisions.*
Keywords: *air quality, traffic, simulation, pollution, model, urban*

INTRODUCTORY CONSIDERATIONS REGARDING THE AMBIENT AIR QUALITY ASSESSMENT METHODS

There are three main methods (instruments) for assessing the atmospheric air quality: the environmental monitoring (analysis), the physical-mathematical modelling (simulation) and the measurement/inventory of the pollutant emissions.

The final purpose of the monitoring activities is not only the simple collecting of the testing data. It also means furnishing the necessary information required by the researchers, statesmen and planners in order to take certified decisions regarding the management and the improvement of the quality of atmosphere. The monitoring evidently stands for a central role within this process, providing the scientific base necessary for a long-term development, as well as for the definition of the priority objectives, the analysis of the existing situation conformity as related to the planned tasks, as well as the assessment of the efficiency of the used measures. Still, the limits specific for the monitoring activities taken separately must be recognised as such. Thus, no monitoring programme, no matter how well designed and financed, cannot hope to be able to deeply quantify the complex characteristics in space and time of the air pollution. In many cases, the isolated measurements acting as case studies might not be enough or might not be clear in order to be able to fully define the level of the epidemiological exposal of the resident population of a city, region or country. This is why very often it is needed to use the monitoring together with other objective assessment techniques, including the numerical modeling, emission measurement and inventory, use of some interpolate and mapping procedures of the environmental information. In the best case, the monitoring supplies with an incomplete but useful image related to the current quality of the environment.

On the other side, assessing the status of environmental factors only based on the modeling is not recommended either. Even though the numerical models can offer a strong instrument for data interpolation, predictive calculations and optimization of environmental control strategies, they can become useless when looking at their credibility until they are not adequately checked and validated by comparison with extended sets of experimental data as a result of monitoring "the real world". At the same time, it is also important *that the used methods to be according to the local conditions, emission sources and topography, as well as to be selected taking into account the compatibility with the available sets of meteorological and emission data. This last aspect most of the times represents a limiting factor because the multiple refined types essentially depend upon the availability of some high-quality input data which are hard to get and operatively assessed.*

A full inventory of emissions from an urban area, region or country must include detailed and documented information with respect to all the categories of sources (point, area and mobile). Moreover, in certain cases, there is also necessary to take into consideration and to assess the pollutants transported from other regions towards the field to be studied (e.g., the cross-border pollution). The emission inventories most of the times appeal at representative emission factors studied by means of measurements for various categories and types of sources coming from different areas of activity. At the same time, they use surrogate statistics such as the density of population, the fuel consumption, the distance travelled by vehicles or the levels of industrial production. Still, in this field, there are also informational limits caused by the availability of emission measurements, often restricted to the large industrial point sources or to several representative categories of vehicles tested under standard driving conditions (functional trial cycles).

Thus, the three instruments used for environmental assessment synthetically described above prove to depend one on another as purpose and as functional applicability. Consequently, the monitoring, the modeling and the inventory of emissions must be seen as complementary elements within any integrated approach in order to assess the exposal to the environmental insalubrity factors or to the determination of conformity with the criteria related to the air quality.

CLASSIFICATION OF AIR POLLUTION MODELS

Through the phenomenon of atmospheric dispersion of the pollutant emissions one can understand the ensemble of their diffusion and transportation phenomena. Because the phenomena of air pollution are basically influences by the atmospheric processes, the most used type of classification is according to the space scales that belong to them. This way, the distinction between the microscale (under 1 km), mesoscale (between 1 km and 1000 km) and macroscale (over 1000 km) is generally accepted. If in the case of modelling according to the microscale (often called as local scale) the transportation phenomena can usually be considered as insignificant as compared to the ones with atmospheric diffusion, in the case of mesoscale and especially for the macroscale, the situation is reversed, the dispersion of the pollutant emissions being dominated by the atmospheric transportation phenomena under the impact of wind fields distribution [1].

The mathematical modeling of the phenomena related to the dispersion of pollutant emissions consists in the assessment through numerical simulation of the pollutant concentration at the ground level and above, according to the characteristics of the sources of emission, of the meteorological and orographic (topographic) conditions, of the atmospheric processes of physical and chemical transformation, as well as of the processes developed at the interface between the atmosphere and lithosphere (the ground). In fact, the numerical modeling of dispersion of pollutant emissions in the atmosphere requires three fundamental categories of data entries [2]:

- *An emission inventory, containing all the necessary information related to the pollutant sources; the characteristic data can be introduced in the dispersion model, in order to simulate the pollutant behavior in the atmosphere;*
- *Data related to the dispersion model construction, allowing the adapting of its application to cases and conditions belonging to certain geographical (topographical) areas;*
- *Meteorological data, having an essential character because they mainly establish the behavior of emitted atmospheric pollutants.*

For a long time, the "classical" problems of atmospheric pollution were represented by the local ones, that is, the ones related to the environmental impact coming from some isolated sources of *emission. Still, during the last decades, the policy of protecting the environment faced more and more regional problems, often with a cross-border impact, such as the acidification, the eutrophication, the forming of photo-oxidiser compounds (especially the tropospheric ozone), the urban pollution or the one created by the atmospheric emissions of the highly-toxic substances and with problems that affect the entire world, i.e. the world climatic changes caused by the gas emissions that produce the greenhouse effect or the impact on the stratospheric ozone layer.*

The atmospheric pollution models can be classified taking into account multiple criteria, such as:

- *according to the space scale: local, local to regional, regional to continental and global (planetary);*
- *according to the time scale: episodic types and long-term statistics types;*
- *according to the way of treatment for the transportation equations: Eulerian types, Lagrangean types and types with "particle wreath" ("puff");*
- *according to the way of treatment of the different atmospheric processes: chemical reactions, dry and wet deposition;*
- *according to the complexity of approach: Gaussian types, semi-empirical types, grid types.*

The studies performed at the urban level probably represent the most important examples of modeling the dispersion phenomena that take place at the local to regional level, practically corresponding to the urban (sub)mesoscale. The mesoscale atmospheric models require a large number of meteorological input information. With this purpose, during the past years, currently there where two different approaches: the diagnostic calculation of the wind field in conjunction with the empirical parameterisation of the intensity of atmospheric turbulence and the prognostic calculation of the wind field as well as of the measures that define the turbulence. The first approach implies the availability of some very detailed sets of meteorological measurements that should allow an accurate reconstruction of the wind field. But more often, this endeavour still represents only an illusion. This is why, currently, the last way of approach, i.e. the numeric simulation of the wind and atmospheric turbulence characteristics from the area of interest is generally preferred [3].

Taking into account the above-mentioned aspects, a mesoscale air quality model represents currently a modelling system consisting in linking a diagnostic or a wind prognostic model to a diffusion model. In case of inert pollutants that do not change due to the atmospheric conditions at the space and time scale taken into consideration, one can use Eulerian models, as well as Lagrangean ones.

An Eulerian dispersion model can be is easily included in a prognostic wind model, this combination being often named a prognostic model of atmospheric pollution at the mesoscale. The Eulerian dispersion models are predominant in the case of reactive pollutants, typically the ozone and its precursors (especially the nitric oxide and the volatile organic compounds). The usual practice in these conditions consists in firstly applying the wind model and then the photochemical dispersion model.

In case of the regional-continental scale, the air quality models have as an object of study the long-distance transportation of the atmospheric pollutants, mostly with the purpose of:

- *quantifying the level of primary atmospheric and photo-oxidant pollutants (especially the ozone);*
- *assessing of the combustion deposits on various elements of the ecosystems crossed by the contaminated masses of air;*
- *understanding the physical and chemical processes coming from the formation, the transport and the deposits of these compounds.*

The winds, the clouds, the rainfalls, the characteristics of the underside surfaces and the chemical mechanisms are elements that determine the large-scale dispersion of the pollutant emissions. The final exits of the models consist of mean concentrations or deposits for square grids whose size varies currently between 50 x 50 km^2 and 150 x 150 km^2.

At the regional-continental scale, currently the Lagrangean models and the Eulerian models are both being used. The Lagrangean models, also *named "trajectory models", allow the performance of some prognoses regarding the concentration of pollutants along a path of the masses of air that consists of the pretty simple numerical treatment of the transportation within the equation of mass balance: the transportation is determined by the paths of the air flows. The use of such models, especially in case of some large chemical or nuclear accidents (like the Chernobyl accident from 1986), consists of the fact that, by coupling the atmospheric models used in an operative way within the weather forecast activity, with the method of effective calculation of the pollution concentrations along the forecast paths, one can obtain information necessary for taking decisions with respect to the protection of the population in such cases of environmental crisis. But due to their main disadvantage, i.e. the fact that it is very difficult to take into consideration the changing processes between the masses of air and the wind shear, the 3D models of Lagrangean type are still not considered to be very reliable (trust-worthy). In this case, the main advantage of the Eulerian models consist of a well-defined 3D formula, evidently necessary for approaching some atmospheric pollution problems more and more complex, such as the ones characteristic for the European regional scale in the future years. The Eulerian long-distance transportation models allow the determination of the contribution of external pollutant sources over the global pollution level from a country or the assessment of the contributions of internal sources to the cross-border pollution with the main atmospheric pollutants (sulphur dioxide, sulphates, nitric oxides, etc.). Taking into account the international conventions for reducing the pollutant emissions that determine the environmental processes at planetary level, such as climatic changes and the rainfall acidification, obtaining such information is mandatory. The Eulerian models also include the physical processes such as the dry and wet deposition or the non-linear chemical reactions between the pollutants emitted in the atmosphere which brings to a time of calculation so large that they can currently be run only for a relatively limited period of time. Still, the development of the computing technique is so fast that, in the near future, it is predictable the fact that these models will be used in an operative regime.*

Such an actual subject for research and development consists in the development of a methodology for linking the mesoscale prognostic models to the 3D microscale models. This way, one can appreciate that the predisposition for using some types of air quality models more and more sophisticated and precise will inevitably lead to the abandonment of the conventional rigid separation of the atmospheric processes according to the individual scales. The multiple-scale integrated approaches will be mandatory in the near future, while the refining of the digitisation techniques on grid mesh is necessary in order to extend the capability of combining the models developed for certain individual scales for the description of the processes, being extended to multiple space and time scales.

Another type of dispersion model that has recently got a large use is the one with "particle wreath" ("puff"). Even though in the beginning they have been created and used for modelling the diffusion and atmospheric transportation phenomena of some accidental interrupted (sequential) emissions, the "puff" models are currently often applied extensively also for the continuous emissions, which are represented (digitised) in this case by series of wreaths of effluents later taken over by a variable wind field. By using these wreaths ("puffs") instead of the emission plumes, the changes induced by the change of the wind direction can be easily modelled.

URBAN SCALE MODELLING

The well-known and strong degradation of the air quality within the large cities is caused by the urbanisation phenomenon, which means the existence of some important masses of population characterised through high-mobility requirements within narrow areas, causing a strong increase of the traffic volumes. This fact has determined the scientific community to proceed to deep investigations over the urban atmospheric pollution, particularly with respect to the representative sources of emission.

The most relevant categories of emission sources in the urban area have been identified as coming from the road traffic, the residential heating systems *and, in some cases, as a result of the some specific industrial activities. The nature and relevance of the problems related to the quality of air from the urban areas are different from one case to another, depending upon the local topographic, climatic and meteorological conditions, the regulation of legislation in force for environment protection and the options for existing urban improvement and planning.*

The necessity of modeling the quality of urban air is a consequence of the increasing interest of the population with respect to those aspects related to the environmental protection and to the health of human communities, as well as to the overcongestion of the traffic flows. The modeling allows people to obtain some fields of atmospheric concentrations for different pollutants in a less expensive way, faster and with a superior space resolution as compared to the experimental monitoring by immission measurements. Consequently, the modeling of the urban air quality has become an essential instrument for:

- *determining the characteristics of the urban area pollution;*
- *modeling the evolution scenarios of the impact of pollution for the purpose of traffic management, e.g. the modernization or the construction of new traffic roads, parking lots for vehicles, a better administration of the existing road infrastructure by efficient packages of traffic engineering solutions (one-way streets, optimizing the cycles of traffic lights in order to relieve the traffic, etc.);*
- *showing the placement of air quality monitors;*
- *assessing the responsibility areas of the main categories of emission sources to the overall pollution impact induced on the air quality in the urban area.*

It is necessary to make a distinction regarding the adopted methodologies for studying the primary and secondary reactive pollutants, the primary non-reactive ones, respectively, to the space and time scale taken into consideration.

In order to make an adequate analysis of the physical and chemical processes that imply the secondary pollutants such as the ozone or the primary reactive pollutants such as the nitric oxides, one need to use the mathematical models applicable for the areas with linear dimensions generally between 50 – 100 km (regional mesoscale). Examples of such classic models are the UAM [4] with applications for multiple American cities [5] and CALGRID [6].

On the other side, for the non-reactive primary pollutants it is possible to reduce the space analysis scale. With respect to the determination of the space distribution of the fields of average concentrations in those respective urban areas, it is very useful to obtain information for scales between 5 and 20 km (urban (sub)mesoscale), with the basic steps of 250 – 1000 m.

The Gaussian dispersion model is the most well known approach world-wide in the field of studies related to the atmospheric impact of the pollutant emissions at this space scale [1]. The widespread and the success of the Gaussian model of dispersion are mainly due to the fact that it is easy to apply, the concept is attractive and it has a high level of confidence due to the great volume of comparison made in time with large sets of experimental data.

The Gaussian models are based on a sole and pretty simple mathematical formula which implies a constant wind speed and a total reflection of the emissions at the ground level, without chemical reactions or deposition (dry and wet) on the soil surface (see Fig. 1):

$$C(x,y,z) = (Q_S / (2\pi U \sigma_y \sigma_z)) \exp(-y^2/2\sigma_y^2) (\exp(-(z-h_S)^2/2\sigma_z^2)+\exp(-(z+h_S)^2/2\sigma_z^2)) \quad (1)$$

where: $C(x,y,z)[g/m^3]$ *– the atmospheric concentration of the pollutant in a receptor point of coordinates (x,y,z);*

Q_S *[g/s] – the mass flow of the continuous emission of the point source;*

U [m/s] – mean speed of the wind at the height h_S*;*

$\sigma_y = \sigma_y(x)$ *[m] – the lateral dispersion parameter (horizontal – transversal);*

$\sigma_z = \sigma_z(x)$ *[m] – the vertical dispersion parameter;*

x [m] – the downstream distance along the central axis of the emission plume;

y [m] – the lateral distance against the central axis of the emission plume;

z [m] – the vertical coordinate;

h_S *[m] – the effective height of the emission, representing the sum of the physical (constructive) height of the source and the rise of the effluent cloud after the stabilization of its movement level.*

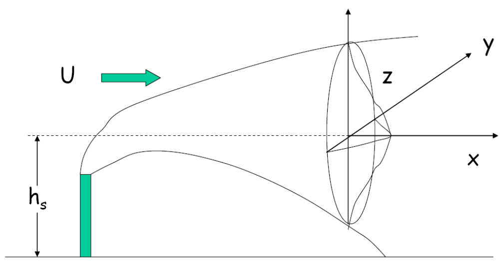

Figure 1. The scheme of the idealized pollutant emission plume with profiles of concentration described by the Gaussian distributions

Such a model type for the urban mesoscale is one of the most renown European dispersion models for the urban point (industrial) sources and area (stationary and mobile) sources, i.e. the OML-Multi model [7]. Developed within the Department of Atmospheric Environment of the National Environmental Research Institute – NERI from Denmark, the Operational Meteorological Model for Air Quality (OML) uses a new generation Gaussian plume approach, where the dispersion parameters are calculated as continuous functions of physical parameters of the planetary boundary layer, obtained through a meteorological pre-processing system (the OML pre-processor) which represents a separate software package [8].

The OML dispersion model requires hourly data regarding the pollutant emissions, the meteorological parameters and the regional background concentrations, as well as information regarding the receptors and the sources, the sizes of buildings placed next to the sources and the field topography. Because the emission data are generally obtained as annual average values, a series of time factors are used in order to identify the fraction of the annual value related to a specific period of time within a year. This type of information depends on the typical hourly, daily, weekly or monthly timeline variations of the emission flows. Such a series of time factors that can be set up are included in the sections of a special developed emission module of the OML-Multi model.

During the studies performed by the Research Department of the Romanian Automobile Register (RAR), the OML model has been applied on a rectangular grid of 20 km x 14 km, covering the most urbanised area and with the most dense road infrastructure within the Bucharest metropolitan area, totally using 315 (21 x 15) receptors for every 1 km towards the East and North, respectively, in order to calculate the fields of concentrations [9], [10], [11]. The OML model has been used for the following pollutants: CO, benzene, NOx, NO_2, O_3 and PM-10 (suspended inhaling particulates with an aerodynamic diameter under 10 μm). Based on the temporal dynamic series of concentration that are issued during the model run for the receptor points chosen by the user (grid nodes or other points of interest), the OML model allows the extraction of some statistics regarding the daily, monthly or yearly time average in order to compare them with the limit values and with the assessment thresholds of the EU Directives, these statistics being presented also as a graph of pollution maps. The OML model has also the important capability of parameterising in an operative way the kinetics of the main tropospheric chemical reactions at the space and time urban scale for modelling the transformations NOx/NO_2/O_3.

In order to model the urban background levels with the help of the OML-Multi model, the road traffic emission sources have been considered as diffuse area sources, placed in each of the grid meshes of the adopted digitisation system.

The predictive performance assessment for using the OML model for the Bucharest urban agglomeration has been carried out by comparing the modelling results with some sets of measured data, provided for the years 2004-2006 by the air quality automatic network belonging to the Bucharest Regional Agency for Environmental Protection. A general good quantitative and qualitative agreement has been observed between the modelling and measured data [10], [11].

The numerical simulations with the urban mesoscale models like OML represent an important alternative for the assessment of the urban background pollution levels from Bucharest and from other Romanian urban agglomerations. The space distributions of the most important and representative pollutants for the urban road traffic provide important information for assessing and forecasting the pollution level that can be reached within those agglomerations.

At the same time, one should also take into account the main natural removal mechanisms of the atmospheric pollutants, by the dry deposition to the *ground surface as a result of the gravitation fall (sedimentation) and by the adsorption phenomenon (by inertial impact) to the soil, vegetation or buildings, as well as for the wet deposition caused by the cleaning ("washing") of the air by means of different types of precipitation. For urban mesoscale modelling, the dry and wet deposition phenomena are taken into consideration especially in the case of particles (suspended powders), taking into account the gravitational effects and the different characteristics of their atmospheric transport as compared to the gas pollutants.*

STREET SCALE MODELING

The further reduction of the space scale of the concentration fields to several meters (street microscale) is also proved to be important. Thus, it is possible to settle the concentration peaks for the urban microstructures (pavements, different floors of the buildings, parks, etc.), as related to the micro-meteorological and emission varying conditions. This analysis is useful mainly for the pollutants with severe harmful effects, such as the carbon monoxide (CO). Moreover, like this it is possible to determine the space representativeness for the unique fixed points for measurement within the monitoring networks of the urban air quality.

In the case of the mobile road traffic emission sources, from the methodological point of view related to the modelling of the air quality at a certain receptor point, in order to assess by means of numerical simulation the total atmospheric concentration of an inert generic pollutant from the chemical point of view at an urban space and time scale, it is necessary to link the dispersion model at the street microscale with a model at the urban mesoscale. The total atmospheric concentration (C) can be obtained by adding the additional local street contribution (C_S) to the background concentration (C_B), representing the mesoscale contribution of all the background sources – coming from the road traffic, as well as from other types of anthropogenic emission sources (industry, residential heating, off-road vehicles, etc.) and natural ones (biogenic and mineral emissions).

The most frequent, due to the relative simple and direct applicability for estimations at local scale, for the assessment of atmospheric dispersion of emissions close to a traffic road, there were used different versions of the Gaussian model for the linear pollution sources [1].

The main roads with an intense traffic can be treated from the microscale modeling point of view as infinite linear sources, characterized through an emission mass flow for the unit of length Q_L [$g\ s^{-1}m^{-1}$]. The established Gaussian model of the linear emission source is based on the superposition principle (effect overlapping), according to which the concentration for a certain reception point can be obtained by adding up the contribution of all the infinitesimal point sub-sources that make up the respective linear source. At the same time, one can consider that the diffusion mechanism for each point sub-source is not linked to other sub-sources that make up the emission line. With this hypothesis, an analytical solution can be obtained by integrating the equation (1) for the point sources relative to the lateral distance y.

The solution of the Gaussian model for the downstream pollutant concentration from an infinite linear source of traffic belonging to a road that makes up an angle Φ with the wind direction is the following [1], [15]:

$$C(x,z) = (Q_L / (\sqrt{2\pi}\ (U \sin\Phi)\ \sigma_z))\ (\exp(-(z-h_S)^2/2\sigma_z^2)+\exp(-(z+h_S)^2/2\sigma_z^2)) \quad (2)$$

If we note with d the perpendicular distance from the receptor point where we calculate the concentration to the traffic road, then the x distance on the wind direction used for computing the vertical dispersion parameter σ_z will obviously be $d/\sin\Phi$. We also mention the fact that in the equation (2) there is no y, due to the fact that for any value of it the concentration is the same for a given x. Also, the horizontal dispersion parameter σ_y is missing because we supposed that the side dispersion for a segment of the linear source is compensated by the side dispersions to opposite directions for the side segments. The equation (2) should use the wind speed (U) measured or assessed for a height of about 2 m for downstream distances from the linear source of some hundreds meters, while the angle Φ between the wind direction and the traffic line should not be less than about 45°, and the effective height h_S of emission is considered to be about 2 m. Taking into account the fact that the average physical height related to *the discharge ends of the car mufflers that make up the road traffic line is about 0.3 m, consequently we take into consideration a rise of the exhaust gas plumes of about 1.7 m.*

The validity of the hypothesis taken for the deduction of relation (2) regarding the independence of individual diffusion mechanisms for each point source as part of the traffic line becomes objectionable when the linear emission source comes with its own turbulence that is created by the car movement, like in the real case of the road traffic and which overlaps the local atmospheric turbulence. Moreover, the performed approximation by applying the overlapping principle becomes in turn arguable and in the long run insufficient in the case of some small angles between the wind direction and the traffic road axis whose impact over the environment is under study.

It is true that when the wind direction becomes parallel with the traffic linear source, that is the wind blows along the road, the angle Φ heads towards 0, which becomes a numerical singularity for the equation (2) for which the concentration heads towards the infinite ($\sin\Phi \to 0$ as the nominator in that relation). From the point of view of mathematical formulation of the calculation hypotheses, this fact is normal because we took into consideration a modelling by means of a linear emission source with an infinite length that is consequently characterised by an emission flow which is also infinite.

A way to avoid this singularity can be reached by taking into consideration a linear emission source with a finite length, by admitting a computing error which cannot be major due to the fact that the decrease of concentrations from the maximum one to the infinite minimum one, especially when close to the source, takes place following a very lean curve. The linear source with a finite length, for $\Phi=0$, heads to the characteristics of the point source with an infinite number of exhaustion points along the wind direction. In this case, the computing of concentrations can be done by using the equation (1) for the point source, by conventionally placing the emission point exactly in the centre of that limited linear source. The emission flow for the equivalent point source is obtained by multiplying the emission flow of the linear source with its limited length.

The most renowned approaches of this type at the worldwide level include the American models HIWAY2 [12], CALINE4 [13], [14] and SLSM [15]. For the HIWAY2 and CALINE4 models, the fields of atmospheric concentrations for the pollutant forecast by using a Gaussian equation of the linear emission source for an arbitrary wind direction are calculated by using a numerical integration procedure. This procedure divides (digitises) the roadway in a series of elements whose concentrations are individually calculated and then added up. Both models allow introducing in the calculation of a finite mixing height.

As opposed to these ones, the American model ROADWAY [16] is based on the flux-gradient approach, due to the obvious advantages regarding the numerical simulation in a more natural way of the interaction between the atmospheric diffusion processes and the chemical transformations of the pollutant emissions [1].

These models allow the assessment of atmospheric dispersion of the pollutant emissions due to the mobile sources for a great variety of geometric configurations of the road infrastructure and topographies of the studied area:

- *at-grade roads, ramps, slopes, fill sections, depressed sections, bridges, parking lots;*
- *aligned road sections, bends, rural and mountain curved alignments (serpentines);*
- *multiple perpendicular, inclined, T-form, Y-form crossroads, roundabouts;*
- *out-of-level crossroads, traffic routing and splitting isles, complex geometrical configurations;*
- *road infrastructure side areas – with an opened and levelled topography, canyons, quays, hill peaks, bunds, etc.*

Modeling the turbulence caused by the road traffic is vital for the cases of atmospheric calm and of the low-speed winds. The mechanical turbulence due to the traffic mainly depends on the driving average speed, on the size of the cars considered as elements of mobile roughness, as well as on the speed of the wind and on the angle between the wind direction and the road axis, taking into account for this last case the overlapping of mechanical turbulence *caused by the traffic over the local atmospheric turbulence.*

Moreover, it is mostly important to model the thermal increased height of the pollutant emission plume, the exhausted gas raising up due to its own thermal flux that supports them and raises them somehow just like the Archimedes force. This thermal (convective) component mainly depends upon the heat emission of the exhausted gas that can be calculated according to the traffic density, the specific consumption of fuel, the average energetic content of the car fuels and the thermal efficiency of the car engines.

The highest levels of pollution are registered on the canyon-type of streets ("street canyons") where the exhaust gas dilution is greatly limited by the presence of high buildings along the pretty narrow roads. This aspect is very important because architecturally speaking the street canyons represent one of the basic structures of the urban topography [17].

The special peculiarities of the flow and the dispersion conditions from the urban street canyons suppose the fact that the traditional (conventional) modeling methods are hard to apply in this case. Thus, with respect to the urban pollution caused by the road traffic, one should take into account the fact that there is no model capable enough to cover all the actual street configurations. Even the most modern and sophisticated models based upon numerical solutions of the flows from the fields of wind and on the scalar dispersion equations find it difficult to treat the extreme initial and the cross-border conditions. An "exact" mathematical description of the pollutant emissions dispersion in the street canyons is consequently impossible to be put into practice. The necessary simplifications of the "real world" conditions often imply restrictions over the field of applicability of models. From the regulation point of view though, for the studies regarding the impact over the environment, the most important is if and where the pollution levels exceed the specific norms of the air quality.

As a principle, there are two major interdependent ways of approaching the studies regarding the pollution specific to the street canyons: by means of physical modeling, consisting in the performance of some scale tests within the aerodynamic tunnels using the similarity criteria of the aerodynamic flows and by the mathematical (numerical) modeling.

The physical modeling, in case of neutral stratification, has been very often used for visualizing the flows and the pollutant concentrations, and for the speed measurements above and within some scaling of street canyons, taking into account at the same time the peculiarities of the side urban roughness. These studies that use a physical model offer a reliable base for validation and testing of the numerical models of urban dispersion, by strictly applying some special elements in order to ensure the quality of data, by supporting at the same time further development and improvement of mathematical modeling by computerized simulation [1].

The urban street canyon geometry does not only lead to the decrease of pollutant emission dilution. It also causes a significant change of the flowing conditions of the airflow led by the wind [1], [2]. Thus, one of the most remarkable characteristics of the flow within the street canyons consists in the creation of a vertical wind vortex (horizontal-axis rotor), for the fact that the direction of the wind at the street level is opposed to the one related to the level above the roofs of the nearby buildings. This aspect can be seen in the Figure 2.

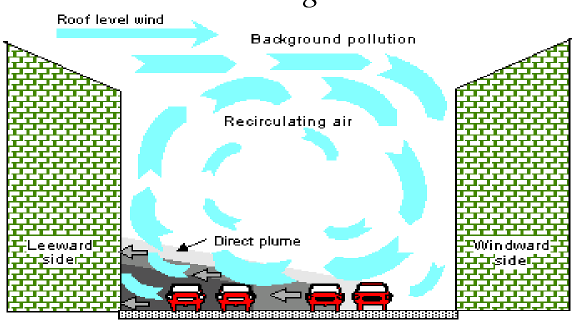

Figure 2. The scheme of wind and pollutant emissions circulation within the street canyon

This peculiar form of the airflow in the street canyons takes us to the creation of those important transversal concentration gradients relative to the traffic roadway. The levels of the pollutant concentrations on the upstream (leeward) side of the road are highly superior to those registered for the downstream (windward) side, directly "blown" by the wind, according to the suggestive graph from the Figure 3.

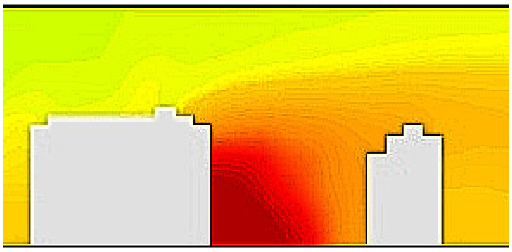

Figure 3. Vertical transversal section through the specific concentration field of the street canyon

The dependence on the wind direction is caused by the formation of the turbulent helical circulation specific for the street canyons. The numerical simulation offers an excellent explanation of this characteristic. The well-known effect of the street canyon is extremely obvious: the upstream concentrations are larger than the downstream ones. A receptor point placed on the downstream side of the street canyon is exposed to the background pollution and only indirectly to the local street traffic emissions which are significantly diluted by the circulating vortex specific to this urban topographic configuration, different from the case of placement on the upstream side which is directly exposed to the emissions caused by the nearby traffic mobile sources (see Fig. 2), so that in this case, the level of concentration is highly raised (see Figure 3).

For the wind speeds under 1 m/s, these differences are still far less, due to the diminishing up to the finishing of the helical eddy circulation. For these low wind speeds, the turbulence produced by the road circulation by means of the so-called advective traffic wave dominates the dispersion conditions inside the street canyon, so that the dependence on the wind direction is less obvious.

At the local level, the pollutant concentration is directly proportional with the emission flow of the street linear source Q_L [g/s/m] and inverse proportional with the wind speed at the roof level U [m/s], but amplified by adding a little correction term U_S (0.3 – 0.5 m/s), for taking into consideration the air movement mechanically induced through the wave of the road traffic. More exactly, the pollutant concentration is inverse proportional with the speed of the transversal wind component. This phenomenon is produced as long as the characteristic swirl is developed. When this thing does not take place, we can suppose that the pollutant emission dispersion is essentially due to the local atmospheric turbulence mentioned before. We can also see that when the speed of wind heads to zero (absolute atmospheric calm) or the direction of the wind is almost parallel with the axis of the street canyon, the concentrations on the two sides of the road become equal [18].

An approximate analytical solution of the Navier-Stokes flowing equations, for an incompressible fluid and specialised for the wind currents and the diffusion equation for the street canyons, has been deduced in 1973 by Hotchkiss and Harlow [21].

The expressions for the wind component U perpendicular on the axis of the street canyon and for the vertical wind component W, respectively, are the following:

$$U = \frac{A}{K}\left[e^{Km}(1+Km) - \beta e^{-Km}(1-Km)\right]\sin(Kx) \quad (3)$$

$$W = -Am\left[e^{Km} - \beta e^{-Km}\right]\cos(Kx) \quad (4)$$

where:

$$K = \pi / Lc \quad (5)$$

$$m = z - Hc \quad (6)$$

$$\beta = e^{-2KHc} \quad (7)$$

$$A = \frac{KU_0}{1-\beta} \quad (8)$$

and U_0 represents the wind speed over the central axis of the street canyon at the roof level, so in the coordinate point x = Lc/2 and z = Hc, where Lc is the width and Hc is the height (depth) of the street canyon.

The wind speed component parallel with the median (longitudinal) axis of the street canyon (V) can be described by using a logarithmic vertical profile, suggested by Yamartino and Wiegand [19], using the relation:

$$V(z) = V_r \frac{lg[(z+z_0)/z_0]}{lg[(z_r+z_0)/z_0]} \quad (9)$$

where V_r is the wind speed component parallel to the street axis, measured at a reference height z_r, and z_0 represents the roughness length.

Yamartino and Wiegand [19] have proposed the following values for the roughness z_0 for the street canyons: z_0 = 0.4 m when the characteristic swirl will not be developed, z_0 = 0.04 m if the swirl is manifested and z_0 = 400 m if one of the buildings of the street canyon is far larger than the others, thus disturbing the flow over the canyon. Evidently, z_0 = 400 m represents a physically impossible value *but this way the report of the logarithms heads toward* z/z_r.

Using the expressions (3) and (4) of the wind field, Hotchkiss and Harlow [21] have established, after some more extra approximations, the following calculation formula for the concentration field Cs:

$$Cs = S\left[\frac{1}{U_W} - \frac{V}{V_t}\right] - $$

$$-\frac{SU_n m}{4KV_t^2(1-\beta)}\left[e^{Km}(1-Km) - \beta e^{-Km}(1+Km)\right]\cos(Kx) \quad (10)$$

where $S = Q_l/Lc$ *represents the emission "density", which is the supposed to be uniform on the street transversal direction, and* U_n *represents the wind speed component on the top of the street canyon, perpendicular (normal) on the longitudinal axis of the traffic road.*

In order to model the turbulent diffusivity (viscosity) V_t*, Hotchkiss and Harlow [21] have proposed the use of a calculation relation where the turbulence speed scale is correlated with the speed of wind on the top of the street canyon (*U_t*) and the correction factor (*U_S*) of the speed due to the turbulence caused by the road traffic:*

$$V_t = L\sqrt{(\alpha_1 U_t)^2 + {U_S}^2} \quad (11)$$

For the length scale L, they simply suggest using the Lc width of the street canyon, and a_1 *is a constant empirically determined. As for the ventilation speed of the street canyon (Uw) which determines the concentration levels on the top of the canyon, the following calculation relation has been proposed:*

$$U_W = (V_t\, U_t / Lc)^{1/2} \quad (12)$$

Chronologically speaking, a first model for the urban street canyon that creates an excellent combination between the operational characteristics and the scientific refinement which made it renown in the whole world was the American-German model CPB – "Canyon Plume-Box" (Yamartino & Wiegand, 1986) [19], [20]. Within this model, the pollutant concentrations are calculated by means of combining a subtype of dispersion by using the Gaussian emission plume formulation for the direct impact of the pollutants emitted by the road traffic, with a "box"-type of model which allows the assessment of the extra impact caused by the recirculating pollutants within the street canyon by eddy flow. The specific peculiarity of such a "box" approach consists in taking into consideration a limited vertical dispersion, in a finite volume of air. The wind field within the street canyon is defined by the Hotchkiss & Harlow rotor model [21] for the transversal components U and W, while the longitudinal component V (along the canyon) is represented by a vertical logarithmic profile which takes into account the roughness length variation according to the wind speed direction. In order to determine the turbulence parameters a_u*,* a_v *and* a_w*, they use a parameterisation empirical model for the turbulence intensity; the used variables for this purpose include the mechanical component, induced by the wind at the roof level of the buildings next to the street canyon, as well as by the traffic advective wave and the thermal (convective) component, depending on the global solar radiation and the heat issued by the exhausted gases of the vehicles quantified according to the traffic flow (the number of vehicles within the time unit).*

A similar approach to the one used by the CPB model has been applied consequently also for the development of the not less established Danish dispersion model OSPM – "Operational Street Pollution Model" [22], [23], [24]. The atmospheric concentrations of the exhausted gases are also calculated by using a combination between the Gaussian subtype plume for the direct contribution and the "box" subtype for the recirculating part of the pollutants in the street canyon. This operational model uses a simplified empirical parameterisation of the flow and dispersion conditions inside a street canyon, still established through an extensive analysis of some very large sets of experimental data, the results of these tests being used for the improvement of the predictive performances, regarding especially different street configurations and meteorological conditions. The parameters considered for the quantification of the influence on the atmospheric turbulence structure are the global solar radiation, the wind speed at the roof level, the road traffic flow and the average speed of the vehicles, the sizes of the street canyon and the geometrical position of the receptor within the canyon. At the same time, it is supposed that the sizes of the turbulent swirl are given by the *geometrical sizes of the street canyon and especially by the directional variable height of the upstream buildings, while the speed characteristic for the turbulence process is within the standard deviations of the wind speed.*

The CPB and OSPM models have proved their good predictive performances as compared to the extended sets of timeline average concentrations, measured in various street locations from the multiple urban areas. The request of the input data on a timeline sequential basis (traffic, meteorological and background pollution data) can be often prohibiting but it is also possible to use this type of models with composite input data that simulate, for example, the worst conditions for dispersion or the long-term climatological statistics; the credibility of this last type of results is not considered to be lower than the "standard" regulatory applications.

An empirical approach has been used also for the development of the Dutch CAR model ("Calculation of Air pollution from Road traffic") meant for studying the atmospheric pollution caused by the road traffic [25]. Mainly, based on some experiments performed within aerodynamic tunnels [26], [27] and [28], a set of empirical correlations has been established between the wind direction and the concentration for various street configurations. The experiences within the aerodynamic tunnels have covered a set made of 49 different configurations according to the sizes, distances and forms of the streets and the nearby buildings, at the same time investigating the influences on the dispersion characteristics of the trees on the sides of the road. The results of these master experiments have been included in a type of Gaussian emission plume model, under the name of the TNO traffic model [26]) which form the basis for the final development of the more operational CAR model, where some of the more distinctive street configurations with respect to the dispersion conditions have been classified. For each type of street it is mentioned a relation between the source and the receptor according to the distance between the receptor point and the axis of that street. Only the annual average concentrations can be calculated, as well as other statistic long-term parameters, based on the empirical correlations coming from the measured data base of the Dutch national network for monitoring the atmospheric pollution, those correlations being updated every year. This operational model is currently applied for the studies related to the impact on the environment performed for the Dutch cities. At the same time, an international version, named CAR International [29], is available.

Finally, one should also mention the Japanese original model OMG [30] which allows for the microscale modeling of the atmospheric dispersion of the pollutant emissions outside the urban street canyon domain where they have been produced, taking into account the report between the built surface and the total surface of the area next to the road infrastructure on a distance of 100 m on the one side and the other of the studied traffic roadway. In this case, one should also take into account the fact that in the urban areas, the mechanical turbulence induced by the presence of buildings influences the car engines exhaust gas diffusion. This phenomenon can be modelled by using the concept of the volume source and quantified by introducing an initial dispersion of the pollutant emissions plume, caused by the turbulent mix from the street canyons and expressed according to the average height and the superficial density of the buildings (the report between the built area and the total available area). The total pollution concentration at a receptor point can be obtained by adding the additional street contribution to the urban background concentrations (regional background plus urban source background contribution), also taking into account the microscale pollutant impact induced by the traffic linear sources developed inside the street canyon next to the studied circulation road.

CONCLUSIONS

The mathematical models that have the capability to describe in an adequate way the correlations between the meteorological conditions and the level of atmospheric concentrations of the pollutant emissions represent at the same time excellent instruments used also for the analysis and the interpretation of the experimental data. It is supposed that the measurements provide with information related to the "real world" conditions, but sometimes it is not possible, only by using *these ones, to explain the apparition of a peculiar situation and its cause. The use of an adequate model can solve this problem. The primary objective of some specialized operational models is meant to supply a fast but still realistic assessment of the pollutant dispersion for the emissions due to the road traffic.*

The anticipated and desired perspective of the medium and long-term modernization and development of the Romanian road infrastructure, will involve in the most normal way, according to the European Union environmental legislation, the extension of application of many assessment procedures for the atmospheric impact caused by the road traffic.

In this context, the microscale numerical modeling offers the opportunity for a detailed simulation of the impact of various scenarios of urban planning, in order to establish and optimize the related strategic decisions. The broad list of the physical processes and the very important number of non-linear interactions lead to the impossibility to assess in a coherent way the consequences of the structural changes without making an appeal to the expert systems for advanced numerical modeling.

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MECHANICAL PROPERTIES OF REACTIVE POWDER CONCRETE WITH VARIOUS STEEL FIBER AND SILICA FUME CONTENTS

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Abstract: *An experimental work was carried out to investigate some mechanical properties of Reactive Powder Concrete (RPC) which are particularly required as input data for structural design. These properties include compressive strength, tensile strength (direct, splitting and flexural), flexural toughness, load-deflection capacity and static modulus of elasticity. The effects of three variable parameters on these properties were carefully studied which are the silica fume content SF (0%, 10%, 15%, 20%, 25%, and 30%) as a partial replacement by weight of cement, steel fibers volume fraction V_f (0%, 1%, 2% and 3%) and superplasticizer type (Sikament®-163N, PC200). The experimental results showed that as the silica fume content (SF) increases from 0% to 30% the compressive strength significantly increases, while the increase in tensile strength is relatively lower. The inclusion of steel fibers leads to a considerable increase in tensile strength, while the addition of steel fibers causes a slight increase in compressive strength of RPC as fiber volume fraction increases from 0% to 3%. The increase in the steel fibers volume fraction and silica fume content improved the load-deflection behavior and consequently gave larger ductility and fracture toughness of RPC.*
Keywords: *reactive powder concrete, mechanical properties, load-deflection capacity, steel fiber, silica fume*

INTRODUCTION

Research over the past decades has yielded a new classification of highly resilient concrete called Reactive Powder Concrete (RPC), now labeled and classified as Ultra High Performance Concrete (UHPC). RPC is one of the latest advances in concrete technology and it addresses the shortcomings of many concretes today [16]. RPC possess ultra high static and dynamic strength, high fracture capacity, low shrinkage and excellent durability under severe condition. The microstructure of RPC is optimized by precise gradation of all particles in the mix to yield maximum compactness [21]. RPC has been shown to exhibit significantly improved tensile strength, both before and after cracking. This tensile strength of RPC is achieved as a result of the interaction of the randomly oriented steel fibers acting as reinforcement on a micro level which prevents cracks from forming. After cracking has occurred, the steel fibers are capable of sustaining additional tensile loads until the fibers are pulled from the matrix and the section severs [15]. The basic principles for the development of RPC were explained by many researchers [13, 18]. These principles can be listed as below:

- There is no coarse aggregate and maximum aggregate size may be between 0.3 to 0.6 mm.
- Powder is carefully optimized to achieve very high compactness.
- Using high cement content, low water to cement ratio (less than 0.2).
- Silica fume or another suitable pozzolanic material can be added to the mix.
- Superplasticizer is in need to get high flowable concrete.
- Steel fibers are to be added to increase the concrete ductility.
- Pressing during hardening may be helpful to get rid of excess water and to increase the paste density.
- Heat treatment during curing can improve the chemical process and strength gain.

Lee and Chisholm [9] studied the effect of steel fibers on the mechanical properties of RPC. They observed that the addition of 2% straight steel fibers with aspect ratio of 65 to the RPC mix primarily improve the normally poor tensile strength of composite cementitious materials. They also found that the addition of steel fibers provided a marked improvement in the measured compressive strength.

Wille et al. [20] carried out an experimental study on the tensile behavior of different Ultra High Performance Fiber Reinforced Concrete (UHPFRC) mixes using four types of high strength steel fibers; straight with aspect ratio 65, hooked with aspect ratio 79, high twisted with aspect ratio 100, and low twisted with aspect ratio 100 with different volume fractions (1%, 1.5%, 2% and 2.5%). The results showed that both the tensile strength and the maximum post-cracking strain are significantly improved by using deformed steel fibers instead of smooth fibers. Moreover the path of the stress strain curves of UHPFRC reinforced with hooked steel fibers and UHPFRC reinforced with twisted steel fibers are similar up to the peak load of UHPFRC reinforced with hooked steel fibers. While UHPFRC reinforced with hooked steel fibers begins softening at post cracking strain ε_{tp} = 0.46%, UHPFRC reinforced with twisted steel fibers keeps increasing the tensile stress up to post cracking strain $\varepsilon_{tp} \approx$ 0.6%.

EXPERIMENTAL PROGRAM

Materials:

- **Cement**

Aljisir sulfate resisting Portland cement, Type V, manufactured in Iraq was used throughout this research. Its chemical and physical properties conform to the provisions of Iraqi specification No.5.

- **Fine Aggregate**

AL-Ukhaider natural sand of maximum size 600 μm was used. Its gradation lies in zone (4). The gradation and sulfate content results of fine aggregate were within the requirements of the Iraqi specification No. 45.

- **Admixtures**

Two types of concrete admixtures were used in this work:

- **Superplasticizer**

Two different types of superplasticizer were used to produce the RPC mixes. They are, Naphthalene formaldehyde sulphonate polymer manufactured and supplied by SIKA® company under the commercial name Sikament®-163N, and polycarboxylate ether polymer manufactured by PAC Technologies company under the commercial name PC 200. These admixtures comply with the requirement of ASTM C494.

Table 1. Fine aggregate properties

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1984, zone 4
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	44	15-50
0.15	7	0-15
Fineness modulus = 1.5		
Specific gravity =2.69		
Sulfate content =0.13% (Iraqi specification requirement ≤ 0.5%)		
Absorption = 0.73%		

- **Silica Fume**

Silica fume has been used as a mineral admixture added to the RPC mixes of this study. The percentages used were 10%, 15%, 20%, 25%, and 30% as partial replacement of cement weight. The chemical composition and physical requirements show that the silica fume conforms to the chemical and physical requirements of ASTM C1240 specifications.

- **Steel Fibers**

Hooked steel fibers used throughout the experimental program. The steel fiber used has diameter 0.5mm, length 30mm (aspect ratio l_f/d_f = 60), density 7800 kg/m³ and ultimate tensile strength of 1180 MPa.

Concrete Mixes

The key features of RPC mix design include high Portland cement content, fine sand with a particle size of between 150 and 600 μm, extremely low w/c ratio made possible by high dosages of the latest generation of superplasticizer, the presence of a high reactivity silica fume, and the incorporation of steel fibers. Sand to cement ratio (S/C) in mortar has a significant effect on compressive strength, *S/C ratio equal to 1.0 was found to be very effective for the optimization of mortar mixture with superplasticizer and mineral admixture [14].*

Within the above limits and according to pervious researches [2,4,6,12,17] many mix proportions were tried in this investigation to have maximum compressive strength and flow of (110+5%) according to ASTM C109 and ASTM C1437 respectively. Ten RPC mixes were used in the present research as listed in Table (2) to investigate the performance of RPC in the fresh and hardened state.

Table 2. RPC mixes used in the present research

Group	Mix symbol	cement kg/m^3	fine sand kg/m^3	silica fume* (%)	silica fume content kg/m^3	steel fibers** (%)	steel fibers content kg/m^3	w/cm ratio	HRWRA *** (%)	HRWRA type
1	MSP-N	935	1100	15%	165	2%	156	0.181	9.5%	Sikament ®-163N
	MSP-P	935	1100	15%	165	2%	156	0.169	8.7%	PC200
2	MSF0	1100	1100	0%	0	2%	156	0.161	8.7%	PC200
	MSF10	990	1100	10%	110	2%	156	0.166	8.7%	PC200
	MSF15†	935	1100	15%	165	2%	156	0.169	8.7%	PC200
	MSF20	880	1100	20%	220	2%	156	0.174	8.7%	PC200
	MSF25††	825	1100	25%	275	2%	156	0.180	8.7%	PC200
	MSF30	770	1100	30%	330	2%	156	0.188	8.7%	PC200
3	MFR0	825	1100	25%	275	0%	0	0.171	8.7%	PC200
	MFR1	825	1100	25%	275	1%	78	0.175	8.7%	PC200
	MFR2	825	1100	25%	275	2%	156	0.180	8.7%	PC200
	MFR3	825	1100	25%	275	3%	234	0.187	8.7%	PC200

†MSF15 in group 2 is the same mix designated MSP-P in group 1
†† MSF25 in group 2 is the same mix designated MFR2 in group 3
** Percent by weight of cement.*
*** Percent of mix volume.*
**** Percent of cementitious materials (cement + silica fume) by weight.*

Three variable parameters were considered in the preparation of these ten RPC mixes. They were;

1. *The silica fume content (as partial replacement by weight of cement). Six ratios were employed (0%, 10%, 15%, 20%, 25% and 30%).*
2. *The steel fibers volume fraction (as ratio of the mix volume). Four ratios were used (0%, 1%, 2% and 3%).*
3. *The type of the superplasticizer used in the mix, which was either type N (Sikament®-163N) or type P (PC200).*

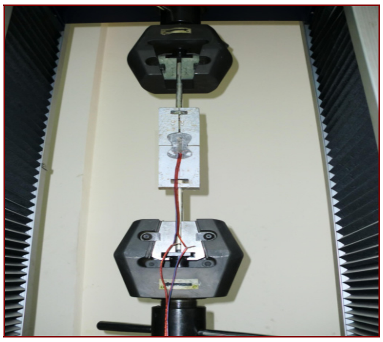
All mixes shown in Table (2) had a flow ranging between 105% and 115%.

Mixing of Concrete

All RPC mixes were performed in a rotary mixer of $0.1m^3$. For RPC concrete, the silica fume and cement were mixed in dry state for about 3 minutes to disperse the silica fume particles throughout the cement particles, then the sand was added and the mixture was mixed for 5 minutes. The superplasticizer is dissolved in water and the solution of water and superplasticizer is gradually added during the mixing process then the whole mixture was mixed for 3 minutes. The mixer was stopped and mixing was continued manually especially for the portions not reached by the blades of the mixer. The mixer then operated for 5 minutes to attain reasonable fluidity. Fibers were uniformly distributed into the mix in 3 minutes, and then the mixing process continued for additional 2 minutes. In total, the mixing of one batch requires approximately 15 minutes from adding water to the mix.

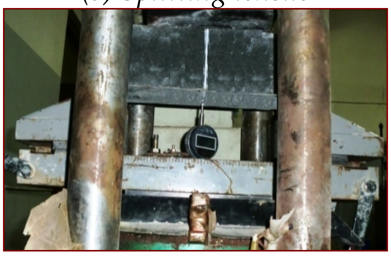
Preparation and Testing of Specimens

All specimens were prepared, cured for 28 days then tested to study some properties of RPC. These properties are compressive strength (using cubes of 100 mm and cylinders of 100 x 200 mm), direct tensile strength (using dog bone-shaped briquettes of 76 mm long, 25 mm thick, and 645-mm^2 cross section at mid-length) as shown in Figure (1a), splitting tensile strength (using cylinders of 100 x 200 mm) as shown in Figure (1b), flexural tensile strength and toughness (using prisms of 100 x100 x400 mm) as shown in Figure (1c), and static modulus of elasticity (using cylinders of 100 x 200 mm) as shown in Figure (1d).



(a) Direct tensile

(b) Splitting tensile



(c) Flexural toughness

(d) Static modulus of elasticity

Figure 1. Tests set-up

Curing

All specimens were demolded after 24 hours, and then they were steam cured at about 90°C for 48 hours in a water bath. After that they were left to be cooled at room temperature, and then they placed in water and left until the end of water curing at 28 days.

RESULTS AND DISCUSSIONS

Compressive Strength

The results of the compression test on RPC cubes and cylinders are shown in Table (3) and Figures (2) and (3). The ratios of cube compressive strength to cylinder compressive strength (f_{cu} / f'_c) at 28 days ranged between (1.008 - 1.067). These ratios are lower than 1.25 that was stated by Neville [11] for conventional concrete and so close to the range of (1.0 - 1.075) for UHPFRC found by Graybeal [7]. This phenomenon can be explained by the high powder content and smaller maximum aggregate size of RPC [8].

Table 3. Cube and cylinder compressive strengths of RPC

Group	Mix Symbol	Silica Fume content SF (%)	Steel fibers V_f (%)	f_{cu} (MPa)	%Increase in f_{cu} with respect to the first mix in each group	f'_c (MPa)	%Increase in f'_c with respect to the first mix in each group	f_{cu}/f'_c
1	MSP-N	15%	2%	126.84	0	118.91	0	1.067
	MSP-P	15%	2%	139.56	10.03	134.33	12.97	1.039
2	MSF0	0%	2%	118.26	0	111.66	0	1.059
	MSF10	10%	2%	134.28	13.54	131.27	17.56	1.023
	MSF15	15%	2%	139.56	18.02	134.33	20.30	1.039
	MSF20	20%	2%	147.49	24.72	146.19	30.92	1.009
	MSF25	25%	2%	153.57	29.86	149.39	33.79	1.028
	MSF30	30%	2%	158.67	34.17	157.48	41.04	1.008
3	MFR0	25%	0%	141.72	0	135.93	0	1.043
	MFR1	25%	1%	146.99	3.72	144.57	6.36	1.017
	MFR2	25%	2%	153.57	8.36	149.39	9.90	1.028
	MFR3	25%	3%	154.33	8.89	151.62	11.54	1.018

The results in Table (3) and Figure (2) demonstrate that increasing fibers volume fraction from 0% to 1.0%, 2.0%, and 3.0% causes slight increase in the cube compressive strength (f_{cu}) of 3.72%, 8.36%, and 8.89% respectively and the cylinder compressive strength (f'_c) slightly increased by 6.36%, 9.9%, and 11.54% respectively. Such increase may be associated with crack arrest theory of the fibers which accounts for the increase in compressive strength. The effect of steel fibers on compressive strength was also *observed by others like Orgass and Klug [12] and Lee and Chisholm [9]. According to the latter the improved compressive strength does likely reflect the contribution of steel fibers to the tensile capacity of RPC. An accepted view was given that concrete under uniaxial compressive load fails because of lateral strain induced by Poisson's ratio effects leading to lateral swelling of unconfined central section accompanied by cracking parallel to the loading axis and shear failure near the specimen ends.*

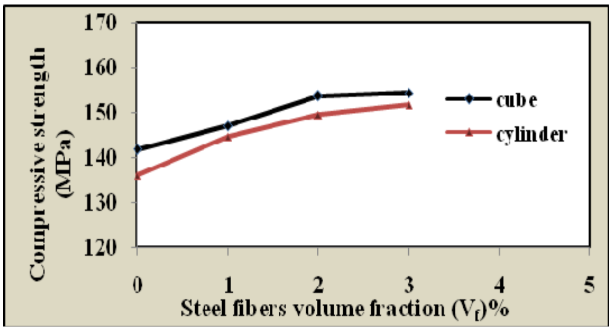


Figure 2. Effect of steel fibers content on cube and cylinder compressive strength of RPC

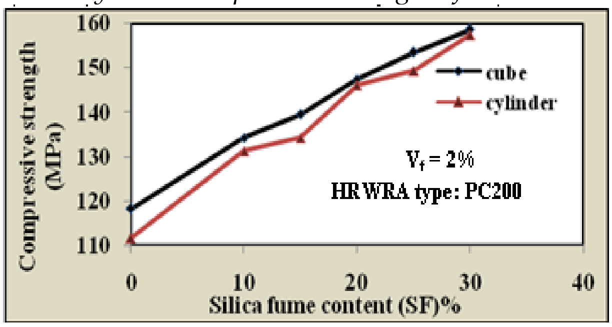


Figure 3. Effect of silica fume content on cube and cylinder compressive strength of RPC

Table (3) and Figure (3) show that increasing silica fume content (SF) from 0% to 10%, 15%, 20%, 25%, and 30% causes a considerable increase in both the cube compressive strength (f_{cu}) by 13.54%, 18.02%, 24.72%, 29.86%, and 34.17% and the cylinder compressive strength (f'_c) by 17.56%, 20.30%, 30.92%, 33.79%, and 41.04% respectively. This can be explained by the high pozzolanic reaction of silica fume particles with calcium hydroxide released from cement hydration leading to pore size and grain size refinement processes which can strengthen the microstructure and reducing the microcracking. The extreme fineness of the silica fume particles provides nucleation sites for calcium hydroxide and the additional contribution to the progress of hydration of the cement occurs. The beneficial effects of silica fume are not limited to its pozzolanic reaction; there is also a physical effect which comes from the enhanced particle packing, this leads to improving the microstructure of RPC matrix and increases its density and the bond strength between cement matrix and fibers [11].

The influence of superplasticizer type on RPC performance in terms of w/cm and compressive strength was also studied in the present research. The results show that in the presence of PC200 the w/cm was much lower than that with the Sikament®-163N, accordingly the compressive strength with PC200 (MSP-P) was much higher than that with Sikament®-163N (MSP-N).

Tensile Strength of RPC

Table (4) and Figures (4) to (9) illustrate the tensile strength results for different RPC mixes used throughout this investigation [direct (f_{td}), splitting (f_{sp}) and flexural (f_r)].

Table 4. Tensile strength results of RPC mixes

Group	Mix Symbol	Silica Fume content (SF) (%)	Steel fibers V_f (%)	f_{td} (MPa)	f_{sp} (MPa)	f_r (MPa)	f_{td}/f'_c (%)
1	MSP-N	15%	2%	7.65	14.78	20.86	6.43
	MSP-P	15%	2%	8.13	15.90	22.77	6.05
2	MSF0	0%	2%	7.82	15.19	20.97	7.00
	MSF10	10%	2%	8.03	15.40	22.12	6.12
	MSF15	15%	2%	8.13	15.90	22.77	6.05
	MSF20	20%	2%	8.56	16.23	24.19	5.86
	MSF25	25%	2%	8.92	17.25	24.57	5.97
	MSF30	30%	2%	9.14	17.55	24.96	5.80
3	MFR0	25%	0%	3.64	6.32	9.22	2.68
	MFR1	25%	1%	5.80	10.50	15.07	4.01
	MFR2	25%	2%	8.92	17.25	24.57	5.97
	MFR3	25%	3%	12.32	21.59	29.24	8.13

Generally, the addition of steel fibers to all RPC mixes improves the direct tensile strength *significantly relative to the nonfibrous RPC specimens. Increasing the volume fraction of fibers from 0% to 1.0%, 2.0%, and 3.0% increase the direct tensile strength by 59.4%, 145.05%, and 238.35%, the splitting tensile strength by 90.88%, 186.51%, and 258.45% and the flexural tensile strength by 52.62%, 166.61%, and 217.27% respectively. This is due to the fact that fibers are able to: (1) bridge tensile cracks and retard their propagation, (2) transmit stress across a crack and counteract crack growth [10]. In general, hooked end fibers lead to a great increase in tensile strength because of the fact that geometry of hooked end fibers influence the bond development between fiber and the matrix causing an increase in energy required to pull the fiber out of the matrix.*

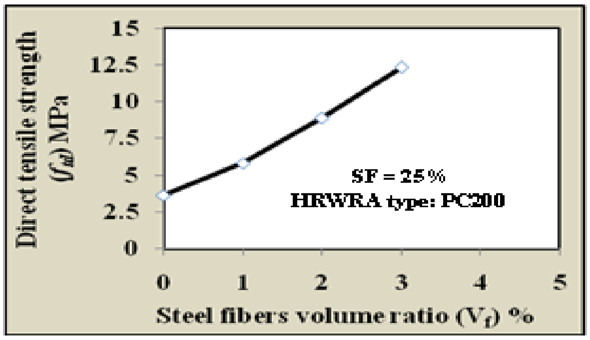


Figure 4. Effect of steel fibers volume fraction on direct tensile strength of RPC

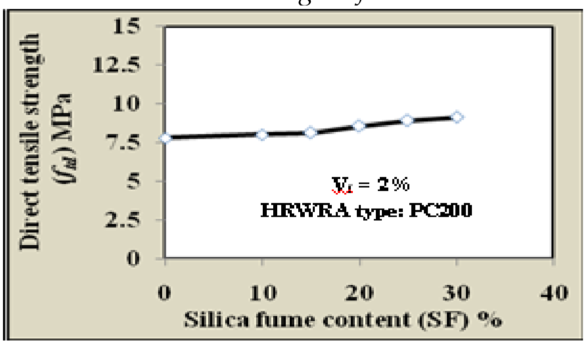


Figure 5. Effect of silica fume content on direct tensile strength of RPC

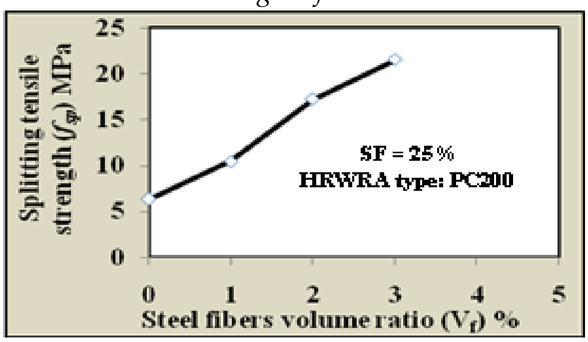


Figure 6. Effect of steel fibers volume fraction on splitting tensile strength of RPC

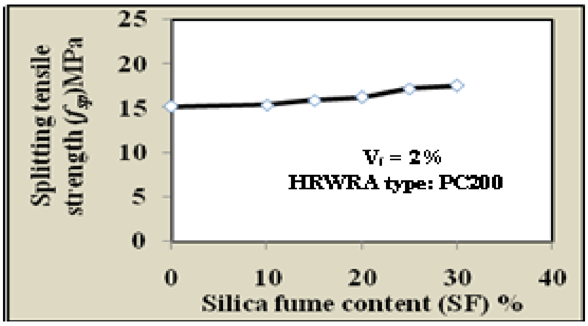


Figure 7. Effect of silica fume content on splitting tensile strength of RPC

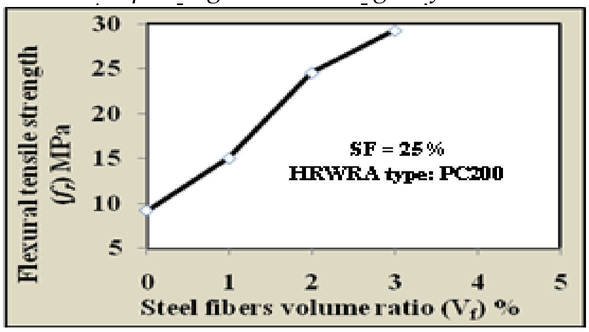


Figure 8. Effect of steel fibers volume fraction on flexural tensile strength of RPC

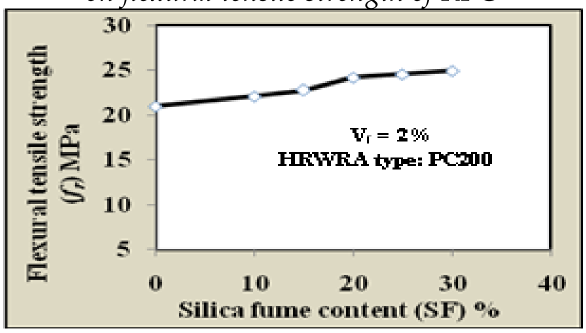


Figure 9. Effect of silica fume content on flexural tensile strength of RPC

The results also indicated that when SF content increased from 0% to 10%, 15%, 20%, 25%, and 30% the direct tensile strength increased by 2.63%, 3.96%, 9.5%, 14.04%, and 16.89%,the splitting tensile strength increased by 1.4%, 4.68%, 6.85%, 13.61%, and 15.57%, and the flexural tensile strength increased by 5.49%, 8.58%, 15.35%, 17.17%, and 19.01% respectively. This can be attributed to the fact that the increase of SF content in RPC matrix enhanced the steel fiber-matrix bond characteristics due to the interfacial-toughening effect. This effect of SF results in densification of the RPC matrix which comes from the enhanced particle packing, which leads to improving the microstructure of RPC matrix and increase its density as well as from the intensive chemical reaction due to pozzolanic reaction [3]. It can be noticed that, the influence of *silica fume content and superplasticizer type on direct tensile strength is less pronounced than that on compressive strength. This is due to the fact that tensile strength of RPC is related to the strength, volume fraction, and geometry of the fiber used as well as the bond between fiber and the matrix [19].*

The ratio of direct tensile strength to cylinder compressive strength (f_{td}/f'_c) for RPC mixes investigated in the present study is illustrated in Table (4). It was found that this ratio at 28 days is 2.68% for the nonfibrous RPC mix and ranged between 4.01-8.13% for RPC mixes with 1-3% steel fibers volume fraction.

Static Modulus of Elasticity

The modulus of elasticity is strongly influenced by the concrete materials and their proportions [10]. The static modulus of elasticity results for all RPC mixes are presented in Table (5) and Figures (10) and (11).

Table 5. Static modulus of elasticity results of RPC mixes

Group	Mix Symbol	Silica Fume content SF (%)	Steel fibers V_f (%)	Ec (MPa)	% Increase in E with respect to the first mix in each group
1	MSP-N	15%	2%	44841	0.00
	MSP-P	15%	2%	46398	3.47
2	MSF0	0%	2%	43836	0.00
	MSF10	10%	2%	45900	4.71
	MSF15*	15%	2%	46398	5.84
	MSF20	20%	2%	47422	8.18
	MSF25**	25%	2%	48295	10.17
	MSF30	30%	2%	49103	12.02
3	MFR0	25%	0%	46262	0.00
	MFR1	25%	1%	47363	2.38
	MFR2	25%	2%	48295	4.39
	MFR3	25%	3%	48538	4.92

It can be noticed that the increase in steel fibers ratio show only slight increases in the static modulus of elasticity. This may be because the modulus of elasticity was calculated to the stress corresponding to 40% of the ultimate load, so it is determined prior to concrete cracking; therefore, the fibers were not activated. In general increasing silica fume content show increases in the static modulus of elasticity and this may be attributed to the interfacial-toughening effect and densification of the RPC matrix which comes from the enhanced particle packing as well as from the intensive chemical reaction due to pozzolanic reaction. This leads to improving the microstructure of RPC matrix and increase its density [3].

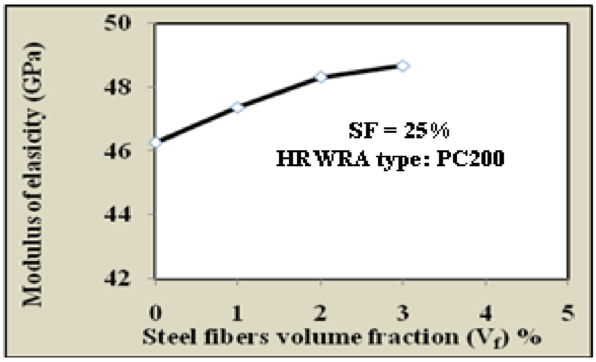


Figure 10. Effect of steel fibers volume fraction on the modulus of elasticity of RPC

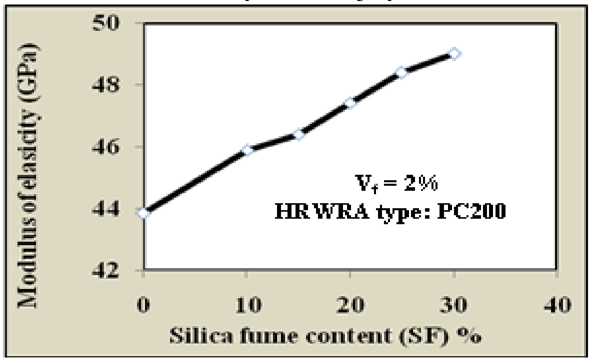


Figure 11. Effect of silica fume content on the modulus of elasticity of RPC

Flexural Toughness and Load-Deflection Capacity

Flexural toughness can be defined as the area under the load-deflection curve in flexure, which is the total energy absorbed prior to complete separation of the specimen [1]. The values of the toughness indices I_5 and I_{10} of the entire tested RPC prisms are presented in Table (6).

The load-deflection curves of RPC for typical nonfibrous control specimens and specimens with 1%, 2%, and 3% steel fibers are plotted in Figure

(12). It can be concluded that plain RPC fails suddenly at a small deflection by separation into two pieces, while fibrous RPC suffers damage by gradual development of single or multiple cracks with increasing deflection, but retains some degree of structural integrity and post-crack resistance even with considerable deflection.

Table 6. Toughness indices for RPC mixes

Group	Mix Symbol	Silica Fume SF (%)	Steel fibers V_f (%)	δ_{cr} (mm)
1	MSP-N	15%	2%	0.55
	MSP-P	15%	2%	0.52
2	MSF0	0%	2%	0.56
	MSF10	10%	2%	0.58
	MSF15	15%	2%	0.52
	MSF20	20%	2%	0.54
	MSF25	25%	2%	0.47
	MSF30	30%	2%	0.53
3	MFR0	25%	0%	0.45
	MFR1	25%	1%	0.43
	MFR2	25%	2%	0.47
	MFR3	25%	3%	0.46

Group	P_{cr} (kN)	def. at peak load (mm)	peak load (kN)	Toughness indices	
				I_5	I_{10}
1	49.9	1.33	69.5	5.31	9.71
	51.5	1.41	75.9	5.36	9.98
2	51.1	1.35	70.0	5.28	9.65
	53.6	1.45	73.7	5.34	9.95
	51.5	1.41	75.9	5.36	9.98
	52.9	1.50	80.6	5.51	10.88
	50.3	1.39	81.9	5.55	11.07
	54.7	1.49	83.2	5.61	11.30
3	30.7	0.45	30.7	1	1
	43.1	0.90	50.2	5.15	9.06
	50.3	1.39	81.9	5.55	11.07
	54.8	1.51	97.4	5.84	12.99

Figure (12) shows that the addition of steel fibers to plain RPC changes the brittle nature of the nonfibrous matrix to a composite mass with a plastic behavior after first crack. On the other hand, the presence of steel fibers led to a continuation of the load-carrying capacity beyond the peak load implying an improved post-peak toughness. It can be seen from Table (6) and Figure (12) that with the increase of the fibers volume fraction from 0% to 3% the load-deflection behavior and consequently the ductility and fracture toughness can be improved.

This can be traced back to the fact that, the fibers are able to transfer emerging loads by bridging the cracks. After reaching the maximum load the descending part of the load-deflection curve doesn't drop down at once.

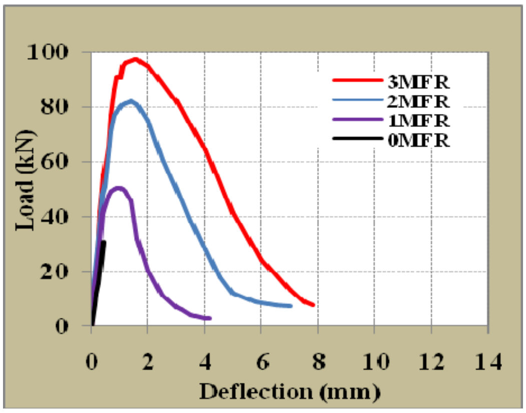


Figure 12. Load-deflection relationship of RPC prisms with various steel fibers contents

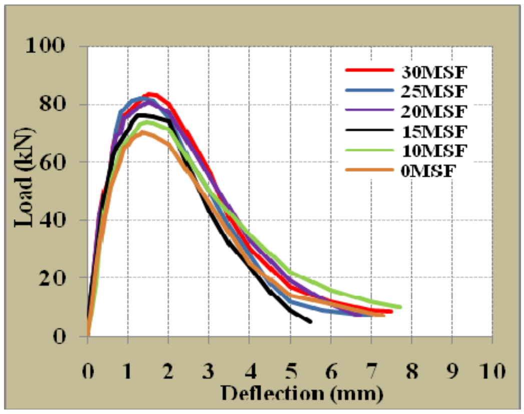


Figure 13. Load-deflection relationship of RPC prisms with various silica fume contents

The load-deflection curves of RPC for specimens with silica fume content of 0%, 10%, 15%, 20%, 25%, and 30% are plotted in Figure (13). The results illustrate that increasing silica fume content causes an increase in the flexural toughness of RPC. This behavior can be attributed to the fact that the incorporation of silica fume will effectively enhance the fiber–matrix interfacial properties due to densification of the mix by the effect of micro filling and pozzolanic reaction of silica fume. This increases the bond between the matrix and the fibers and therefore the pullout energy is remarkably enhanced causing an improvement in toughness [3, 5].

Regression Analysis for RPC Properties

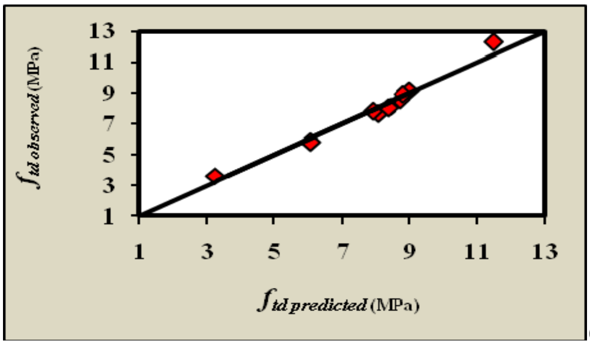
Regression analysis is an important statistical method that uses the relationships between two or more quantitative variables to generate a model that may predict one variable from the other(s).

- ***Relationship between Direct Tensile Strength and Cylinder Compressive Strength***

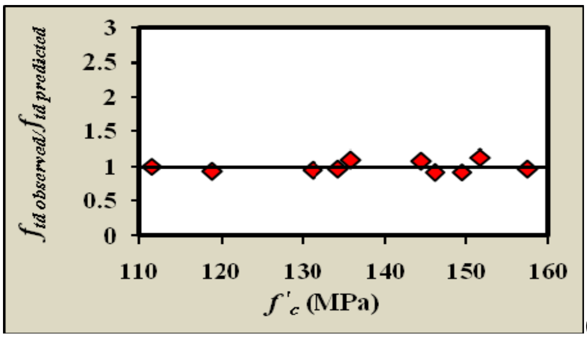
Compression test is frequently used as a quality control method for structural concrete; therefore, engineers often attempt to relate other characteristics of concrete behavior to this parameter. Results of tests carried out on the ten RPC mixes investigated in the present study show that fibrous RPC has direct tensile strength to compressive strength ratio higher than that for nonfibrous RPC. This is expected since the inclusion of steel fibers leads to a considerable increase in direct tensile strength while the increase in compressive strength is relatively lower. Therefore to include this important effect of steel fibers volume fraction, a data fit computer program has been adopted to carry out a regression analysis for the sake of establishing an empirical equation to predict the relationship between direct tensile strength and cylinder compressive strength for the ten RPC mixes investigated in the present study with $R^2 = 0.969$ *as given below.*

$$f_{td} = 0.024\,(f'_c) + 2.614\,(V_f) \qquad (1)$$

where: f_{td}*: direct tensile strength (MPa).*
f_c*: cylinder compressive strength (MPa).*
V_f*: steel fibers volumetric ratio.*



(a)



(b)

Figure 14. (a) Observed versus predicted values of direct tensile strength, (b) The ratio $f_{td\,observed}/f_{td\,predicted}$ *versus the cylinder compressive strength* f'_c

Eq. (1) gives a mean value statistic mean (μ) of ($f_{td\,observed}/f_{td\,predicted}$) *for the test results of this investigation of 1.0 with standard deviation (SD) of 0.0528 and coefficient of variation (COV) of 5.28%. Figure (14a) shows the direct tensile strength obtained from the experimental work (observed) versus the corresponding calculated strength using Eq. (1) (predicted), while Figure (14b) shows the ratio* $f_{td\,observed}/f_{td\,predicted}$ *versus the cylinder compressive strength* f'_c*.*

- ***Relationship between Static Modulus of Elasticity and Cylinder Compressive Strength***

Figure (15) shows the relationship between the static modulus of elasticity (E) and the cylinder compressive strength (f'_c) *for the different RPC mixes investigated in the present study. Results indicated that the static modulus of elasticity and compressive strength of RPC are related to each other such that when the compressive strength increases, the static modulus of elasticity also increases at a certain rate. A data fit computer program has been adopted to carry out a regression analysis for the sake of establishing an empirical equation to predict the relationship between E and* f'_c *for RPC. The equation obtained (Eq. 2) has* $R^2 = 0.985$*, as given below.*

$$E_c = 113.43\,(f'_c) + 31126.74 \qquad (2)$$

where: f'_c*: cylinder compressive strength (MPa).*
E_c*: static modulus of elasticity of RPC (MPa).*

Eq. (2) gives a mean value (μ) of ($E_{c\,observed}/E_{c\,predicted}$) *for the test results of this investigation of 0.99 with SD of 0.004 and COV of 0.406%. Figure (16a) shows the static modulus of elasticity obtained from the experimental work (observed) versus the corresponding calculated static modulus of elasticity using Eq. (2) (predicted), while Figure (16b) shows the ratio* $E_{c\,observed}/E_{c\,predicted}$ *versus the cylinder compressive strength* f'_c*.*

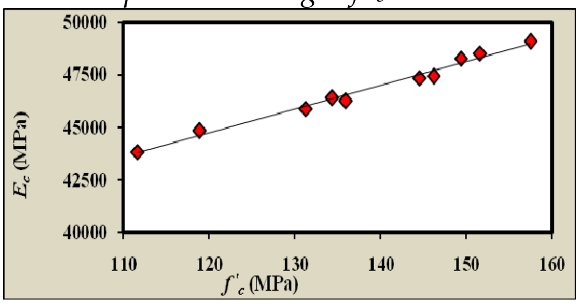


Figure 15. Relationship between compressive strength and static modulus of elasticity for RPC

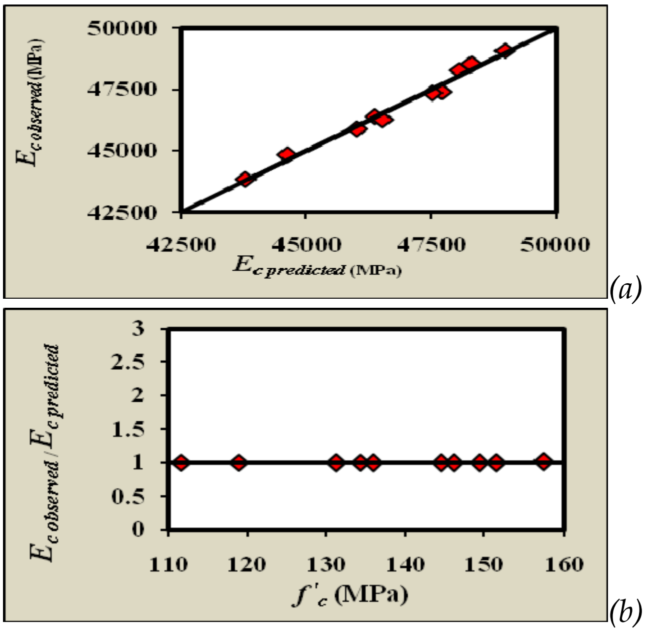


Figure (16) (a) Observed versus predicted values of static modulus of elasticity, (b) The ratio $E_{c\ observed}/E_{c\ predicted}$ versus the cylinder compressive strength f'_c

– ***Relationships between Direct Tensile Strength, Splitting Tensile Strength, and Flexural Tensile Strength***

A data fit computer program has been adopted to carry out a regression analysis for the sake of establishing two empirical equations, the first equation (Eq. 3) estimates the RPC direct tensile strength from the splitting tensile strength with R^2 = 0.974, while the second equation (Eq. 4) estimates the RPC direct tensile strength from the flexural tensile strength with R^2 = 0.943.

$$f_{td} = 0.53 * f_{sp} \quad (3)$$

$$f_{td} = 0.37 * f_r \quad (4)$$

where: f_{td}: direct tensile strength (MPa), which is f_{te} for RPC with strain softening behavior and f_{tp} for RPC with strain hardening behavior.

f_{sp}: splitting tensile strength (MPa).

f_r: flexural tensile strength (MPa).

Eq. (3) gives a mean value (μ) of ($f_{td\ observed}/f_{td\ predicted}$) for the test results of this investigation of 1.0 with SD of 0.043 and COV of 4.299%. Figure (4-59 a) shows the direct tensile strength obtained from the experimental work (observed) versus the corresponding calculated strength using Eq. (3) (predicted), while Figure (4-59 b) shows the ratio $f_{td\ observed}/f_{td\ predicted}$ versus the splitting tensile strength f_{sp}.

Eq. (4) gives a mean value (μ) of ($f_{td\ observed}/f_{td\ predicted}$) for the test results of this investigation of 0.999 with SD of 0.052 and COV of 5.237%. Figure (4-60 a) shows the direct tensile strength obtained from the experimental work (observed) versus the corresponding calculated strength using Eq. (4) (predicted), while Figure (4-60 b) shows the ratio $f_{td\ observed}/f_{td\ predicted}$ versus the flexural tensile strength f_r.

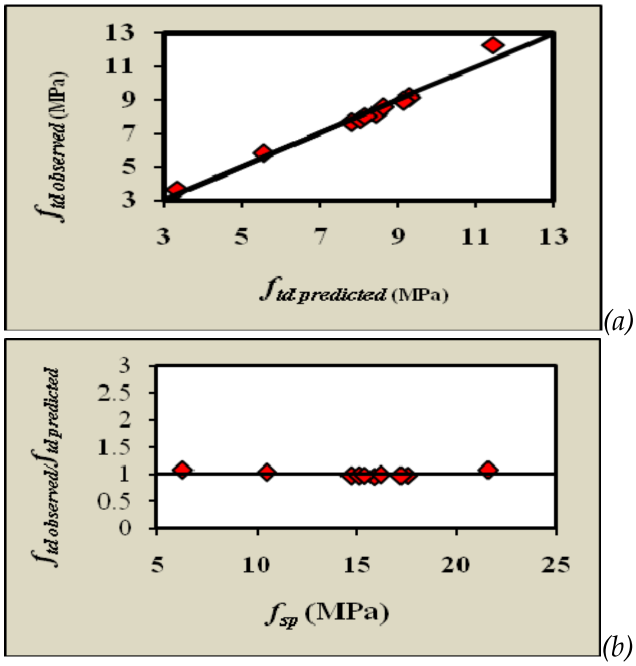


Figure 17. (a) Observed versus predicted values of direct tensile strength, (b) The ratio $f_{td\ observed}/f_{td\ predicted}$ versus the splitting tensile strength f_{sp}

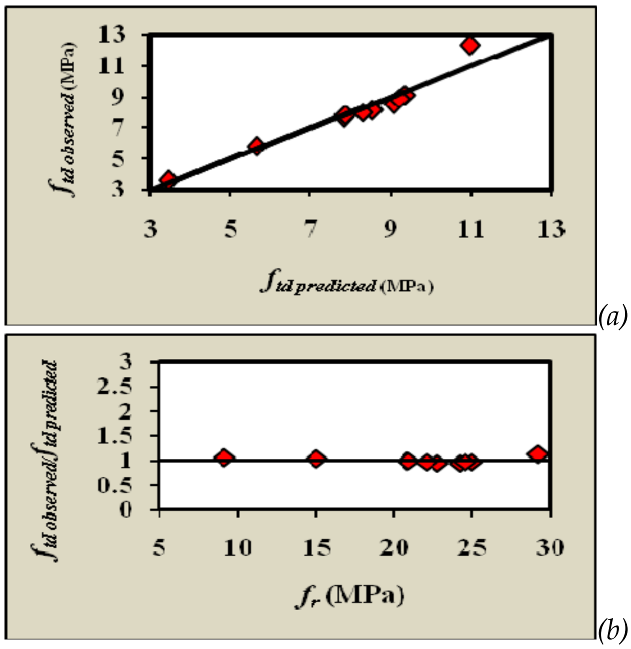


Figure 18.(a) Observed versus predicted values of direct tensile strength, (b) the ratio $f_{td\ observed}/f_{td\ predicted}$ versus the flexural tensile strength f_r

CONCLUSIONS

From the experimental results presented in this study, the following conclusions can be drawn:

1- *Results indicated that by increasing the volume fraction of fibers from 0% to 1.0%, 2.0%, and 3.0% the cube compressive strength was increased by 3.72%, 8.36%, and 8.89% respectively, while the cylinder compressive strength was increased by 6.36%, 9.9%, and 11.54% respectively.*

2- *Increasing SF content from 0% to 10%, 15%, 20%, 25%, and 30% caused a considerable increase in the cube compressive strength by 13.54%, 18.02%, 24.72%, 29.86%, and 34.17% respectively, as well as a comparative increase in the cylinder compressive strength by 17.56%, 20.30%, 30.92%, 33.79%, and 41.04% respectively.*

3- *The inclusion of steel fibers leads to a considerable increase in tensile strength (direct, splitting and flexural). Increasing the volume fraction of fibers from 0% to 1.0%, 2.0%, and 3.0% resulted in an increase in the direct tensile strength by 59.4%, 145.05%, and 238.35%, the splitting tensile strength by 90.88%, 186.51%, and 258.45% and the flexural tensile strength by 52.62%, 166.61%, and 217.27% respectively.*

4- *The increase in the steel fibers volume fraction and silica fume content improved the load-deflection behavior and consequently gave larger ductility and fracture toughness of RPC. Addition of steel fibers to nonfibrous RPC was found to change the brittle nature of the nonfibrous matrix to a composite mass with a plastic behavior after first crack. The presence of steel fibers gave a longer plastic range of the load-deflection behavior with higher peak load and larger post-peak toughness.*

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NEW TECHNOLOGIES GENERATE NEED FOR A NEW ORGANIZATIONAL PRACTICE

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Abstract: *The paper reflects on development of new technologies and mentality of its developers. Authors have selected important technologies which shape future life style. Each of selected technologies has specific characteristics which require different mentality of own developers. New ways of thinking and acting are necessary for different type of education. Today we are living in the period when science strongly produces new knowledge that is simultaneously translated into in new technologies. The speed of creating new technologies increases permanently, whereas the speed of change management lags behind the technology development. Because of this, it is important that management is innovated, i.e. that management processes are reengineered. Development of new technologies has marked number of evolutionary steps that different industries have made. Once competitors have reached similar level of technological advancement, exploration of new drivers of differentiation and competitiveness entered a "soft orbit". Companies started paying additional attention to innovation and talents. Therefore authors underline the connection between selected technologies, new ways of thinking and development of more adequate organizational practice, and human resources management that support it.*
Keywords: *new technologies, management of technology development, organizational practice, human resources management*

INTRODUCTION

John Naisbitt was right to say that every stone thrown into the water make waves, as every new technology does. New technologies make waves which should be recognized by the consequences introduced and if those are wanted by the human kind. Directions of technology development are changing in relation to overall society level of knowledge. Present civilization is at new, higher level of restructuring, where people and institutions are getting into new roles. Such role and mission are coming from something that Naisbitt simply defined. [1]

Technical understanding and artist' creativity… It's of high importance to balance – high technology and high art.

Some scientists share his opinion. One of them, physicists and mathematician Stephan Douplii names his own creative work as poetphysic or poe$_{fly}$physics [2] and says… Poetry, a supernova of feelings. Physic, a supernova of ideas. New strings of letters, a new string of mathematical symbols are the two sides of the Moon, an alien Бнary… History of science informs us that some of the developments are made of art of mathematics (e.g. James Clerk Maxwell – electromagnetic radiation/radio waves, Paul Dirac – antimatter), while for many other developments, wide comprehension was required (e.g. Warner Heisenberg – uncertainty principle). Certainly some scientists like Douplii interested in super symmetry and non commutative structures in mathematics and physics, had different mental approach then those scientists engaged with problems based in tangible world around us.

The need to create different ways of expressing thinking is an outcome of recent developments of science and technology, which is nowadays defined as technoscience. The Technoscience is complex phenomenon which is at the same time science, *scientific technology and technological science [3] A product of technoscience is not only an understanding of nature and of its phenomena, but that also necessitates and provides the capability to create phenomena and design ways to control and manipulate them, or technoscientific process embodies the dialectic between the two trajectories of the science–technology relationship: science-driven technology and technology-driven science. Besides, we also can notice increased pace of developments of trans-disciplinary sciences as for instance biomechatronics. Such sciences and derivate technologies require different model of thinking, with expressed holistic approach and process judgment.*

Within the paper we are exploring some of modern technologies with an aim to detect its characteristics which are shaping mentality of people engaged in their development, and especially those who manage these processes.

PROBLEM FORMULATION

Ervin Laszlo notes that human brain functions as quant computer and raises the question what such revolutionary discovery on human brain capacity means for the future of human kind [4]. Quantum consciousness – QC is the type of consciousness to which human being accesses when it uses potentials of quant-computerized brain. The brain is a macroscopic quant system, although it's used as exclusive classic biochemical system. At quant functioning, the brain receives not only information collected by sensor organs (eyes, ears, skin) but also those from wider environment where humans are networked – non local connections. Modern civilization has undermined such human capacity. The author is at the stand that the next phase of development will be actually on this segment of consciousness and will save human kind. Why? Because: the quant consciousness is immediate, intuitive and linked with environment. It inspires empathy towards people, nature, brings an experience of openness and belonging. Not only that the QC makes people more accountable towards other people and the Planet, it also initiates them to fight collectively with the problems. The most of people cooperate with members of their family and society, while cooperation and relations at global level are of vital importance. Without aligned acting the human kind would hard respond to emerging problems and threats. Without an aligned acting there is a risk of extinctions as many species unable to adapt to changed circumstances. Although that request for global cooperation is necessary at this stage of civilization development, seems that people are not yet ready for it.

The need for different type of approach, as well different technology development is noticeable indirectly through analyses of science classification. If compared The Frascati Manual (Organization for Economic Co-operation and Development) 2002 and 2007 edition, it's visible that ethics emerges around many of science disciplines (e.g. ethics in medical biotechnology or ethics in agricultural biotechnology), which suggests on many areas of co-acting [5].

On the other side, philosophers of science pay more attention to evolutionary psychology which has developed on basis of sociobiology [6]. The evolutionary psychology as an alternative research programme, which yet needs to position own status, aims to establish close relations between evolution and social sciences.

Therefore it suggests new model of social science – Integrated Causal Model, which is based on human capabilities such as learning of symbolic languages, understanding and concluding, comprehension of material worlds, anticipation, organization of social life, reproduction and food selection, recognizing faces in order to resolve complex tasks. Supporters of such model consider that traditional social sciences have not succeeded due to limited respect towards biological dimensions of human existence. Social sciences should therefore be based on the theory of evolution. By linking human behavior which is subject of social sciences and evolution, as biological discipline, there would be a bridge created for deeper understanding of creative work and quant consciousness, and we would be able to design programmes of higher probability to ignite common acting with a consciousness that everything is interlinked.

Within the paper we begin from the presented point in an attempt to further develop this theme. The authors consider there is a relation between development of new technologies and mentality of *its' developers. As the new technologies are based at new science findings which are mainly beyond direct comprehension of senses or techno science, the authors recognize that managers needs to pay an additional attention to human resources management. They need to understand specific mental modalities of people who develop new technologies and to change existing management and business systems of technology development. In theory and practice of technology management there is still limited attention to mentality of technology developers.*

In order to be able to change the process of technology development based on new approach towards human resources management, there is a need to change educational system, especially in higher educations. It should be based on support of creativity, development of emotional intelligence, and comprehension that everything is interconnected as a basic principle of sustainable development.

PROBLEM SOLUTION

Nanotechnologies

Nanotechnologies are closely related to nano science, therefore N&N. The N&N are at initial phase of development. It's considered that development pathway of nanotechnologies has passed 4 phases, e.g. there are 4 generations of nano technologies [7]. Products of the first generation are commercialized, the second generation is still in laboratories, and the third and fourth generations are under experiments. The most advances N&N are named molecular manufacturing – M&M. Development of such complex products will be based on positioned and controlled mechanical and chemical managed systems of the molecular machines. The power of the M&M lays with possibility to use devices called personal nanofactory, which could be placed at any working surface, supported by miniature chemical process, computer or robot and could produce range of products. The N&N would not only produce high quality products at reasonable low price and high pace yet would generate new factories producing under high quality and low price. Such unique ability to generate owns production capacities are the reasons that nanotechnologies are called exponential technologies. The N&N are increasingly more linked with Bionics and create new, unlimited possibilities.

Characteristics of the N&N – the acronym itself describes strong ties between the science and technology in simultaneous process of development. Secondly, many of science disciplines are embedded within the N&N (molecular physics, science on materials, chemistry, biology, computer science, electro engineering, etc.) so that development depends on the pace of integration of different knowledge under range of disciplines. The integration of disciplines requires cooperation competence at the same time.

Consequences to mentality – there will be an enormous discontinuity which would manifest at the interruption of the present social system. Such change would not remain within the borders of the develop world. Therefore Intuitive Linear View [8] should be abandoned. New mentality would need to manager terms like frog jump and exponential growth. Such mentality needs to remain open and confident, as this can manage fear from new or unknown, which is specific to people. The fear from new can be noted at scientist which consider that M&M is just a science fiction. However, none of them is active in the N&N but chemistry, physics, biotechnology, etc. Max Planck has noted long ago that realization of new ideas goes only with new people, not with persuasion on validity of such new ideas. Vision of the N&N future requires discussion on Social and Ethical Issues – SEI. As that the role of the N&N is not fully defined, discussion programme could be clearly defined also [9]. Key for understanding of the N&N is that these are technologies of wide opportunities for improvements of existing processes and that will leads towards industrial revolution.

Industrial ecology and ecodesign

Industrial ecology and ecodesign could also be considered as integration of science and technology. Contrary to the N&N, industrial ecology and ecodesign would not generate developments of high intensity, but changes of high wide intensity. Industrial ecology as the science of physical, chemical and biological interactions and inter relations within and between industrial systems and its surroundings [10] or could be *considered as a science on sustainability [11]. One of the key objectives of the industrial ecology is change of industrial systems from linear to circular systems. Such change requires new tools. One of these is Life Cycle Assessment – LCA, which considers evaluation of environment burden based on industrial processes, products or activities. The other tool is Life Cycle Design – LCD and Design for the Environment – DfE which considers that during the phase of design, principles of sustainable environment are projected into final design. In such manner the innovations and design became potential for regeneration of environment, cultural and society as an added value product, for clients, business and society [12].*

Characteristics of Industrial ecology and ecodesign – Introduction of ecodesign is looking of solutions within the design process at two directions – bottom-up and top-down. The top-down entry is wide and includes academic research, environmental expertise, access to research knowledge, application of developed tools, etc. The bottom-up entry is coming from industrial reality and from managers. These two directions are frequently conflicting, so the development process itself could be looked from the perspective of optimization of conflicting objectives.

Consequences to mentality. Industrial ecology has brought debate on education, or more specifically, where it would be though – independently or incorporated within other disciplines. Whatever solution prevails, it's certain that those, whom develop technology in alignment with industrial ecology, should possess holistic approach to problem solving. Additionally, due to potentially conflicting objectives, they should develop specific value system which would contain moral, ethics and integrity. At this stage, researches from range of R&D sectors demonstrate different sensibility towards usefulness and strategic interest of ecodesign. There is also high level of suspicion towards new methodology based on fear from additional expectations. Additionally, industrial ecology and ecodesign have underlined needs for new range of process thinking. Every phase of development demands specific implementation principle of the environment protection, which implies that ecodesign cannot focus on just specific phase of product development but to be involved in all phases under different arrangements and strategic values delivered for each of phases.

Neuroeconomics: Brain and Business

Neuroeconomics science has evolved from the need to better understand humans in order to define ways for coping with business environment influenced by new technologies and new techniques required for leading and developing organizations. Carmen Nobel, a senior editor of Harvard Business School Working Knowledge, has become attract with fact that economists have been paying increasing attention to how the brain works [13]. Though, a neuroscientist and a business school might seem an odd fit, the research of Christine Looser on how people brain detects aliveness and the possible implications for organizations is being carefully observed by the business world.

The field of neuroeconomics has gained ground in the past 10 years, with exploring the brain activity that influence decision-making processes. Additionally, there is a fast-growing field of neuromarketing, which uses brain-tracking tools to find out why consumers prefer some products over others; and neuroleadership that relate neuroscience to management research. With her research, Looser is trying to integrate insights from social psychology, neuroscience, and business, and want to understand how we interact with other people. If we think about this, it's surprisingly hard to come up with any business transaction you can do alone. But Looser sees practical applications as well. At Harvard, she is conducting research to determine whether we're more likely to retain and remember information—data and objects—if the information is followed with a picture of a human face. Such information would help marketers to create more memorable product advertisements and executives to design presentations that are really attached with their customers, clients, and employees. From one side, there is a possibility that the human face may be distracting, so we will lose the thing but remember the face; but the other possibility, which appear to be more likely, is that seeing a human face will give us entrée to advanced cognitive mechanisms, that will encode things more deeply because they're paired with a face. Looser also plans to study whether our brains *get overloaded in the presence of too many faces, which may yield insight into the effects of a crowded office; or how to test how much energy we lose by being around large crowds; and is there a way to be around a crowd of people in such a way that it doesn't feel draining. There are a lot of open questions that psychology and neuroscience can help answer. And this can have a real impact on the way organizations build relationships with employees, stakeholders, and shareholders.*

NEW KNOWLEDGE

In this new fast changing world shaped with new technologies, economic growth, business success and global stability will increasingly depend on the creation of new mind set. 21st century economy need leaders with a mind set that understand, interact, and use new technologies; that support and participate in the evolution of those technologies; and are able to transfer that knowledge. Those leaders are capable to understand emerging trends and positively respond to the major challenges associated with the knowledge society. In the emerging knowledge society which is expanding in both rich and poor countries, significant focus must be placed on:

1. *cybercitizenship, e.g. democratization and massification of connectivity and digital access; and*
2. *building new forms of socioeconomic, entrepreneurial and governance organization where innovation and talent leadership play a key role.*

In this new context, the path towards development becomes ever more complex and demanding. Development of the new technologies and the consequent globalization of the economy generate huge changes, disruptions and challenges regarding the current ways of producing, consuming and living, cultural pressures as well as a growing international competitiveness. This all have positive and negative consequences. Though, such changes, at economic and social level may initiate feelings of loss, crisis, disappointment and denial, they may also give rise to a global and positive vision, focused on a promising future with new opportunities at all levels: economic, social, cultural and political. In this environment colored with uncertainty, the difference between positive and negative approaches lies on:

1. *understanding major emerging trends and being able to meet the challenges of the knowledge society consisting of creation of new technologies; and*
2. *the existence and quality of adequate leadership; mobilizing and inspiring leaders oriented towards socially and economically sustainable results.*

There is a wide consensus on the fact that knowledge has become the key resource of the 21st century's economy. The arrival of the knowledge society and increasing influence of new technologies implies major changes for organizations. Today, it is estimated that 70 to 80 percent of economic growth in OECD countries is due to new and better knowledge.

Knowledge has value, but so too does knowledge about knowledge. The key issue knows how to create and to capture that value. However, good practice of the leading global organizations is showing that the creation of value lies essentially in talent and innovation management; and to be able to capture created value depends much more on the reinforced practice of strategic leadership rather than on the implementation of rigid procedural and organizational control systems. Leadership that energizes ideas and emotions in favor of high performance becomes therefore the most decisive organizational process. Leaders with new mind set, create magnetic fields which motivate, develop and mobilize results-oriented talent rather than just managing the status quo.

From the micro level (organizational), the new organizational context requires a new type of leadership oriented towards unlocking the talent of others. It is talent, and the imagination and innovation associated with it, that forms the soul of successful organizations. This is why, an effective leader has to be, above all, a talent facilitator, along with three key components:

- *intellectual capital (creative and rational),*
- *emotional capital (capacity to work with others), and*
- *social capital (value of knowledge network).*

Looking from the macro level (economies), countries should focus more on employment and *talent attraction and development strategies than on industrial strategies. For example, productive delocalization resulted from the knowledge economy, allows countries to more easily change the specialization pattern of their economies, namely through technological modernization. It also enables to create new economic sectors (activities), such as the Information and Communication Technologies (ICT), particularly in value chain segments at worldwide level, where geographically disintermediated services (telework) may be delivered in a more competitive way.*

Apart from that, the dramatical situations happen at universities, those very institutions where knowledge is being created and disseminated. In the USA, the most developed world country; the 1980 Bayh-Dole Act and 1986 Federal Technology Act are being accepted. In those acts the profit-making out of intellectual property is being enabled, whereas the commercialization of the university knowledge spreads up faster and has intensified.

Knowledge is evaluated, above all, on the basis of the share in creating product and processes for the recently-created markets, i.e. the markets that will be created in close future. Today we are living in the period when science strongly produces new knowledge that is simultaneously translated into in new technologies. The speed of creating new technologies increases permanently, whereas the speed of change management lags behind the technology development. Because of this, it is important that management is innovated, i.e. that management processes are reengineered.

Creation of new mind set call for the education that integrates science and technology, and incorporate all aspects influencing economical and social environment. This may become foundation for nurturing people educated to understand, design, develop, innovate, and inspire continuous creation of new knowledge and new technologies that will simultaneously evolve with the economical, technological, and social evolution.

Needs for new organizational practice

Development of new technologies has marked number of evolutionary steps that different industries have made. Examples of such transformation are well known and documented – we are clear on development pathways, driving forces and enablers which helped change. Once competitors have reached similar level of technological advancement, exploration of new drivers of differentiation and competitiveness entered a "soft orbit". Companies started paying additional attention to innovation and talents over the last 20 years – these were recognized as the "War for talent".

Although successful companies focus were in developing human capital and innovation strategies, return of such investments was not always coming quickly enough to keep the competitiveness in a comfort zone and new explorations were launched to look beyond existing transformational arsenal. Companies have to remain mobile and agile in search for its future structure (Survivors are the most adaptive, not the most advanced – C. Darwin). This invites for continuous transformations against and beyond known and predictable trends. However capable thinkers we can have in our organizations, pace and speed of developments and increasing number of variables which could place an impact to the organization, require additional stretch and organization learning in no-traditional manner.

However, new chapter in the book of organizational development goes into direction of cross-industry sharing of best practices, which are driving the need to remain competitive and demonstrate organizational ability to convert and develop own future. Getting a license for existence and stakeholders support simply means remaining agile, flexible and driven at the path of constant improvement. Phase of self-reinvention cannot generate required level of change and competitiveness, and small, gradual self-paced improvements in own business models within an industry should be replaced by cross-industry learning and clever transfer of successful business models. Such companies are open to listen and watch others and are actively exploring beyond the industry fence. Richard Brenson of Virgin has a simple look over such process - "I have no regrets trying to break the mould and taking a different approach. That has resulted in Virgin being one of the best known brands in the world".

Regardless of the industry in focus, if an organization would look at range of other industries there are perhaps dozens of examples and ideas which could be copied. Yet, simple copying would bring the risk of inapplicability. Therefore "smart copying" is actually relaying on extrapolation of successful examples under your organization operational circumstances and framework.

Having sad that, the pathway could look too easy, and too simple. We could say that many businesses across different industries face similar issues and similar business functions. Common roles which should be interchangeable are in finance, planning, human resources and sales. But in each of those functions there is something in other industries which could be beneficial and add value to your practices, processes, standards and business model.

New competencies for new HR

Inevitably, organizational agenda based on learning for development requires investment in human resources and introduction of new standards for workers in 21st century. These skills cut across industries, functions and actual job titles, presenting a new golden standard. As this implies new thresholds for self-development, it equally well informs students or aspirants in career development on areas for improvement, either through education, on-job learning or exposure in circumstance which enable required development.

We consider that critical set includes:

- ***Adaptability skills** – critical thinking and problem solving, time management, flexibility and lifelong learning. Workers which are fixed to their job description, rigid and slow in adapting would face serious difficulties in remaining competitive in ever-changing labor market;*
- ***Information management and communication** – ability to quickly and selectively collect data, analyze, understand, and select information of critical importance and impact for transfer into forms appropriate for range of potential audiences. Cultural sensitivity and effective negotiation are of additional importance;*
- ***Business skills** – finance and project management, matrix and network management, as well as product marketing and management;*
- ***Science, technology, engineering and math (STEM)** – advance knowledge of STEM and quick adaptability to new requirements followed with capacity to immediately apply;*
- ***Interdisciplinary skills** – combining technical skills with business acumen.*

In order to maximize advantage from cross-industry learning, organization has to have capacity to absorb new knowledge and flexibility to quickly adapt to the new procedures/practices. This is where the power of HR lays. The HR function creates tangible value in organizations by focusing primarily on delivery of HR practices (staffing, development, compensation, labor relations, etc.), based on professional and often research-based principles. These practices are important, and research indicates that when they are done well they add tangible value to the organization. However, professional practices alone do not systematically address the increasing sophistication and importance of talent markets and decisions to today's competitive challenges. HR department should develop own competencies required for molding and shaping talents. The new HR role is to know:

- *how to create the innovative profile of an organization;*
- *how to stimulate creative experience and actions;*
- *how to increase employee satisfaction rate (because this is in close relationship with the attraction and retention of employees);*
- *how to control the workforce stability (this represents the biggest threat to intellectual capital drain, since unwanted departure of best performing employees and talents significantly influence competitiveness of the organization),*
- *how to attract and retain experienced employees that create new approaches, services, products or processes based on their experience, etc.*

In addition of investment in in-house talents and promoting vertical development, organizations can opt for double win – recruiting talents from other *industries. If properly targeted and carefully deployed within the organizations, talents could provide many benefits for new employer – strategic mindset, unique skills, fresh perspective, innovation, new visions and then invigorate present management structures and decision making. At the same time they need to learn new industry intricacies, business complexity and driving forces in order to properly utilize their previous experience, expertise and skills. Again, if done just in too bluntly manner, staff takeover can harm organizational performance. So the mastery is not just in making a copy-paste, but doing this in a way that adds value to the operational and organizational context – well thought on benefits, systematically planned, culturally and value-sensitive, and with clear transformational objectives. In order to succeed, cross-industry talents must possess a number of specific characteristics, like:*

- *ability to interact at all levels, including back-of-the house employees;*
- *excellent relationship builder;*
- *superb communication skills and a great active listener;*
- *passion for new industry, customer service and the team;*
- *ability to drive change while respecting the past.*

CONCLUSION

Based on the presented, there is undoubted need for the new education that integrates science, technology, engineering and mathematics.

Engineering allows students to understand the design. They develop understanding of the attributes of design, engineering design, the importance of problem solving, research and development, invention and innovation, and experimentation in problem solving.

Mathematics encourages creativity. Technology is viewed through the four stages of the process: design, construction, implementation and production. And, science develops scientifically spirit and knowledge. Science is part of the culture. It is impossible to understand the science and appreciate the history, society and language of the people who create. Science and technology are no socially and morally neutral categories. They are the activities of the man and society for society.

New and a wonderful knowledge that every day inspire innovation and diffusion of ICT is responsible for irreversible changes in business processes, e.g. electronic commerce, communicating via video conferences, employees personal ICT equipment that allows direct access to the business processes, etc. In an environment that continually shifts business practices, employers' requirements are transforming. Companies are looking for authentic people, that quickly adapt and change, enjoying the volatility, and nurturing their talents and creativity. Continuing advances in information and communications technology have made possible new forms of international coordination within global companies and potential new ways for them to cultivate in these fast-growing markets. There are many individual success stories, but, generally, organizations are still struggling to adapt. The ICT is clearly one of the major influences undoubtedly impacting organizational environment, and calling for more adequate management, learning methodology and leadership styles.

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ON THE SUSTAINABILITY OF WIND ENERGY REGARDING MATERIAL USAGE

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Abstract: Material sustainability and efficiency in the different phases of the product life-cycle are relevant and necessary perspectives for improving the environmental and economic sustainability of products. Renewable energies need to be sustainable in all the aspects, particularly wind energy which gained the most renewable power capacity around the world in 2011. Sustainable production, maintenance and disposal of wind turbines support sustainability of the energy source. This paper identifies raw materials, auxiliary materials and operating supplies along the life-cycle of wind turbines. Furthermore, an overview of material requirements and potential improvement areas for sustainable material usage is developed and discussed.
Keywords: wind energy, sustainability, raw material, material efficiency

INTRODUCTION

Presently, people consume daily resources and energy more and more. This trend will presumably continue through technical advances and progress that are continuously being made. However, exhaustible raw materials and resources as well as ever-increasing environmental problems illustrate that this attitude is not sustainable long term. When attempting to solve this problem, certain areas are affected, including higher material efficiency, higher system effectiveness or usage of endless resources. Out of several solutions that ensure a sufficient energy supply for the coming generations, the use of renewable energies is a common one. Chief among these renewable energies is wind energy, which was the top added renewable power capacity worldwide in 2011 [1].

Wind energy promises a solution for a environmental friendly and sustainable energy supply. Key facts are:

- Wind is an inexhaustible source of energy.
- The average time for energy amortization is approximately 6 months [2].
- 1 MW wind turbine can provide electricity for an average of 350 households [3, 4, 5].
- Currently, if all needed materials are recovered, over 90% of the wind turbine can be recycled [6].
- There are no CO_2 emissions during running time, without taking into account the maintenance and monitoring.

However, a large amount of material usage in the wind energy sector is needed when producing, constructing, maintaining, and disposing of wind turbines. The total weight amount of material used to produce a wind turbine, including tower, nacelle and blades (foundation not considered), varies depending on size. However, for an average 1.5-2 MW wind turbine model, weight varies between 164 and 334 tonnes [7].

In addition, when regarding the total materials balance of a wind turbine, foundations must be considered as well as the waste materials produced and the materials that become waste in the production processes. This means that the material input of the production processes is higher than *strictly needed for a finished wind turbine. Moreover, operating supplies are needed within the operation phase. These materials, the final product, production waste materials and supplementary waste materials must be disposed of. This affects the overall sustainability and efficiency of a wind turbine life-cycle.*

This paper also provides a brief overview of raw materials, auxiliary materials and operating supplies used in the life-cycle of wind turbines. The focus lies on production, usage and end-of-life material input and output. Some initial approaches regarding sustainable and efficient material usage practices are given.

MATERIAL SUSTAINABILITY AND MATERIAL EFFICIENCY

Material efficiency in production systems describes the ratio between material output and material input, which leads to an ecological characterization of production processes.

A higher material efficiency can be reached by producing more with less material input. In the same way, material efficiency improvement is present in products that allow the fulfilment of the same function with a reduction of used material [8, 9, 10]. Based on these definitions there are two main strategies to apply in order to improve material efficiency. Either the amount of material input brought into the system can be reduced, or a sustainable route of materials or products can be provided.

Measures for each of the strategies are proposed as follows [11]:

Reduction of material input into the system:

- *Material-efficient product design: designing lightweight products;*
- *Decreasing production waste: changes in production processes can allow a better use of resources reducing production waste;*
- *Decreasing maintenance replacements: products design with minimal needs of maintenance replacements;*
- *Increasing Life-cycle performance: using products more intensively, designing products for longer life-cycle or providing means to repair, upgrade or remanufacture products.*

Sustainable disposal route:

- *Material substitution: replacement of the original material by another more sustainable one in terms of energy and end-of-life.*
- *Product designed for re-use: designing products with focus on re-use after their main life-cycle.*
- *Product designed for recycling: designing products with focus on recycling after their life-cycle.*

Focusing on wind energy, the high material input for wind turbine production is apparent. Furthermore, products today are characterized by relatively new materials and supplementary composite materials. While technological progress is rapid in this field, the interest for designing environmental friendly products is growing in the wind energy sector. In regard to the development of the market, it seems that technological leaders in this sector have to address material efficiency from the economic and environmental perspective in order to hold their position [12].

Material sustainability can hardly be reduced to the availability and environmental performance of used materials. It is a long term perspective of the availability of needed material in the future and their potential to be recovered. Recycled materials are often related to other, lesser environmental impacts because less energy input is used for processing.

However, the quality and the availability of the materials are essential. Rare materials require more effort to recycle than other materials. In addition, the existing, efficient recycling process must be taken into account, which would result in higher recycling quotas.

When referring to wind energy, we identify some lack of existing industrial recycling options for some parts of the wind turbine, like rotor blades. This is because of the composition of materials which complicates the path to a sustainable solution. There is a solution for the recycling of rotor blades (example: geocycle [13]), but it is still a new solution. Wind park operators are often not aware of it, or try to find other solutions like incineration.

MATERIAL NEEDS IN WIND ENERGY

Primary materials needed for wind turbines include mainly steel, pre-stressed concrete, *magnetic materials, aluminium, copper, wood, epoxy, glass fibre reinforced plastic (GFRP) and carbon-filament reinforced plastic (CFRP). Dividing a wind turbine into four main parts, the figure 1 illustrates the material types involved in each of the parts [14, 15, 16].*

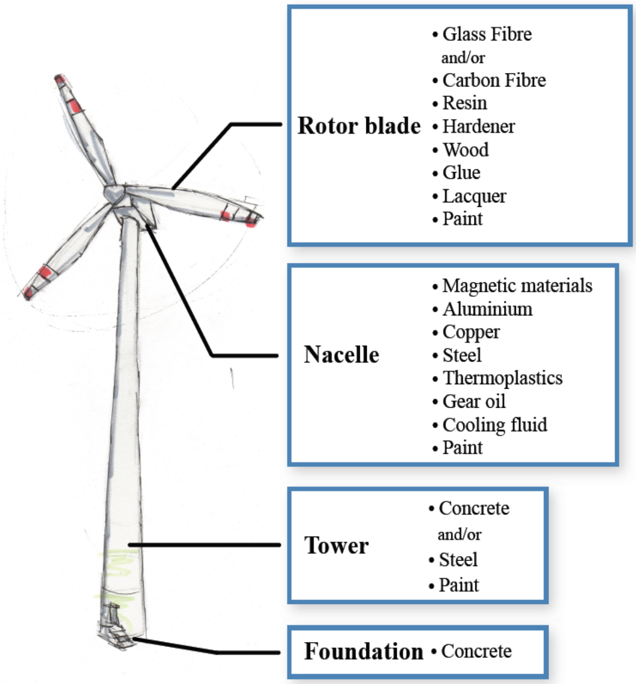

Figure 1 – Materials involved in each part of the final wind turbine [14, 15, 16]

Taking all parts except the foundation into account, the usage of steel is dominant with approximately 89% of total weight present. Furthermore, fibreglass and fibre-reinforced plastics are significant materials in regard to the proportion of weight, the characterization of the industry sector, and especially the costs. Figure 2 illustrates the percentage of other main materials involved in a 1.5 MW wind turbine and its according proportions of weight, excluding the foundation [17].

When regarding the different life-cycle phases, more materials than those directly involved into the wind turbine are needed. From a holistic point of view, further materials are needed in each life-cycle phase as they are used to accomplish related tasks in each phase. The life-cycle phases that must be considered are research, development, production, operation & maintenance, and end-of-life.

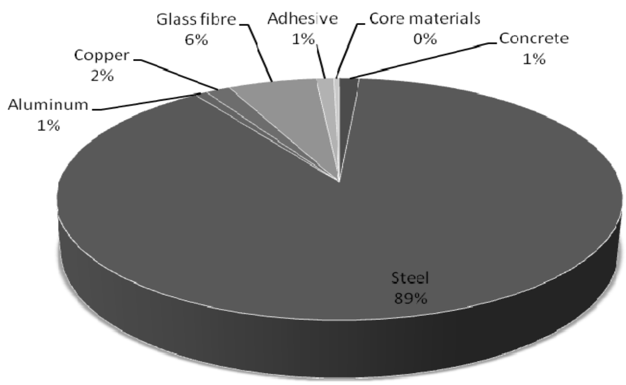

Figure 2 – Distribution of raw materials in wind turbines without foundations (1.5 MW) [17]

Intense material usage is found in production, operation (due to maintenance) and end-of-life phases. Moreover, the weight, variability and costs of materials in research and development phases are insignificant when compared with materials involved in the other phases [6]. The remaining parts of this chapter will focus on material needs for production and operation; the challenges of today with be illustrated accordingly. Based on the discussion, considerations of disposal routes for production and maintenance waste and for the wind turbine itself will follow.

Production

In the production processes, raw materials are more or less directly involved in the wind turbine production. Furthermore, there are auxiliary materials that are not part of the final product, but are needed within the production processes. In regard to three main parts, namely tower, nacelle and blades, raw materials and auxiliary materials are presented in the following subchapters.

¤ ***Tower***

Commonly available materials used to construct towers of wind turbines are steel and concrete. There are different structures of the tower within the wind power market; the most common tower is made of tubular steel structures and represents about 85% of the wind turbines around the world. [15, 18] Table 1 shows a comparison between the material needs for a 100 m height tower of tubular steel tower and the pre-stressed concrete with their foundation material needed for on-shore wind turbines:

Table 1 – Comparison of material needs between Steel and Concrete tower [19]

	Steel Tower		Concrete Tower	
Total weight per part	tonnes	%	tonnes	%
Tower	295	13	1.817	65
Foundations	1.911	87	1.077	35
Total tonnes	2.206		2.894	
Total weight per material	tonnes	%	tonnes	%
Steel	339	15	100	3
Concrete	1.867	85	2.794	97
Total tonnes	2.206		2.894	

Assuming that the tower can be 100% recycled, and the foundations only 60%, we see a huge loss of material for steel towers. Until now, there have been no figures summing up the lost material of the foundation. However, the advantage of concrete is that this material will be available in future without conflicting with other known technologies. Steel might become critical if its growing worldwide demand increases the cost. On the other hand, the recycling of steel is an established process and through melting it, it can be used for new steel parts as well. Concrete can be recycled as construction material but cannot be used for the construction of new wind turbines. Therefore, we find a downcycling of concrete, and the material flow never goes back into the turbine.

¤ ***Nacelle***

The nacelle contains most of the electric equipment of the turbine and therefore contains the most metals by weight. The casing is either made of cast iron, thermoplastics, or glass fibre reinforced plastic. The electric equipment composes of cast iron (generator, drive, etc.), aluminium, copper and other metals that are considered critical within the European Union [20]. Mass per weight varies according to different manufacturers. Most precious metals are located in the nacelle. Most parts inside the nacelle can be refurbished as well. The casing is made of similar material to the rotor blades, and can enter the same recycling process.

¤ ***Rotor Blades***

The blades used in commercial wind turbines are mostly made of glass fibre, mixed with smaller amounts of more expensive but stronger carbon fibre. A switch to more carbon fibre due to bigger rotor blades is being addressed, which will have a higher stress load with a more reasonable weight. While the broad usage of composite materials is still relatively new in the industry in general, smaller wind turbines manufacturers have started to study the possibility of other solutions. One such solution is the usage of thermoplastics composites for the production of rotor blades [21]. Researchers are also looking at the appropriateness of this solution. Delft University Wind Energy Research Institute [22] is paying close attention to the study of composite properties, and has already developed a one meter demonstrator. Furthermore, the research project GreenBlade is currently trying to produce glass fibre-reinforced propylene (Twintex®) thermoplastic blades for 6 kW and 15 kW. GreenBlade is developing a 12.6 meter long thermoplastic composite demonstrator blade. The possibility of recycling the whole blade at the end of its life-cycle as well as manufacturing waste and cuts-off [23] can be identified as the main advantages when using this material. However, it is not clear yet if these solutions are suitable for larger and commercial rotor blades.

Nowadays, most manufacturers produce rotor blades with GFRP through a vacuum infusion process called Vacuum Assisted Resin Transfer Moulding (VARTM), while others produce with prepreg (pre-impregnated) technology. Prepreg presents a Fibre-Reinforced Polymer (FRP) reinforcement that is pre-impregnated with a resin. Its usage in the airplane construction industry and in the production of rotor blades has many advantages. It is the optimal solution of glass fibre and resin proportion, with very little unnecessary material used, and the quality and conformity of the final product are improved greatly. However, using prepregs requires higher material costs as well as the need of special storage conditions. [24, 25] The data presented in Figure 3 is based on the production of rotor blades with GFRP through a VARTM process. The amount of raw materials needed to produce one rotor blade, including manufacturing waste, is considered, as well as auxiliary materials that are used to complete the production process. The VARTM process is mainly operated manually and raises the usage of auxiliary materials to up to fifty different materials.

Although the length of rotor blades varies in mass and material, a 40 meter long finished rotor blade made through VARTM process contains mainly GFRP or glass fibre. The total weight of the final product is around 7 tons of materials. The approximated material weight distribution is as follows in Figure 3 [16].

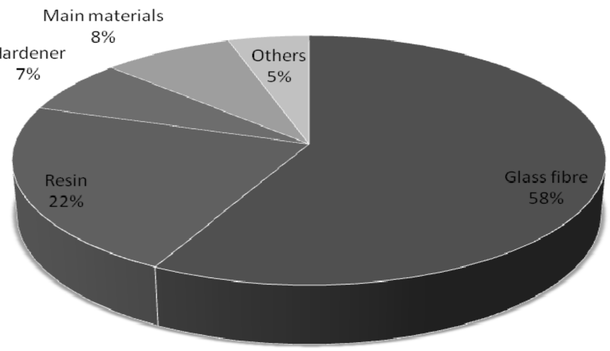

Figure 3 – Material distribution in a 40 meters and 7 tons rotor blade [16]

Many different materials are found in the waste generated by the production of 180 rotor blades during one year using the VARTM process. This waste includes production waste, packaging waste, maintenance waste and administration waste of the offices. This amounts to the entire amount of waste related to the production plant and their related activities.

The total amount of materials to dispose of is more than 800 tons. In this case, every rotor blade induces an additional material usage of more than 4 tons compared to the 7 tons of the final product [16]. The distribution of different waste material types is presented in the following Figure 4.

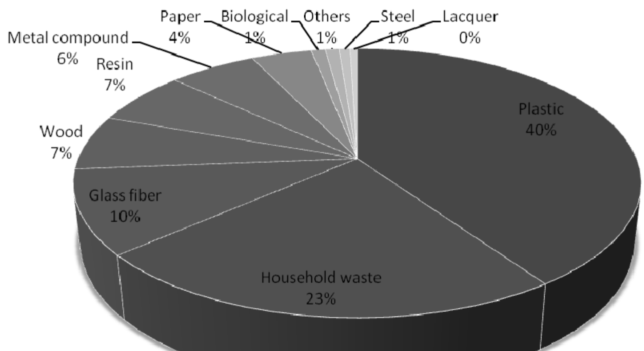

Figure 4 – Waste generated to produce 180 rotor blades [16]

Plastic materials represent the highest waste stream (40%), followed by normal household waste (23%). GFRP represents only 10%, mainly cut-offs. The plastics are part of the VARTM production process as the resin must infuse in a vacuum with the fibre layers. For the VARTM process to run correctly, plastic auxiliary materials like vacuum foil, plastic hose, perforated foil, green mesh, resin channel, fleece stripes, and many different types of adhesive foil are needed. Most of these materials are then removed after the process is finished and become plastic waste. As these materials are needed within the production process, the waste can only be minimised by changing the process itself.

Operation and Maintenance

The operation phase is the longest phase within the life-cycle. When considering current off-shore wind turbines, it must be remembered that 20 years of operations have been the basis for reliability engineering of main components of wind turbines. From a technical perspective, a complete maintenance-free operation of a wind turbine is not possible, due to the state of the art. Depending on the particular maintenance strategy, divided mainly into reactive and preventive ones, maintenance actions and the according material flows must be considered throughout the operation phase. Preventive maintenance with respective time intervals, also known as periodic maintenance, is the most common of such strategies in the wind energy sector. This strategy consists mainly of two actions, inspection/service and troubleshooting. Ongoing support for the rising usage of condition monitoring systems to measure crucial technical parameter does not change the general necessity for both actions. Rather, it aims at rescheduling the periodic intervals and lowering the amount of troubleshooting missions. Analyzing the material usage in the operation phase can then be detailed according to those actions.

In general, inspection and service is a yearly maintenance action, where crucial parameters of the components of wind turbines are observed, as prescribed by checklists [26]. Basic technical services like lubricating tribological systems, changing carbon brushes of the generator or replacing filters are some examples, often done during inspection and service. Related material *flows include mainly operating materials, whereas the refilling of wear-out reservoirs as well as replacements for related waste must be considered. Aside from that, auxiliaries that are needed to execute different actions must be disposed of.*

Besides the regularly planned inspections and services, technical failures of wind turbines can lead to extraordinary troubleshooting missions [26]. The range of particular actions that have to be executed is wide. This is also reflected by the related material flows, i.e. normal operating materials that could be needed, as well as more complex components in the electrical or mechanical systems. Normally replacements are performed on an item level, such as pumps, electrical controller, etc. Depending on the values of the components, replaced components are either disposed of or refurbished. In case of unlikely replacements of the big main components like main gear, blades or converter within the planned operating period, total aggregates are replaced and usually refurbished later on.

End-of-life

The end-of-life of products and materials is a necessary factor to study, in order to achieve a sustainable approach that allows and ensures the use of future products from the material perspective. When regarding the total percentage of material related to wind turbines that are theoretically reused or recycled, the development seems to point in the right direction. The entire wind turbine can theoretically be more than 90 % by mass [6] recycled on the material level, without taking into account periphery materials involved in electrical networks or the wind turbine foundations. This is due to the differences between on-shore and off-shore installations.

However, the 10% of industrial wind turbine material that cannot be recycled equals at least 15 tonnes of material. The practical recycling degree of the main materials used in a wind turbine is shown in Table 2.

In Table 2, some assumptions have been formulated to achieve these recycling quotes. One of these assumptions is that rotor blades or GFPR are recycled or used in a cement plant as a raw material to produce cement. This is a solution that has been developed in North Germany to provide a sustainable dismantle option for the end-of-life of rotor blades, as this method avoids any kind of waste and reduces the CO_2 emissions of the cement plant [13].

Table 2 Practical recycling degree of main materials [6]

Material	Practical Recycling Quote %
Aluminium	100
Copper	97
GFPR(Glass Fibre Reinforced Plastic)	100
Cast iron	98
Steel	100
Concrete	60

Cement plants recycle the rotor blades on a material level due to the GFRP being included into the clinker formation. Another solution available is the incineration of the rotor blades outside of a cement kiln. This is associated with a high ash content of an average 50% of the ash input. Not only this, but the energy needed to shred the rotor blades into smaller pieces must be taken into account as well. For the cement solution, rotor blades must be shredded to a maximum particle size of 30 mm, whereas in the incineration solution the maximum size must be 500 mm. The energy needed in each of these cases is different, and an exhaustive analysis of energy needs will help to support or refuse the sustainability of the cement solution.

Table 3 Economic comparison of disposal rotor blades possibilities

	Incineration solution	Cement solution
Costs pro tonne	550€	650 €
Treatment costs (shred)	Yes	Yes
Logistic costs	Yes	Yes
Dismantle costs	No	No
Total costs pro wind turbine (6,5 tonnes rotor blades)	10.725 €	12.675 €

From an economic perspective, Table 3 represents an economic comparison between the cement solution and the normal incineration solution. This comparison is for 3 rotor blades (each 40 long and 6.5 t weight) that must be transported a total of 250 km. In this comparison, logistics and treatment costs are included, but dismantle costs to remove the rotor blades from the wind turbine are not.

There is a price difference between both solutions, which is greater when disposing of larger rotor blades, or a big amount of rotor blades. The complex pre-treatment is the main reason for using the rotor blades in the cement solution. The need to shred the rotor blades into smaller pieces requires special machinery and more intensive energy use. In order to achieve the best environmental friendly solution, a proper footprint analysis is needed that takes into account the energy, CO_2 emissions and material use. As of the present, the incineration solution is still the most reasonable from a business perspective, as it has lower related costs. Currently, no regulation in Europe determines which party has the responsibility to recycle rotor blades.

Other than the rotor blades, we have not identified efforts that will recycle the entire wind turbine foundation in the future. Rather, discussions with experts have rather shown that the recycling of foundation concrete can be as little as 60 %. Additionally, there is no concrete decommissioning plan for the steel foundations used in the wind parks in the North Sea, and there are also discussions about new "artificial reefs".

CONCLUSIONS

In this paper, we wished to highlight the current awareness of material sustainability for renewable energy derived from wind. Currently, regulations for this sector are lacking, and some issues must still be taken into account. No fully sustainable solution has found at this point. The non-regulated fate of a foundation during its wind turbine decommissioning is a prime example of this problem. Removing all parts of the foundation after the use phase of the wind turbine in both installations, on-shore and off-shore, is still an open question. However, off-shore wind turbines might be more interesting in this case.

Also, the production waste during the costly rotor blade manufacturing can be reduced by making the process more efficient. To sum up, wind energy is a sustainable energy supply. However, for future progress we must keep the materials involved in each of the life-cycle phases in mind, and must provide a sustainable end-of-life for each of these materials. Based on this, further research must focus on designing wind turbines for disassembling and recycling under consideration of more economic studies regarding the entire wind turbine disposal.

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LITERATURE SURVEY OF GSCM WITH INTERRELATED CONCEPTS

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Abstract: *This paper is a review of papers with keywords Green Supply Chain Management, Lifecycle Assessment, Product Lifecycle Management, Product Life Cycle Management and Life Cycle Management. Number of articles and doctoral theses written with above mentioned concepts, methods and models were analyzed, leading to a summarized presentation of papers with their interrelated appearance. This paper is an extended article of paper published on 5th International Conference: Management of Technology - Step to Sustainable Production (MOTSP 2013).*
Keywords: *Green Supply Chain Management, Life Cycle Assessment, Product Life Cycle Management, greening*

INTRODUCTION

Nowadays, the increase in greenhouse gas (GHG) emissions in the atmosphere is currently one of the most serious environmental treats. Due to GHG emissions we will be witnesses of climate change which will cause damaging impacts in the next few decades [1]. These will primarily affect the natural and human systems [2]. At the same time these emissions are also a limiting factor for the economic growth of some countries, especially those in the transition process [3]. One of the reasons for that is the Kyoto protocol, adopted in December 1997 at The Third Conference of Parties (COP-3) in Kyoto, at which the industrial world agreed to reduce the emissions of greenhouse gases approximately 6 to 8 % below 1990 levels by 2008–2012 [4]. In the meantime, also due to the climate change and the increase in environmental awareness all over the world, the concept of Green Supply Chain Management appeared. It is often defined as integrating environmental thinking into supply chain management [5].Within that concept many greening elements aimed at the reduction of materials, energy, waste, pollution and emissions, or promoting the usage of recyclable materials and renewable energy sources, are introduced in various segments of supply chains. The proof lies in number of examples from industry, as well as in significant interest of academic community that could be seen through research papers, doctoral thesis and research projects.

There are three main reasons why companies implement the greening process into their corporation [6, 7]:

– Legislation - they have to comply with the environmental regulations,
– Marketing - addressing the environmental concerns of their customers,
– Ecological awareness - mitigate the environmental impact of their production activities.

Today there are many concepts, methods and models which are dealing with ecology, cleaner production, greener supply chains etc. However, mentioned examples and literature is not always fully clear and identical in terms of terminology used, while those various concepts, methods and models are appearing as a topic with practically same ultimate goal - greener processes of supply chain/production.

This paper is an overview paper of Green Supply Chain Management (GSCM) with Life Cycle Assessment (LCA), Product Lifecycle Management (PLM), Product Life Cycle Management (PLCM) and Life Cycle Management (LCM) terms. The research was based on literature survey within two *databases that contain number of relevant scientific journals, databases of doctoral thesis, and additionally standards and directives related to sustainable development. Research methodology is explained with more details in chapter 2 and findings in chapter 3, preceding with the brief explanations of mentioned concepts, methods and models. This is the first part of the research with aims to identify interrelations among those concepts, methods and models similarities and differences appearing in approaches of various authors, leading to an overall better understanding of broad concept of GSCM.*

Life Cycle Assessment, Product Lifecycle Management, Product Life Cycle Management, Life Cycle Management

The development of LCA methodology has its roots back in the late 1960's and early 1970's when the first studies applying a life cycle perspective on a process system took place in the USA, focusing on environmental impacts from different types of beverage containers [8].

When we compare LCA and PLM/PLCM/LCM we can found some differences. In ISO 14040 LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". Thus, LCA is a tool for the analysis of the environmental burden of products at all stages in their life cycle - from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (in effect, therefore, "from the cradle to the grave") [9].

In industry, PLM is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal, and should be distinguished from PLCM. PLM describes the engineering aspect of a product, from managing descriptions and properties of a product through its development and useful life; whereas, PLCM refers to the commercial management of life of a product in the business market with respect to costs and sales measures [10]. While LCM is an integrated model to assist in businesses managing the total life cycle of products and services towards more sustainable consumption and production patterns [11]. Figure 1 presents LCA method while Figure 2 presents PLM model.

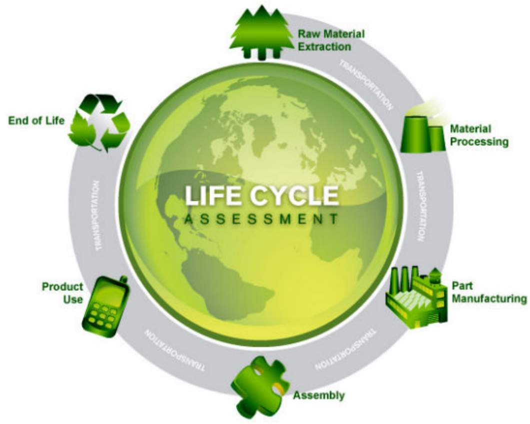

Figure 1 – LCA method

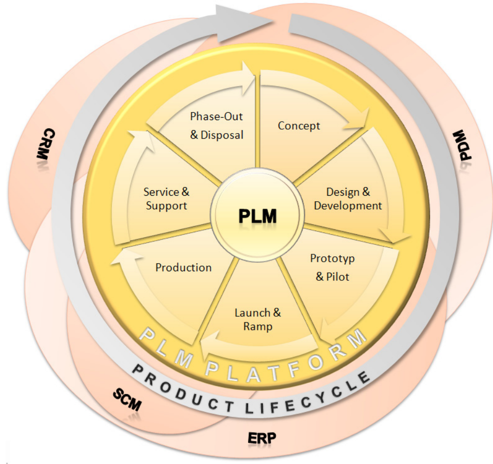

Figure 2 – PLM model

From the definition and picture we can see that the major difference between LCA and PLM is that LCA analyzes raw material and its extraction, material processing and product life cycle, while PLM deals only with product life cycle. Also LCA/PLCM/LCM are very similar; all take the whole life cycle thinking into consideration, only LCA is a tool for analyzing environmental burden of products while PLCM and LCM are models which can use LCA as a tool in their life cycle thinking.

Green Supply Chain Management

From the definition of Supply Chain management given by the Council of Supply Chain Management Professionals (CSCMP) [12], "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities." Importantly, it *also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers and customers. In essence, supply chain management integrates supply and demand management within and across companies. Making it green, it could be simply illustrated as in Figure3.*

GSCM is a field of implementation of green thinking in all the segments of companies' activities and with focusing on the definition of SCM and the three basic groups of activities - procurement, operations and logistics, green supply chain management could be illustrated as in Figure 4 [7].

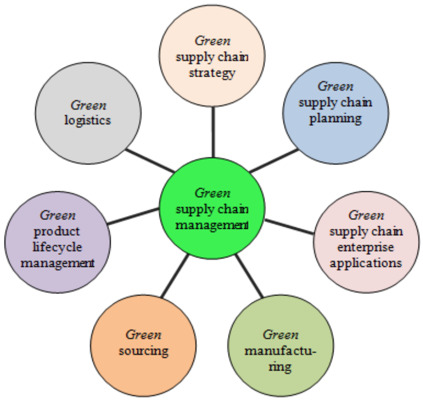

Figure 3 – Elements of Green supply chain management

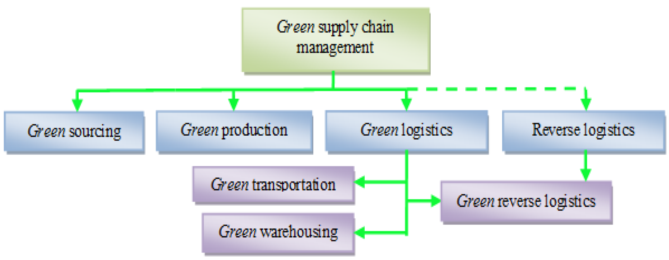

Figure 4 – Basic groups of GSCM activities related to SCM definition

RESEARCH METHODOLOGY

The research was done through these two databases:

- *Science Direct,*
- *Scopus.*

These databases contain some relevant journals in field of energy, industrial engineering, production and ecology such as:

- *Journal of Power Sources,*
- *Journal of Cleaner Production,*
- *Journal of Manufacturing Processes,*
- *Journal of Ecology,*
- *Journal of Environmental Economics and Management,*
- *Journal of Computer Assisted Learning,*
- *Journal of Applied Ecology,*
- *Journal of Industrial Ecology,*
- *Journal of Operations Management,*
- *Journal of Advanced Research,*
- *Computers & Operations Research,*
- *European Journal of Operational Research,*
- *International Journal of Life Cycle Assessment,*
- *International Journal of Logistics Systems and Management,*
- *Logistics Research,*
- *European Journal of Purchasing & Supply Management,*
- *Journal of Purchasing & Supply Management.*

Research of papers was done in three steps. In the first step, these databases were searched using the following terms:

- *GSCM or Sustainable Supply Chain Management (SSCM) or Environmental Supply Chain Management (ESCM),*
- *LCA,*
- *Life Cycle Engineering (LCE),*
- *PLM or PLCM or LCM,*
- *Green Logistics (GL) or Sustainable Logistics (SL) or Environmental Logistics (EL) or Clean Logistics (CL),*
- *Green Production (GP) or Sustainable Production (SP) or Environmental Production (EP) or Clean Production (CP),*
- *Greening,*
- *Industrial Ecology (IE).*

In the second step of the research, the data bases were searched in order to find papers that are mentioning the following terms:

- *(GSCM or SSCM or ESCM) and (LCA),*
- *(GSCM or SSCM or ESCM) and (PLM or PLCM or LCM),*
- *(LCA) and (PLM or PLCM or LCM),*
- *(GSCM or SSCM or ESCM) and (LCA) and (PLM or PLCM or LCM).*

In the third step, papers mentioning (GSCM or SSCM or ESCM) and (LCA) and (PLM or PLCM or LCM) are analyzed.

In addition to the above mentioned concepts, methods and models some standards and directive are also connected with sustainable development.

So, with the concept of sustainable developments are often associated the following standards and directives:

- *ISO 9001 Quality management systems - Requirements,*
- *ISO 14001 Environmental management systems - Requirements with guidance for use,*
- *ISO 14040 Environmental management - Life cycle assessment - Principles and framework,*
- *ISO 14051 Environmental management - Material flow cost accounting - General framework,*
- *ISO 14062 Environmental management - Integrating environmental aspects into product design and development,*
- *ISO 14064 Greenhouse gases - part 1, 2, 3,*
- *ISO 26000 Guidance on social responsibility,*
- *ISO 50001 Energy management systems - Requirements with guidance for use,*
- *OHSAS 18001 Occupational health and safety management systems,*
- *WEEE Waste Electrical and Electronic Equipment Directive,*
- *RoHs Directive on the restriction of the use of certain Hazardous substances in electrical and electronic equipment,*
- *IPP Integrated Product Policy,*
- *EuP Energy using Products directive,*
- *ELV End of Life Vehicles directive,*
- *EPA Environmental Protection Act,*
- *PPW Packaging & Packaging Waste directive,*
- *EMAS Eco-Management & Audit Scheme directive,*
- *VOC Volatile Organic Compounds directive,*
- *ED Eco-design directive.*

RESEARCH RESULTS

The results of the first step are presented in Figure 5, while Figure 6 presents the results of the second step of the research.

From the results of first two steps of the research it is evident that number of published papers is raising yearly. More and more papers are related to sustainability, and their numbers is proving actual trends and complexities in this area. In order to investigate deeply the current state regarding this issue, third step of research was done. 83 papers using (GSCM or SSCM or ESCM) and (LCA) and (PLM or PLCM or LCM) were identified and analyzed. Figure 7 presents a classification of those papers according to the origin of authors, while Figure 8 presents the classification of papers according to the type of the paper.

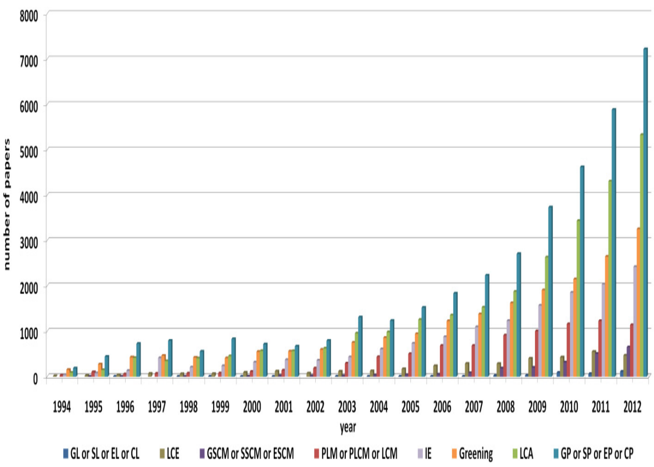

Figure 5 – Numbers of published papers by year after the first step of the research

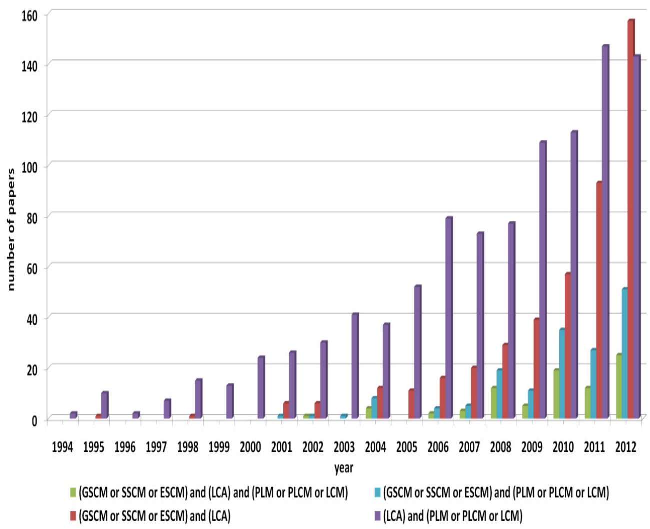

Figure 6 – Numbers of published papers by year after the second step of the research

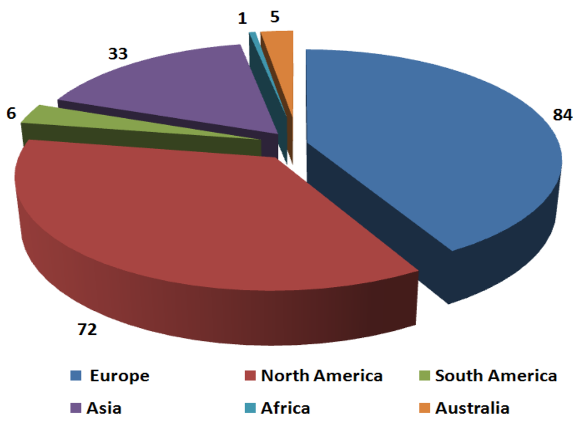

Figure 7 – Classification of papers according to the origin of authors [number of papers]

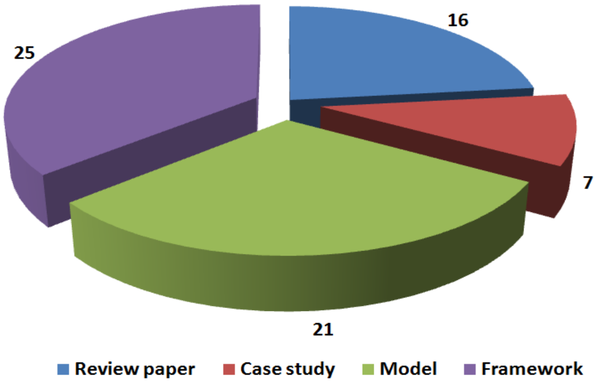

Figure 8 – Classification of papers according to the type of paper [number of papers]

From Figure 7 it is evident that most papers come from Europe and North America, which allows assumption that these two continents are working the most in the field of sustainability. Although 83 papers were found in databases, some of them appear in both databases, so 69 papers (references from [13] to [81]) were actually analyzed. 7 of them are case study papers, presenting an example of the implementation of a concept, method or model of sustainability in practice. There are 16 review papers of written literature. The rest are scientific papers, divided into two categories. In first category there are 21 papers aimed to define some kind of mathematical model. In the second category there are 25 papers aimed to propose a conceptual model, framework or guidelines. That category has the most papers. To illustrate the topics and approaches, bellow is given brief overviews of some of them. Complete list of analyzed papers is given in Table 1.

Chen and others [17] gave a reviewed literature related with green strategies within green supply chains such as (green design, green procurement, green production and green marketing).They also defines a model for the selection of appropriate strategies using analytical network process.

Despeisse and others [20] analyzed the written papers related to sustainable production (they search database according on the terms: green manufacturing, clean production, sustainable production, eco-conscious production, industrial ecology, etc.). Based on a review of written literature and analysis of gaps in the literature and practice, they define ecosystem production model based on industrial ecology. The model is based on the flow of the materials, energy and waste in order to for better understanding and defining the interactions between operations within manufacturing, suppliers and the building in the environment.

Table 1 – Overview of analyzed papers

LCA, PLM, PLCM, LCM, LCE	Bejarski & others [16], Cellura & others [22], Heiskanen [30], Lainez & others [46], Lai & others [57], Balkau & Sonnemann [71] and Serung [74]
ISO 14001, OHSAS, European environmental directives	Prajogo & others [45], Asif & others [54], Yung &others [58] and Khanna [59,64]
GSCM, ESCM, SSCM	Ageron & others [13] Chean & others [17], Gopalakrishnan & others [26], Guillen-Gosalbez & Grossman [27], Hassini & others [29], Hutchins & Sutherland [31], Kumar & Putnam [34], Kuo & others [35], Lainez & Puigjaner [36], Liu & others [37], Munoz & others [42], Lainez & others [46], Seuring [47-50, 74], Zhu & Cote [51], Zhu & others [52], Sarkis [53], Nakano [55], Jaegler & Burat [62], Hollos & others [63], Mollenkopf & others [65], Hong & others [66], Olson & others [69], Jaegler & Burlat [70], Vermeulen [73], Mele & others [75], Metta & others [76] Liu & others [79] and Vermeulen & Ras [81]
Model for supplier selection	Bai & Sarkis [14] and Bala & others [15]
Eco-design of the products	Chen & others [18], Ellram [23], Ferrera [24], Kengpol & Boonkanit [33], Pigosso & others [44], Ramani & others [67], Olson & others [69] and Metta & others [76]
IE	Despeisse & others [20] and Serung [74]
GP, EP, SP, CP	Despeisse & others [20], Duflou & others [21], Ellram [23], Gunasekaran & others [28], Ilgin & Gupta [32], Luh & others [38], Maxwell & others [41], Park & others [43], Nakano [55], Dou & Sarkis [56], Haapala & others [60], Arena & others [61], Wang & Cote [68], Geldermann & others [72], Dunk [77], Liu & others [79] and Bi [80]
Review paper	Chiu & others [19]
Energy saving	Duflou & others [21]
Waste management	Geng & others [51]
GL, EL, SL, CL	Venus [95] and Lai & others [57]
Sustainable marketing	Mariadoss & others [40], Vermeulen [73], Dunk [77] and Sarkis & others [78]

Hassini & others [29] gave a framework for the introduction of sustainable supply chain management based on literature studies of written papers about sustainable supply chain since 2000 to 2010 year. In paper they also gave an example of implementation of SSCM in the Canadian company that produce and distribute electricity. The emphasis is given to the importance of defining and measuring the performance of SSCM's. Authors point out that each company must develop its own indicators that can be matched and their importance is to measure the achievement of sustainable initiatives and allowing the new initiatives to be created.

Seuring [50] 2012 analyzes written papers in the past 15 years dealing with GSCM and SSCM. He analyzes papers that propose a mathematical model of GSCM, or SSCM. The same author [74] analyzed the similarities and differences between the integrated supply chain management, industrial symbiosis, LCM and supply chain management.

Sarkis [53] shows the relationship between GSCM and other green strategies, such as network management of supply chains, the sustainability of supply and demand, or corporate social responsibility network, ESCM, green purchasing and green procurement, environmental purchase, sustainable supply chain and EL and GL. This paper provides a framework that helps to understand the difference between the methodologies. Author also defines five flows of resources related to green supply chains and 9 boundaries and limitations of green supply chain. Thus, the flows within the green supply chain are: flows of materials, services, finance, information and waste, while the boundaries of green supply chain are: information, legal, cultural, organizational, technological, political, economic, temporary and proximal (physical and geographical location).

Holos & others [63] analyzed papers related to the sustainable supply chains. They propose a triple bottom line approach which involved economic, environmental and social component. They conducted a survey in Western Europe related to sustainable supply chains and analyzed it. The survey concludes that sustained cooperation of suppliers, in relation to the strategic-oriented procurement has a positive impact on green and social procurement. While social practices and sustainable cooperation between suppliers do not have a significant impact on the performance of the enterprise, green practices have a positive impact on reducing the cost and performance of the company.

Liu & others [95] analyzed more than 100 papers dealing with sustainable concepts, methods and models. An analyzed paper deals with the study of LCA, multi-criteria decision-making, sustainable design, with SP and sustainable supply chains. In conclusion, the authors said that there are three trends related to sustainability: sustainability has moved to the entire LCA from the evaluation of a single phase, sustainability has moved from single criteria decision-making to the multiple criteria decision-making and sustainability has become an integrated systematic methodology compared to the previous stand-alone approach.

Bi [80] analyzed the production models and sustainability within them. In paper he analyzes three things, the production needs, differences between models and limitations and bottle necks of the model. The author proposes 6R model of sustainable production as a model that provides the largest component f sustainability. Model 6R is consists of: remanufacture, redesign, recover, reuse, recycle and reduce.

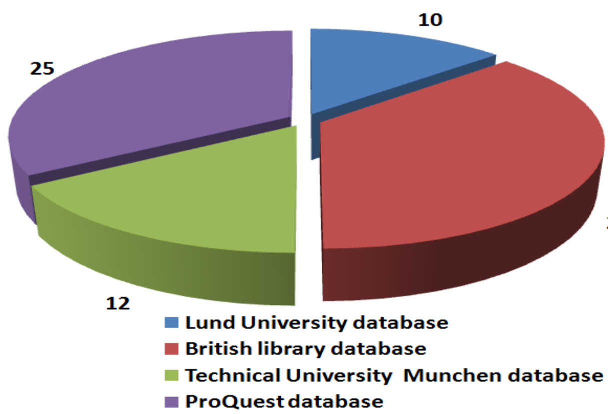

Figure 9 – Number of doctoral thesis appearing in 4 available databases

In order to obtain detailed insight into the current state and trends, doctoral theses are also researched regarding the topic of sustainability. Research was carried out according to the concepts, methods and models presented in Figure 5 (as in first step for *the paper), using four available databases. Results are presented in Figure 9, while overview of analyzed doctoral theses is presented in Table 2.*

Table 2 – Overview of doctorial theses

LCA, PLM, PLCM, LCM, LCE	den Boer [83], Winkler [84], Fuchs [85], Herrmann [89], Weckert [90], Frad [91], Bitzer [92], Bungert [93], Lindhqvist [95], Tojo [96], Nawrocka [97], van Rossem [99], Johansson [100], Li [107], Nunes [114], Mead [118], Plant [121], Kamal [129] and Whatling [130], Choi J. [131], Hutchins [134], Hazen [135], Reap [136], Kim [137], Camacho [138], Ilgin [139], Vaccaro [140], Zhou [141], Chaabane [142], Cunion [143], Francois [144], Al-Fandi [147]
ISO 14001, OHSAS, European environmental directives	Nawrocka [97], Kronsell [98], van Rossem [99], Johansson [100], Rodhe [101], Parekh [112], Stewart [120], Plant [121] and Collins-Webb [127], Choi J. [131], Khiewnavawongsa [132], Kim [137], Zhou [141], Cunion [143], Cooper [150], Noh [151], Mil-Homens [153], Robinson [155]
GSCM, ESCM, SSCM	Abukhader [94], Nawrocka [97], Kogg [102], Schwartz [104], Hall [105], Huang [109], Nunes [114], Mason [117], Saibani [119], Hoejmose [122], Nassar [123], Holt [124] and Kim [126], Khiewnavawongsa [132], Wolfe [133], Hutchins [134], Hazen [135], Kim [137], Camacho [138], Ilgin [139], Vaccaro [140], Zhou [141], Chaabane [142], Cunion [143], Altuger-Genc [145], Al-Fandi [147], Huang [148], Choi D. [149], Cooper [150], Ozcan [152]
Eco-design of the products	Tojo [96], Dewberry [110], Plant [121], Hussain [125] and Elias [128], Choi J. [131]
GP, EP, SP, CP	Hanssen [89], Lindhqvist [95], Tojo [96], Nawrocka [97], van Rossem [99], Rodhe [101], Abukhader [103], Nunes [114] and Hussain [125], Kim [137], Ilgin [139], Vaccaro [140], Al-Fandi [147], Huang [148]
Energy saving	Jones [115] and Stamford [116]
Waste management	Zisuh Asong [82], Winkler [84], Zhang[112] and Stewart [120], Sankaranarayanan [146]
GL, EL, SL, CL	Bogatu [87], Garg [88], Davies [111], Nunes [114] and Collins-Webb [127], Sankaranarayanan [146], Al-Fandi [147], Huscroft [154]
Sustainable marketing	Abukhader [103], Jahdi [106], Wang [110] and Mason [117], Cunion [143]

From the researched papers it was seen that graduate students at the University of Lund (Lindhqvist [95], Tojo [96] Nawrocki [97], van Rossem [99]) uses the term Extended Producer Responsibility (EPR) while talking about the responsibility of manufacturers to the entire product lifecycle. On the other hand, British and Americans uses term GSCM when talking about the same topic (Schwartz [104], Hall [105], Huang [109], Nunes [114], Mason [117], Saiban [119], Hoejmose [122] Nassar [123], Holt [124] and Kim [126], Khiewnavawongsa [132], Wolfe [133], Hutchins [134], Hazen [135], Kim [137], Camacho [138], Ilgin [139], Vaccaro [140], Zhou [141], Chaabane [142], Cunion [143], Altuger-Genc [145], Al-Fandi [147], Huang [148], Choi D. [149], Cooper [150], Ozcan [152]). Germans, (den Boer [83], Winkler [84], Fuchs [85], Herrmann [89], Weckert [90], Frad [91], Bitzer [92], Bungert [93] uses terms PLM and LCA when talking about manufacturer's responsibility to the entire product lifecycle.

CONCLUSON

As mentioned before, this paper is a review paper regarding an interrelation between GSCM, LCA and PLM/PLCM/LCM appearing as topics in scientific literature. The vast number of papers could be found dealing with one or more mentioned concepts, methods and models. The purpose of this paper was to narrow the set, identifying and analyzing papers with interrelations between mentioned concepts, methods and models. There is no paper that really connects and analyzes all of the mentioned concepts, methods and models. Most papers are only dealing with just one or two concepts, methods or models, without detailed analysis of others (just mentioning them in paper). Therefore, further research regarding interrelations of all mentioned concept, methods and models is needed. Additionally, it is necessary to link this concepts, methods and models with standards and EU directives for better understanding of trends in sustainable development. The idea is encompass all concepts, methods, models, standards and directives into one general, but applicative framework for implementations of GSCM concept into companies.

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NOVEL OPTICAL DESIGN OF FOLDED FABRY-PEROT DISPLACEMENT MEASUREMENT INTERFEROMETER

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Abstract: *Due to its high resolution and the large measuring range, laser interferometer has been applied widely to the precision industrial measurement and calibration. Fabry-Perot interferometry was often used for the micro-displacement, because of its common optical path structure being insensitive to the environmental disturbances. In the past researches, some kinds of modified Fabry-Perot interferometers with corner-cube reflector have been proposed to enhance the measuring range. With such new optical structure, the Fabry-Perot interferometer can be used in the purpose of hundred milometer displacement measurement. This will be beneficial to realize the high precision displacement in the large measuring range and under the ordinary measuring environment. In this investigation, a novel folded Fabry-Perot interferometer has been proposed. With the optical design, the optical resolution is about 158.2 nm and the measurement range of the Fabry-Perot interferometer can be enhanced up to 200 mm without any tilt angle compensation system.*
Keywords: *Fabry-Perot interferometer, corner cube reflector, displacement measurement, optical structure design*

INTRODUCTION

Laser interferometers have demonstrated outstanding measuring performances for high precision positioning or dimensional measurements in the precision industry [1, 2], especially in the length measurement. For the mechanical displacement measurements, it provides the traceable definition of length by the Laser wavelength. The major advantage of interferometers is their coexisting characteristics of large measuring range and high resolution. Te two-beam interferometers such as the Michelson interferometer are the major equipment for the linear positioning measurement. But these kinds of interferometers are sensitive to environmental disturbances, because of the different environmental variations between the measurement arm and reference arm. Contrarily, multi-interferometric interferometers such as the Fabry-Perot interferometer are a kind of interferometer with the common-optical-path where the displacement measured is precisely defined by the distance in the optical cavity, independent of an external reference interferometer arm and not involved with a beam splitter in the optical path [3-5]. For this reason, the environmental effect will be obviously minimized. Hence the displacement measurement by Fabry-Perot interferometers is more insensitivity to environmental disturbances. But conventional Fabry-Perot interferometers have a critical problem of the limited measuring range due to the tilt angle of the measuring mirror during the displacement motion. Therefore, conventional Fabry-Perot interferometers are hardly for the dynamic displacement measurement.

In 1961, the folded Fabry-Perot interferometer is proposed by P. Rabinowitz et al.. Because of the tilt-angle-insensitive characteristics of the corner cube reflector, the limitation of the measuring range can be eliminated. For enhancing the applications of common-optical-path interferometric system, the serial researches about the multi-interferometric displacement measurement system has been described in this investigation.

MEASUREMENT PRINCIPLE

The previous research is shown in the Fig. 1 [6]. This modified optical structure design with corner-cube prism (CCR) has been proposed to resolve the problem of limitation of the measurement range of the multi-interferometric interferometer. The measuring range has been enlarged to 160 mm without any tilt angle compensation system. Nevertheless, in this stage, the position of the transmitted interference laser beams will be influenced by the tilt angle of the measuring mirror. For this reason, the unestimable phase shift of the signal will occur during the measurement processing.

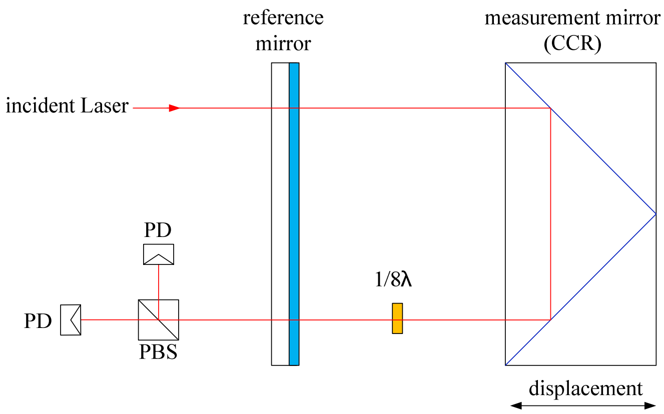

Figure 1 – Optical structure of the previous research [6]

In this research, the reflected beams will be the sensing signal of the interferometric system. By this way, the unestimable phase shift must be eliminated. The optical design of the proposed interferometer is shown in Fig. 1. The Laser light source passes through the BS into the optical cavity. The one eighth waveplate in the cavity is employed to form interference signals with the orthogonal phase shift. And the polarization axis of the waveplate must be the same as that of PBS. By this arrangement, the orthogonal signal can be acquired by two photodiodes (PDs) and then transmitted to the signal processing module.

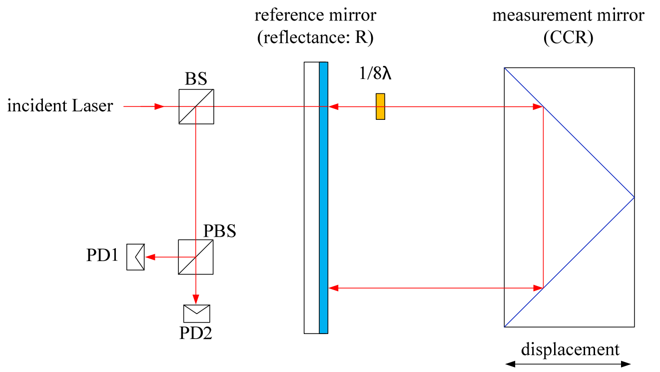

Figure 2 – Proposed interferometer

The corresponding equation of intensity distribution can be expressed as equation (1) and (2). Where A_0 is the amplitude of Laser source, R is the reflectance of the coated mirror and phase difference (δ) is equal to 8πd/λ. Fig. 3 is the interferometric intensity simulations when R is 25%. This orthogonal signal can be easily counted by a commercial encoder counter. It is convenient for the signal processing. With this aid, the resolution about 40 nm can be achieved.

For s-type (PD1) intensity,

$$I_s = \frac{1}{8}A_0^2 \times \left[\frac{2R\times[1-\cos(\delta+\frac{\pi}{4})]}{1+R^2-2R\times\cos(\delta+\frac{\pi}{4})}\right] \quad (1)$$

For p-type (PD2) intensity:

$$I_p = \frac{1}{8}A_0^2 \times \left[\frac{2R\times[1-\cos(\delta-\frac{\pi}{4})]}{1+R^2-2R\times\cos(\delta-\frac{\pi}{4})}\right] \quad (2)$$

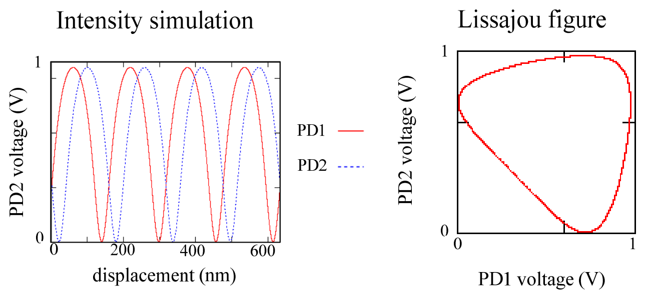

Figure 3 – Simulation of the interferometric intensity distribution

OPTICAL STRUCTURE DESIGN

For the modified multi-interferometric interferometer, its optical structure arrangement is shown in Fig. 4. The Laser source with the fiber coupler is fixed on the fiber mount. The BS and the

PBS are set on the BS set. The reference mirror mount is the place where is the coated mirror fixed on. The waveplate mount for the one-eighth waveplate is able to be regulated rotationally. The complete volume of this sensor head is less than 100 mm³. The compact sensor head will be desirable to reduce the thermal expansion error during longer measuring period.

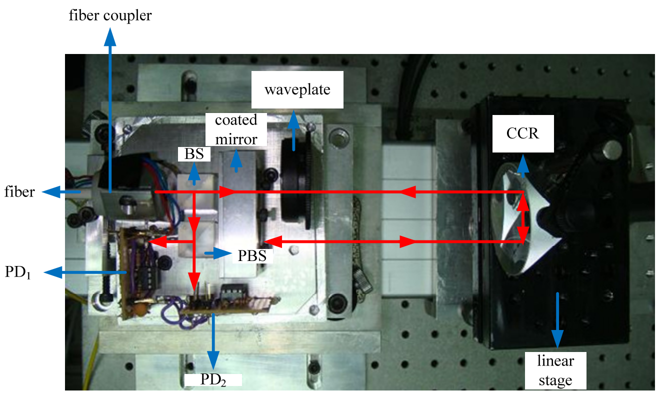

Figure 4 – Experiment setup

EXPERIMENTAL RESULT AND ANALYSES

To verify the measurement performances of the proposed interferometric system, comparison measurements with a commercial interferometer as reference standard have been carried out. The experimental scheme of the comparison measurements is arranged as Fig. 5. The proposed interferometric system and the reference standard are installed opposite and the linear stage and involving measurement mirrors are located between them. For minimizing the Abbe offset, the optical axes of two measurement systems are aligned as coaxially as possible and the distance of the two CCRs is as short as possible.

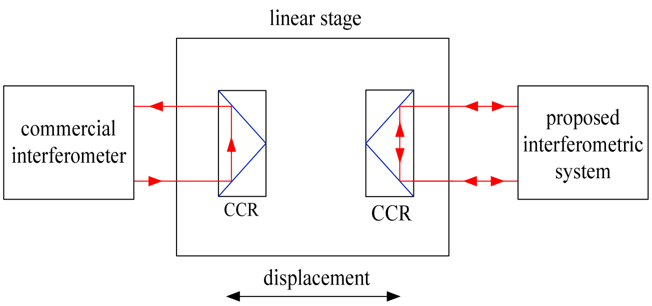

Figure 5 – Optical structure design

The comparison experimental measurements between the proposed interferometer and the above-mentioned reference standard have been performed in the measuring ranges of 200 mm. These two interferometric systems are arranged in same linear stage and measure displacements of a liner stage simultaneously whose measuring intervals are 20 mm in the range of 200 mm. Forward displacement experiments have been repeated five times.

The displacement differences between both systems have been analyzed and demonstrated in Fig. 6. The maximum standard deviation is 0.1459 μm. The detailed analysis values have been listed in the table 1. According to the results, there should be some systematic errors in this experimental mechanical structure. The major error sources for comparison measurements between two systems are the tilt angle and the straightness of the stage. Although the optical axes of two measurement systems are aligned as collinear as possibly, there are still some geometric offsets between two measurement mirrors. Because the measurement mirrors are corner cube reflectors, the result will be influenced by the straightness. These systematic errors will be repeatable and can be observed in the experiment results.

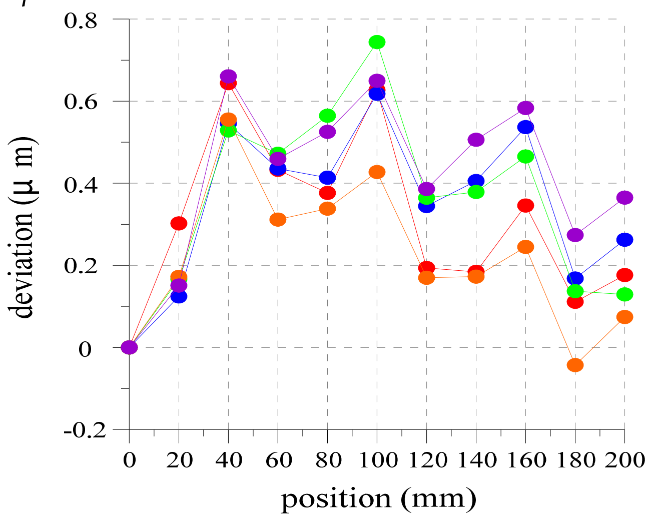

Figure 6 – Comparison measurements in the range of 200 mm

Table 1 – Standard deviation of the measurement results

position (mm)	STD (□m)	position (mm)	STD (□m)
20	0.0691	120	0.1018
40	0.0607	140	0.1459
60	0.0640	160	0.1391
80	0.0973	180	0.1145
100	0.1153	200	0.1146

CONCLUSIONS

A self-developed interferometric displacement measurement system with common-optical-path has been proposed and its measurement features have been verified experimentally. The experimental results demonstrate that this proposed interferometer is feasible for the precision industrial measurement. Hence the modified optical structure has the potential of high precision displacement measurements in the large traveling range. From the comparison experiments it has revealed that the maximum standard deviation is 0.1459 µm in the measuring range of 200 mm. It yields that the proposed interferometer can be realized for the aim of submicrometer order measurement in ordinary environment with the compact structure and convenient signal processing.

In the future work, the advanced signal interpolation algorithm for the folded multi-interferometric interferometer should be designed for the better resolution. With the enhanced measuring precision and the enlarged range, that multi-interferometric interferometer would be more available for the contribution in the application of nanometrology.

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X-RAY CT IN METROLOGY OF GEOMETRIC FEATURE

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Abstract: *3D X-ray CT in metrological applications is the latest field of coordinate measuring technique. The first commercial measuring devices appeared on the market around 2005. Since then, gaining new market areas that previously were reserved for other devices of coordinate measuring technique. An important advantage of CT is the ability to control closed space and simultaneous verification of internal structure - for example, casting bubbles. The paper gives an overview of CT method and its potential applications as one of the newest measurement device.*
Keywords: *coordinate measuring technique, X-ray 3D CT, CT, measurement accuracy*

PHYSICAL BASIS OF X-RAY TECHNIQUES

The X-ray tomography is a class of radiology technic, for which common attribute is the movement of the X-ray [2, 3]. This movement allows for obtaining a clear picture of the test objects inside structures. The device performing the test is called the computed tomograph (CT) while the resulting image the tomogram. The word 'tomography' comes from the Greek tomos (layer) and graphia (describe). This name was adopted in 1962 by the International Commission on Radiologic Units and Measurements for all radiography techniques which snap layer view of the workpiece [5]. Computer tomography CT is a type of X-ray tomography, a method enabling to obtain tomographic images (sections) of the object [6, 7]. It applies submission of the object projections from different directions to create a cross-sectional images (2D) and spatial (3D). CT is based on the theorem of Austrian mathematician Johann Radon, who in 1917 proved that the image of two-and three-dimensional object can be reproduced totally from an infinite number of the workpiece projections [10, 12].

The discovery of X-rays owes to W.C. Röntgen, who did it in Würzburg in 1895. The first X-ray photograph of his wife's hand represented (Fig. 1).

Figure 1 – The first X-ray photograph of W.C. Röntgen wife's hand represented

X-rays are – similarly to light – electromagnetic waves. The wavelength is in the range of 0.001 to 10 nm, as shown in Figure 2.

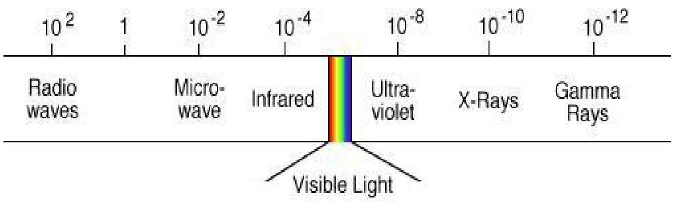


Figure 2 – Wavelength of X – rays (values in [m])

X-rays are generated by the inhibition of fast electrons in solids (Fig. 3a). This effect is dominant.

An additional effect is the sputtering of electrons, on which position empty places arise. In those places electrons from higher levels jump through, resulting in a cascading effect (Fig. 3b). The emitted radiation characteristic appears in the spectrum in the form of discrete lines.

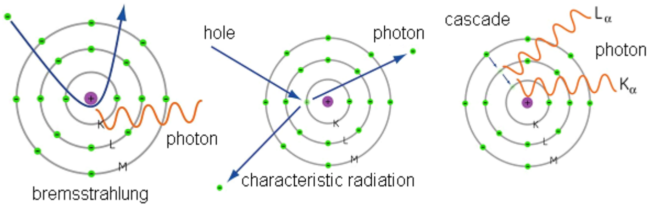


Figure 3 – Generating of X rays

X-rays are absorbed in varying degrees by different materials. Absorption increases with the density of the material, which increases with the atomic number. Thus, for example, lead with the atomic number 82 is applied to the screens against X-rays, and objects of steel (Fe 26) are harder to X-rays from aluminium (Al 13).

DESIGN AND FUNCTION OF CT

The first tomograph was constructed in the years 1969 - 1972 by Hounsfield and Cormack. The production was in 1973. Its appearance is shown in Figure 4.

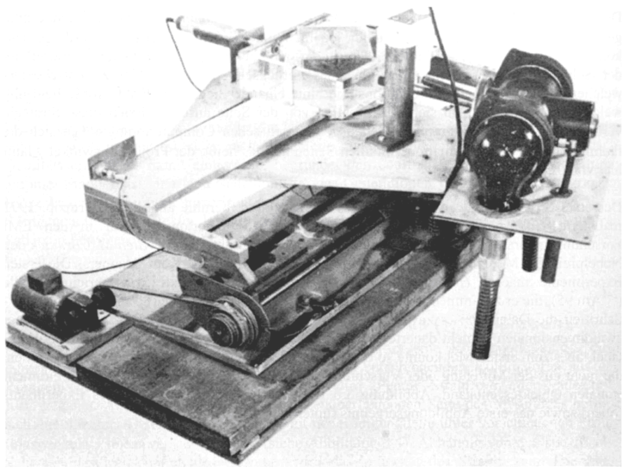


Figure 4 – The first tomograph

The first commercial X-ray tube was developed by WD Coolidge from General Electric in 1913. He used heated tungsten filament to form an electron beam in a glass tube with a vacuum. The appearance of this lamp is shown in Figure 5.

Nowadays, in metrological CTs two basic types of lamp are used: transmissional and directional. Transmission tube allows for greater magnification while directional one for greater power. The pattern shown in Figure 6.

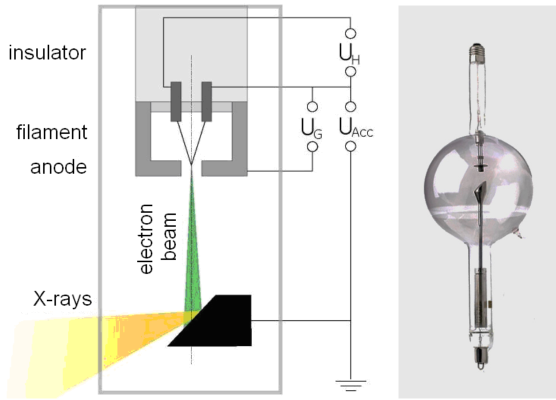


Figure 5 – The first commercial tomograph lamp

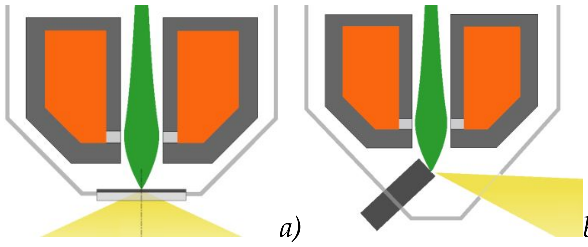


Figure 6 – Lamps applied in tomographs
a) transmissional, b) directional

In order to obtain better resolution of the CT a microfocus and nanofocus tubes are applied (Figure 7).

Especially in the latter one, additionally equipped with a shutter allows for a very small spot size, even less than 1 micron, with an additional stabilization of tension.

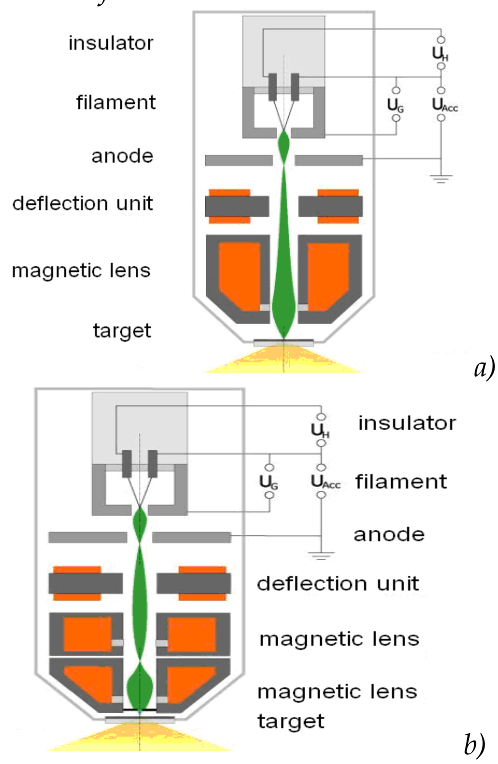
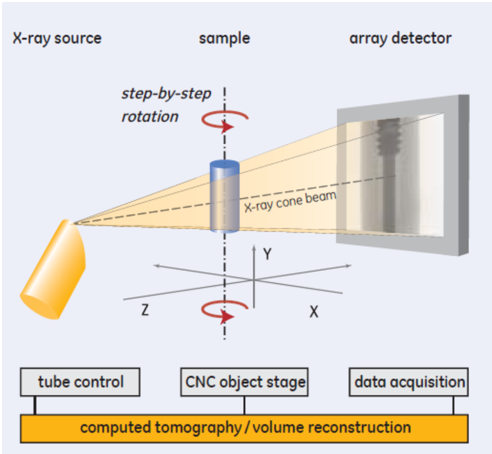
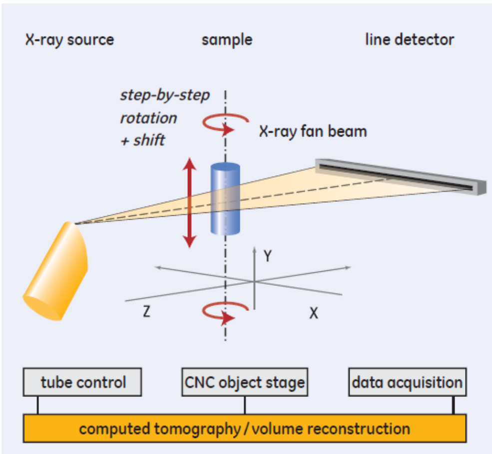


Figure 7 – Lamps applied in tomographs:
a) microfocus, b) nanofocus

The CT can be constructed in 2D and 3D version. 2D CT is known as a flat beam CT (Fig. 8a), while 3D ones as cone beam CT (Fig. 8b).



a)



b)

Figure 8 – Tomograph:
a) with cone beam, b) with fan beam.

Another important element of CT is the detector, which is the system that presents the resulting image. Firstly, X-rays are converted to visible light by a film or scintillation crystal. Then this visible light is received by photodiodes, making possible presentation of the image. Schematic layout of the detector is shown in Figure 9.

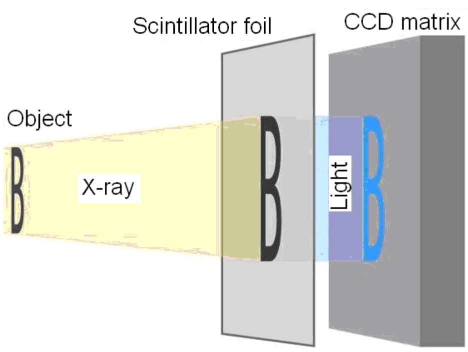


Figure 9 – Detector in CT

IMAGE ANALYSIS

The next step after collecting the images is reconstruction of the whole element [9, 11]. It takes place in space, considered as a three-dimensional array of voxels. By definition voxel (called volumetric element - similar to the pixel) is the smallest element of the 3D space, the equivalent of a pixel in 2D (Fig. 10).

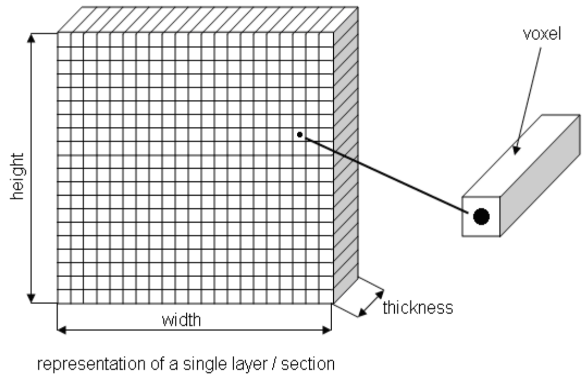
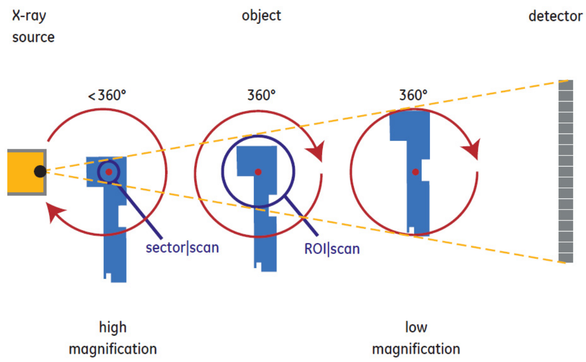
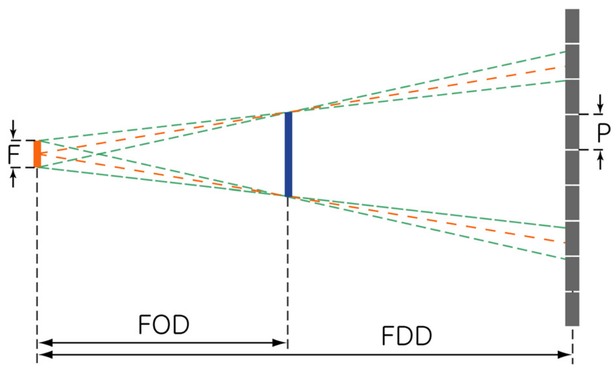


Figure 10 – Graphical presentation of voxel

The accuracy of the reconstruction is affected substantially by the size of the voxel V and the spot size at the focal point F (Fig. 11a), which is the limit of resolution [4]. In addition, there are relations between: V = P / M, M = FDD / FOD, where P – pixel, M – zoom. ROI is the area of observation (Fig. 11b).



a)



b)

Figure 11 – Image analysis: a) area of observation, b) size of the spot and zoom

Geometric zoom is therefore dependent on the distance between the lamp and the object, as shown in Figure 12. Image sharpness depends on the size of the focal spot as presented in Figure 13.

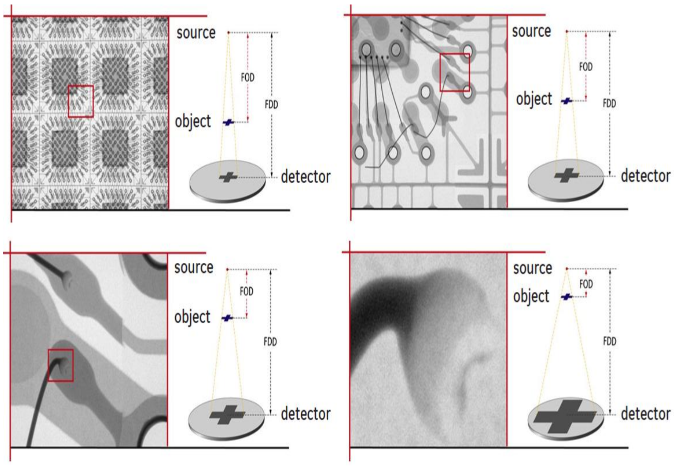


Figure 12 – Following steps of the image zoom

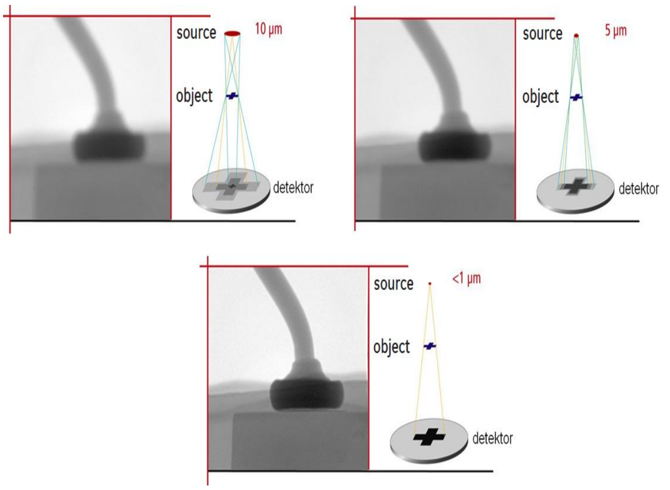


Figure 13 – Following steps of obtaining sharp view

ANALYSIS OF THE VOLUME - DEFECTS

One of CT functions in metrology is searching defects [1, 8]. The example is shown in the cast aluminium (Figure 14).

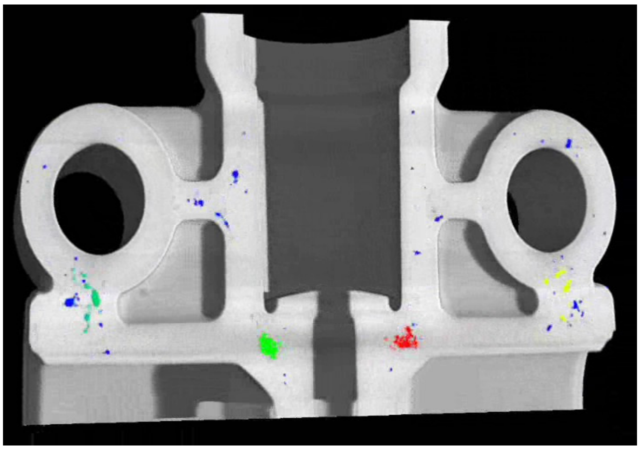


Figure 14 – Porous of different size in a cast

Porous size is presented in colours:

- *Up to 10 µm – blue*
- *Over 10 µm to 50 µm - green,*
- *Above 50 µm to 100 µm – yellow*
- *More than 100 µm - red.*

Such analysis allows to quickly diagnose a potentially dangerous place.

MEASUREMENTS & CALIBRATION ON CT

The sequence of measurement performed using the CT is shown in Figure 15. Data from the tomograph (volumetric) are converted to the surface, and then aligned to the CAD model. Comparative analysis can show in which areas there are irregularities. For images specific linear dimensions or tolerances can be add.

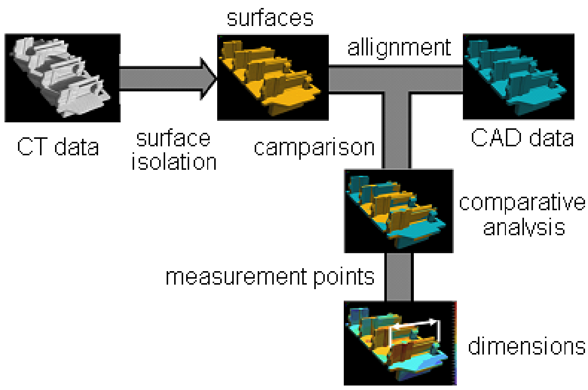
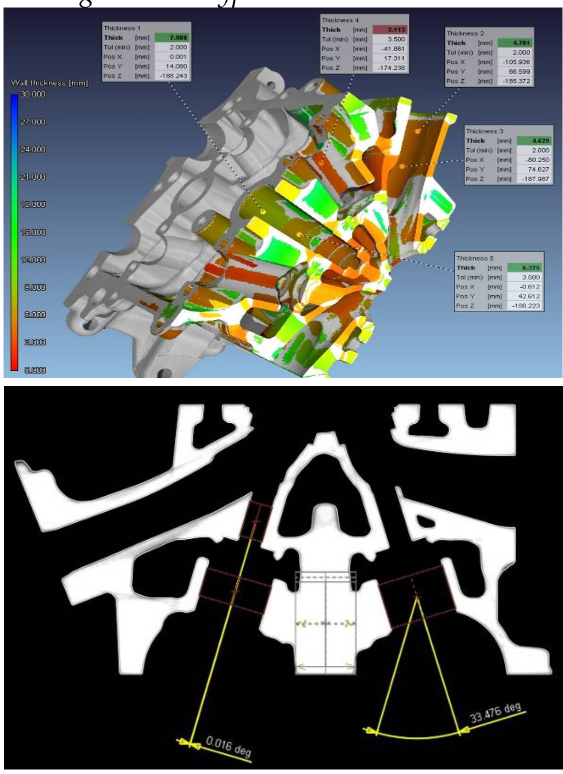


Figure 15 – Typical measurement on CT

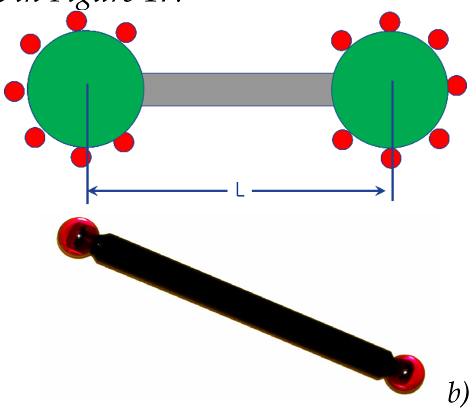


a)

b)

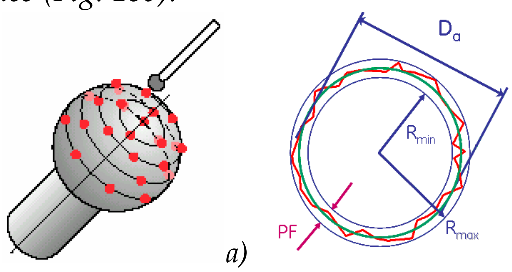
Figure 16 – Engine head: a) automatic measurement of material thickness, b) example of dimensions

Figure 16a presents an example of automatic measurement of the thickness of 3 - cylinder engine head.
Using the finished image data, solid of geometric figures can be entered and, on this basis, measurement of distances, angles, radius etc. can be conducted.
Analyzing tomographic measurement accuracy, the guide VDI / VDE 2630 (in preparation) connect the procedure to the standard ISO 10360. It defines specific permissible errors for CT in metrology. Length measurement error ESD = L_m-L_r is expressed as the difference between the measured value and the nominal one, for the item shown in Figure 17.



a)
b)
Figure 17 – Diagram of length measurement error (a) and the pattern (b)

The pattern consists of two ruby balls connected with the rod made of carbon fibres. The calibration was performed on the coordinate measuring machine with high accuracy, for example, the uncertainty
U_{CMM} = ± 0.5 µm for length under 100mm. Other maximum permissible errors are the error of probing form PF = R_{max} - R_{min} shown in Figure 18a and measurement error of probing size PS = D_a - D_r. (the difference of the measured and nominal diameter) to denote the location of the surface (Fig. 18b).



a) b)
Figure 18 – Diagram of determining form probing error (a) and size probing error (b)

According to VDI / VDE 2630 modern CT achieve the level of uncertainty in the PS = 1.5 + L/300 [µm], where L is given in mm. Examples of systems are shown in Figure 19.


Figure 19 – Examples of CT (producer GE / Phoenix x-ray)

SUMMARY

Computed tomography is a new measuring technique, entering the length and angle metrology. For visible surface, it aspires to be compared to coordinate measurement technique. For hidden part of the element it is a unique technique that enables all reliable measurement data collection and performance measurement. X-ray tomography enable measurement of various materials, including plastics, aluminium and steel. Considering measuring possibilities and parameters of the hardware the most important aspect is adequate generation and detection of X-ray CT. The value of maximum measurement error of CT determined according to guide which is in preparation is about single microns.

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INCREASING THE EFFICIENCY OF CLOSED LOOPS OF REUSABLE CONTAINERS IN PRODUCTION ENVIRONMENTS CONCERNING CONTAINER CLEANING

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Abstract: *Today reusable containers, widely used in closed loops in production environments, are cleaned irrespective of their cleanliness-status and thus the actual necessity for being cleaned. This often leads to a considerable degree of technically superfluous container-cleaning, associated with high costs, transport efforts and resource utilization. This paper aims at investigating ways to harness the savings potential of a necessity based triggering of the cleaning process amid securing the quality of the container supply, controlling the uncertainty introduced into the container-loops through the status-dependent triggering of cleaning and establishing a process transparency enabling a reduction of the overall container inventory. A case study performed in an automotive supplier is included.*
Keywords: *reusable container, efficiency, container management, Auto-ID*

INTRODUCTION

In modern production, in particular in the automotive supply chain, reusable load carriers and small containers are widely and increasingly used [1] [2] – yet, little effort and attention goes into the management of the container loops and the cleaning process of the containers, resulting in high costs of container usage. This paper presents a concept in the making, aimed at increasing the efficiency of container management and the container cleaning process in particular, by building a concept around the status dependent cleaning of containers and increasing the controllability of the container loop with Automatic Identification Technology (Auto-ID).

In the majority of current industry applications the level of transparency in container loops is very low [3]. To ensure a secure supply of containers and load carriers for production processes, companies have to rely on high safety stocks. Furthermore, since the containers have to be cleaned regularly, due to dust and dirt exposure in production and logistics processes, and are cleaned irrespective of their actual need for cleaning, the cleaning efforts – costs and resource consumption – are higher than necessary. Since the cleaning process is usually conducted by external washing-plants, transports and handling efforts arise and lead to unnecessary emissions of CO_2 gas. Although the current ineffectiveness of these container and load carrier loops leads to significant excess costs, resource consumption for the companies as well as environmental pollution and strain on transport and road networks, the problem of container management is underrepresented in both companies' development schemes and scientific publications.

The aim of the presented approach, which is currently being developed in the course of a research project, is to reduce the cleaning efforts by applying an automatic detection of the container cleanliness status and only sending the soiled containers to the cleaning-bay, while introducing an Auto-ID supported container loop monitoring and control that could enable a lower overall container stock in the system. Included in the *research consortium are Auto-ID system providers, experts in sensor-technology as well as application partners in the automotive supplier industry. A case study with the latter is an integral part of the ongoing work.*

This paper is meant to provide an overview of the subtopics involved in the project, present the approach, report on the current status and give a preview of some preliminary findings of the work so far.

FUNDAMENTALS, BACKGROUND & DEFINITIONS

The following section will give a brief background of the terminology associated with the presented problem: containers and container management as the main subject including the current concepts available for this planning task, followed by dirt detection and measurement and finally Auto-ID as the key elements of the new approach.

Container Management

In modern production reusable load carriers are widely used in closed loops inside production plants as well as in open loops including suppliers and customers. This is especially true for the automotive industry where the standardized load carriers and small containers are used in transport, consignment and picking systems. Furthermore, modern logistics concepts with standardized transport and handling concepts require standardized load carriers, which also help increasing process safety and quality – nonreturnable packaging in contrast is prone to facilitate the formation of dust on the production floor – and enable (partially) automated handling and transport processes for material [4].

The term container in this context refers not to standard metal freight containers but rather to all kinds of (smaller) Reusable Plastic Containers (RPC) and load carriers used for transporting, handling, supplying and picking of material [5]. In the latter category there are pallets, load carriers and small load carriers as well as blister trays that are tailored towards holding a batch of a certain material and are usually contained within Small Load Carriers. The standardized plastic Small Load Carriers are very common in a large variety of production environments and are the container type considered in the case study.

Due to the sheer number of load carriers in industry applications – in a typical load-carrier loop associated with one production plant, such as the inventory of load carriers in the case study, can easily exceed a million units – and with a unit price of ~15-4.000 € [5] the costs associated with setting up, maintaining and using this kind of load carrier are an important factor for the operating costs of a production. The costs involved are [6]:

- *inventory costs (i.e. capital holding costs)*
- *maintenance costs*
- *administration costs*
- *handling costs*
- *depreciation costs*
- *storage costs*
- *out of stock costs*

The goals for a container management system, derived from the basic logistics goals, are:

- *ensuring a timely supply of containers at the point(s) of use*
- *low operating costs*
- *low inventory costs*

Despite the importance to manage these load carrier loops efficiently to secure a reliable supply amid the lowest possible operating costs, this topic has largely been neglected by the companies that maintain the container loops as well as by researchers [6]. A study conducted by the University of St. Gallen shows that almost a third of the companies have no IT-support for their container management, another third at least registers the load carriers in their ERP system, but only a minority employs systems that support the planning, monitoring and control of their load carrier logistics.

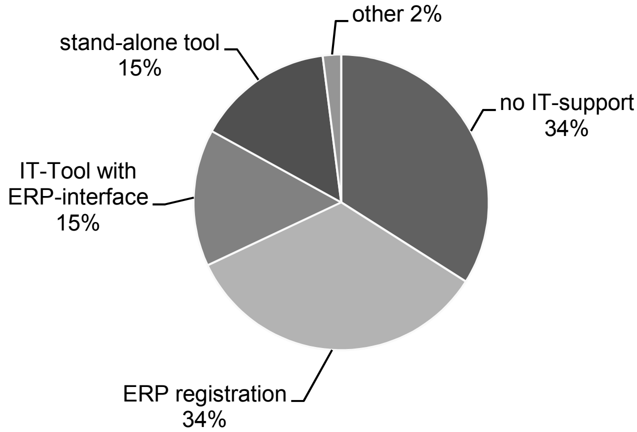

Figure 1 – Tools used by companies to manage container loops, source: [6]

One measure that is increasingly applied in the industry is outsourcing the container management and logistics to a third party logistics provider – thus creating cost awareness within the service requester.

Dirt Measurement

As mentioned in the introduction, it is common practice in companies using small load carriers to have their containers cleaned irrespective of the actual need for the specific container to be cleaned. This, together with the high number of containers in a system and the necessity of transports for an outsourced container management and cleaning, potentially leads to either excess costs plus resource consumption due to the unnecessary cleaning of still clean load carriers or to a compromised quality due to soiled load carriers being fed into production processes. An initial survey among companies indicates the first effect to be of more relevance than the latter.

To prevent this excess effort, the presented approach incorporates a cleanliness-status dependent initiation of cleaning processes for every load carrier. This can be achieved by implementing the following three options, all of which are currently being investigated in the research project:

- *manual control of the container-cleanliness status (visual inspection)*
- *(semi-) automatic control of cleanliness status (using sensor technology)*
- *determining the number of cycles or time spent in the system that a container can be used before it has to be cleaned and monitoring every container accordingly (i.e. via an Auto-ID system)*

The (semi-) automatic identification has to rely on the technical implementation of measuring dirt on the outside of and inside the load carriers. Dirt in this context can be residues originating from exposure of the containers to its environment in production, handling or transport processes that have the potential to compromise the quality of the material that is being transported and stored in the containers. This includes liquids, dust, chips and residues from packaging materials and labels. Figure 2 shows possible measuring principles for measuring dirt that are potentially relevant in the context of load carriers [7].

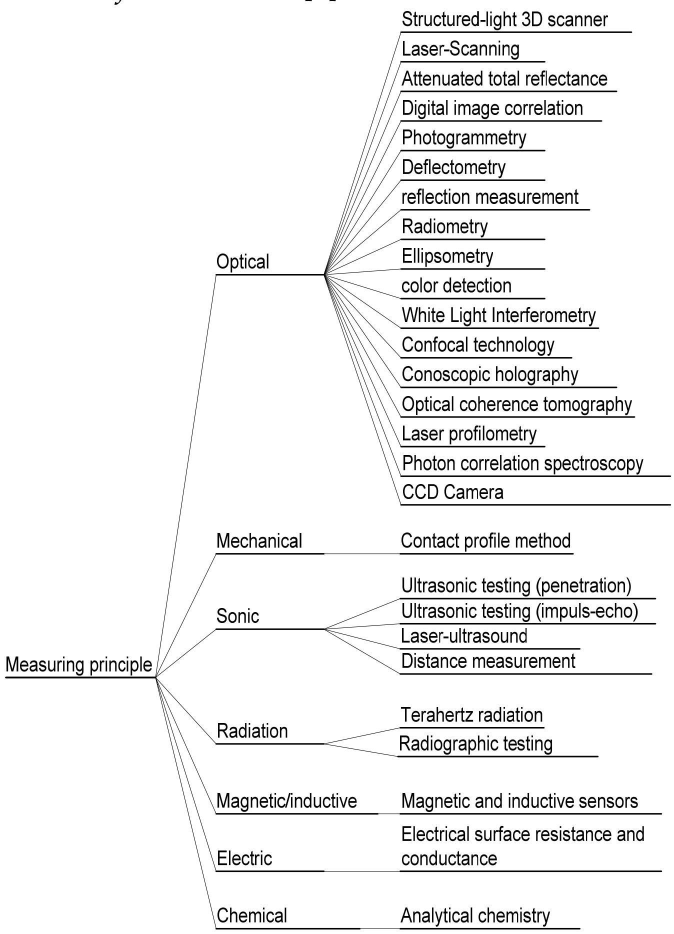

Figure 2 – Overview of measuring principles for dirt measurement

Basically the measurement can be based on identifying the shape, color and size of dirt on the container surface or it may detect changes in material behavior (e.g. conductivity, reflection) or it might identify physical characteristics of the material that constitutes the dirt (e.g. mechanical, chemical, optical or electrical characteristics).

Auto-ID

The third option of achieving a status dependent and thus demand-based cleaning of every load carrier, monitoring for every container the time spent in the system or the number of usage cycles, can best be achieved by employing an Auto-ID system. This technology enables the quick and automatic identification of every individual load-carrier in the system at every identification point – for example after being used and emptied in a production facility – so that the status of every container can be monitored, e.g. with a barcode and updated either in a corresponding database or, with *some Auto-ID technologies like RFID, directly on the container itself, thus reducing the necessity for a permanent connection to a database IT-infrastructure.*

The characteristics of Radio-Frequency Identification (RFID), compared to other Auto-ID technologies, are the ability to identify objects via electromagnetic waves sent between RFID readers and transmitters (tags), transmitting information about the object from the tags to the readers. It is possible to identify multiple tags on multiple objects virtually simultaneously and some tags also enable changing the data saved on the tag memory, which is called dynamic memory. While the basic functionality of RFID is the automatic remote identification of tagged objects, the technology offers a large variety of additional benefits and applications, utilizing the full range of technical capabilities and the versatility arising from a combination of the RFID technology with other information technologies, such as WLAN, Sensors and GPS modules [8].

Since RFID enables both options, database storage of status information and a dynamic memory with decentralized data storage, and a recent study [6] indicates that experts consider the potential for an RFID application in the field of container management as very promising, it will be the major technology investigated in the context of the current research project as well as in the case study.

METHODS AND CONCEPTS

In the section to come, the key conceptual elements of the approach and their development and adaption will be presented, starting with simulation as a way of predicting the effects of changes in the complex system of container loops and thus providing a tool to design and evaluate possible new and improved container loop configurations. This is followed by methods-time measurement (MTM) as a concept of ensuring simulation results with relevance to planning real world industry applications. Also, the development of the envisaged container management configurator concept, incorporating the simulation element, will be introduced.

Simulation

The system of a reusable container loop is a complex logistical system with a complex system of goals. The system complexity arises both from the multitude of input variables and actuating variables – e.g. work schedules, capacities, arrival rates – as well as the number of stations included in the material flow – e.g. various load carrier types and various interdependent workstations were they are combined, batched, separated, stored and transferred.

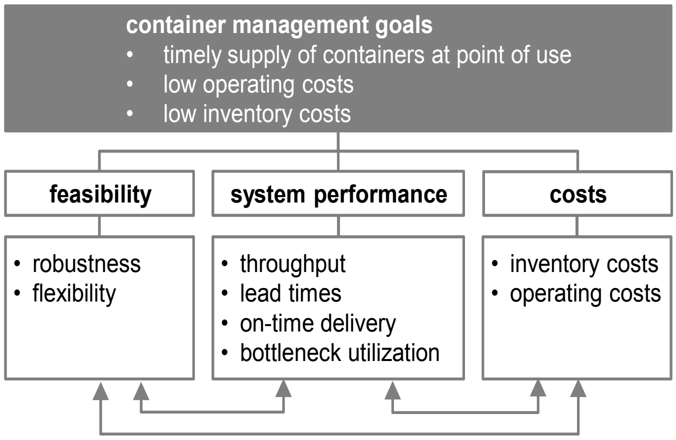

Figure 3 – Basic goal system for the simulation of container loops

Figure 3 illustrates the goal system. Another method of planning complex systems are optimization techniques that may also be combined with simulation – in that case simulation works as the evaluation function of the optimization algorithm [9]. Due to the complexity of optimization techniques and the fact that the problem at hand is not trying to optimize one given system but creating and comparing different model system variants – to be able to evaluate the effects of introducing automatic cleanliness detection and Auto-ID and to compare these variants – simulation will be used without optimization in the current work.

Simulations can either be:

- *dynamic or static*
- *deterministic or stochastic*
- *continuous or discrete*

In the context of material flow simulations in logistics processes, usually a dynamic system behavior with stochastic components is being observed at different points in time in what is called a Discrete Event Simulation (DES) [9] [10].

Determining the apt degree of detail for the simulation model is the main objective of an economic model building approach since more detail results in complexity, which in turn results in increased modeling efforts. There are different modeling environments available for simulation tasks – some of which are based on rather basic coding while others are more end-user-oriented and require less simulation specific knowledge; the latter will be used in the course of this research project.

Methods-Time Measurement

In order to create a realistic simulation model and to be later able to create reliable results of what-if scenarios of different model variants, it is crucial to determine realistic parameters for the simulation model, especially for the not yet implemented future scenarios that are to be evaluated. In order to obtain reliable parameters for logistics operations, especially those including manual operations that are prone to a high stochastic fluctuation, the planning tool Methods-Time Measurement (MTM) will be applied. MTM is a system of predetermined motion times for manual operations, originating in industry research by Maynard, Stegemerten & Schwab in 1940s [11].

The system is based on standard times for basic manual movements such as grasping, reaching, moving and releasing, which were originally analyzed by experts evaluating high speed camera footage of these operations being executed by skilled workers, considering the factors effort and skill of the workers, as well as the conditions of the working environment and consistency of the work performance [11]. While the predetermined times do factor in learning effects, they still include a certain amount of buffer capacity, so that skilled workers can achieve the times without difficulty. All movement-times in MTM are measured in Time Measurement Units (TMU), with one TMU equaling 0,036 s, and are encoded in a standardized format, defined by the MTM council. In recent decades, the standard time system for basic movements, named MTM-1, has been complemented by accumulated times for more comprehensive movements, ranging from movement combinations to basic processes to entire work procedures in specific industries [12], as shown in Figure 4. For the logistics processes in the context of simulating load carrier loops, the system of standard processes for logistics will be applied. Using these aggregated time modules defined for certain fields of application, i.e. standard logistics procedures, rather than conducting a detailed MTM planning from scratch for every process used in the simulation model, helps keeping the simulation model at an appropriate level of accuracy and thus avoiding excess modeling efforts. However, it is necessary to ensure the validity of the aggregated time modules for every processes in the simulation for which they are used.

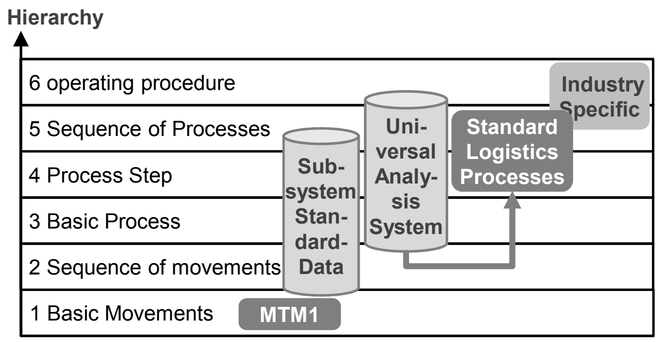

Figure 4 – Overview of the system of MTM standards, see: [12]

Resulting Concept

Simulation and the MTM aided configuration of the logistics material flow model of container loops are the core methods that will be adapted and developed, together with technology selection methods for Auto-ID and dirt measurement, into a configurator for an optimized container management, including a demand dependent container cleaning scheme. An overview of the configurator concept currently in the making is depicted in Figure 5.

The configurator is meant to provide planners with a tool with which to assess the opportunities of integrating a status dependent cleaning of containers as well as integrating an Auto-ID supported container management. It will support the selection of both technology systems, according to the requirements, using a questionnaire, by giving recommendations for suitable system variants. The tool will further assist in mirroring the current situation of a container loop and generating possible future state variants. As a last step, the system will enable a comparative evaluation of current state and the generated *future state variants, according to logistics performance criteria – the goals of which are defined in the sections 2.1 and 3.1 – thus providing planners with recommendations for improving their container loops.*

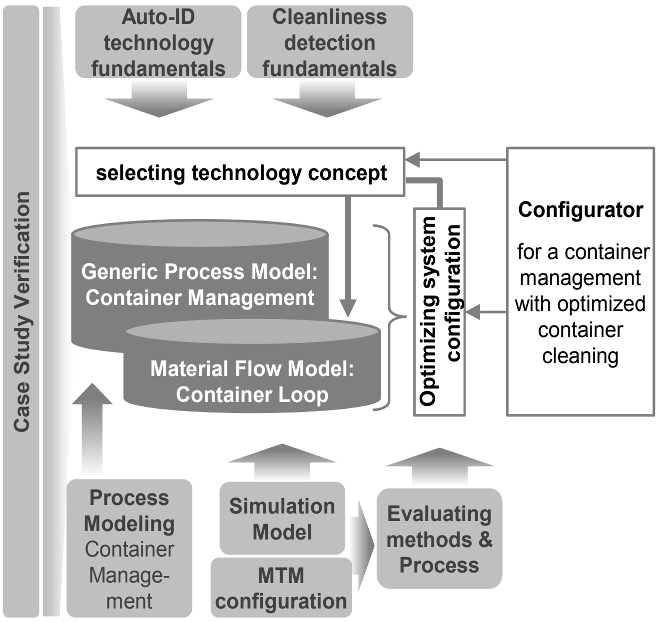

Figure 5 – Overview of the container management approach

CURRENT AND PRELIMINARY RESULTS

The section to follow is meant to give a brief report on the current status of the research work and show exemplary preliminary results gathered so far.

Technology Selection

In order to find a suitable technology for the semi-automatic detection of dust, thus enabling a cleanliness evaluation of the containers in a loop, the measuring principles and options in section 2.2 have been investigated. All options have been evaluated according to their principal technical ability to detect the type of dirt that is to be expected in container loops in industry settings.

Furthermore, an evaluation concerning the prospect of each technology to be implemented in a real life factory environment and the effort associated with this implementation have been evaluated. An evaluation table on the example of optical measurements is shown in Figure 6.

Due to its availability as standard products, its robustness and history in other industry applications – e.g. quality control applications – and the relative versatility in detecting a variety of "dirt" types, the first technology to be investigated in detail is the use of CCD-cameras, in combination with an image processing algorithm to detect dirt particles in container images.

<table>
<tr><th rowspan="2">Measurement Principles</th><th colspan="4">Dirt Type</th></tr>
<tr><th>Chips</th><th>Liquids</th><th>Dust</th><th>Packaging residues</th></tr>
<tr><td>Structured-light 3D scanner</td><td>◕</td><td>◑</td><td>○</td><td>◕</td></tr>
<tr><td>Laser-Scanning</td><td>◑</td><td>◑</td><td>◔</td><td>◑</td></tr>
<tr><td>Attenuated total reflectance</td><td>◕</td><td>◕</td><td>◑</td><td>◕</td></tr>
<tr><td>Digital image correlation</td><td colspan="4">○</td></tr>
<tr><td>Photogrammetry</td><td colspan="4">○</td></tr>
<tr><td>Deflectometry</td><td colspan="4">◔</td></tr>
<tr><td>Reflection measurement</td><td>◕</td><td>◕</td><td>◕</td><td>◕</td></tr>
<tr><td>Radiometry</td><td>◕</td><td>◕</td><td>◕</td><td>◕</td></tr>
<tr><td>Ellipsometry</td><td colspan="4">◔</td></tr>
<tr><td>Color detection</td><td colspan="4">◔</td></tr>
<tr><td>White Light Interferometry</td><td colspan="4">◑</td></tr>
<tr><td>Confocal technology</td><td colspan="4">◑</td></tr>
<tr><td>Conoscopic holography</td><td>◑</td><td>◑</td><td>◑</td><td>◑</td></tr>
<tr><td>Optical coherence tomography</td><td colspan="4">◔</td></tr>
<tr><td>Laser profilometry</td><td>◕</td><td>◑</td><td>◕</td><td>◕</td></tr>
<tr><td>Photon correlation spectroscopy</td><td colspan="4">○</td></tr>
<tr><td>CCD-Kamera</td><td>●</td><td>●</td><td>◑</td><td>●</td></tr>
</table>

- ● **"suitable":** technically fit for the application, practical implementation well foreseeable
- ◕ **"limited suitability":** technically fit for the application, practical implementation complex
- ◑ **"possibly suitable":** technically in principle fit for the application, practical implementation probably problematic
- ◔ **"impractical":** technically theoretically fit for the application, practical implementation not foreseeable
- ○ **"not suitable":** technically theoretically fit for the application, practical implementation not foreseeable

Figure 6 – selection of measuring methods – example optical measuring methods.

Currently a trial application is being tested with example load carriers in different cleanliness states in the case study. First experiments have shown that it is necessary to use multiple cameras from different angles and a light source, all encased in a tunnel-like structure to ensure stable lighting *conditions, to properly check the load carriers for dust and other types of soiling. Using reference images of clean containers to compare them to be tested containers against, the major task now is to distinguish visual conspicuities other than dust and dirt – e.g. dents and scratches that do not affect the quality – from dirt. One possible approach is the use of additional image processing algorithms looking for the characteristics of these "not-problematic" visual signs, while another would be supplementing the camera system with another type of sensor or adding a pressured air cone to detect whether the suspected particles change their position in-between two successive scans while being exposed to an air stream – thus indicating they might be dirt particles. To utilize the full potential of automatic dirt detection it is beneficial to consider the use of a system of conveyor belts. The conveyor belts are able to place the load carriers in the camera-cell described above and hold it in place exactly long enough for the system to measure the dirt level and still being able to keep the time the container has to stay still in the camera cell as short as possible, enabling the fastest possible material flow through the dirt detection unit. The conveyor belt system with a few switch plates would also be able to take over some of the sorting of load carriers, thus potentially increasing the sorting process and relieving the workers assigned to the sorting task of a considerable amount of their workload. Whether the conveyor belt system will prove economically beneficial to the overall system performance and efficiency according to the described goal system is the subject of current simulation experiments, which are elaborated on in the following section. To be able to transport all kinds of containers, which in the case study are small load carriers and blister-trays, without having to use additional transport skids, the conveyors have to be of the belt conveyor type.*

For the Auto-ID technology selection, a capability profile of existing technology variants has been compiled. This was then compared to a requirements profile. The case study showed that the ability to not only identify the container type but also individual containers would be of additional value: It would on the one hand enable precise statistics for the container inventory – e.g. how often have containers been used in production or for transport and how long have they been circulating in the system – that would enable a precise planning of successive container circles as well as planning the substitution of old containers before they break in use, and on the other hand the loss of containers, especially of valuable types, could be precisely monitored. The precise statistics for each container would also enable the possibility of not having to implement the automatic cleanliness detection at all – in less quality sensitive applications, the containers could be monitored and after a certain number of use-cycles they could be transferred to the cleaning process. To ensure no soiled containers are used, experiments have to be executed to determine the number of permissible cycles each container type is allowed to accumulate before they need washing. This counting of cycle times can either be done by keeping and updating a variable inside a database for each container or by storing that information on each container – the latter option is only enabled by RFID Transponders with a dynamic memory. Due to the benefits of identifying individual containers in the system and the possibility of also storing and manipulating data on transponders applied to the load carriers themselves, RFID technology has been selected as the preferred Auto-ID technology within the case study.

Within RFID technology the same selection procedure applies: the capability profile of different RFID variants is compared to the requirements profile, ranging from read-distance to mechanical durability requirements due to the environmental conditions in the washing plant through which the containers have to pass frequently. In a first step, passive Ultra High Frequency Transponders have been selected for the first case study trials, mainly due to their combination of low prices, availability of durable PU adhesive labels and their reading range.

It is important to note that the abovementioned technology selection is only a preliminary selection for the first trials currently in progress in the course of the case study within the research project. For the configurator tool as the pursued end result, *this technology selection process is currently being implemented in a selection assistance system that will allow planners to be provided with technology suggestions by entering key characteristics of the respective application environment they are faced with.*

Status of concept and Case Study

Concerning the general concept and the configurator functions regarding the creation of possible future state variants of the container loop and its management, the first efforts have been dedicated to setting up a simulation model in a suitable DES environment. With an apt simulation model it will be possible to run a number of experiments to determine the savings potential achievable by introducing cleanliness detection and RFID into container loops and gain data on how to configure the resulting system for efficiency, according to the goals described in section 2.1 the simulation model also serves as the basis for the to be compiled optimization routine that the resulting container management configurator will eventually include.

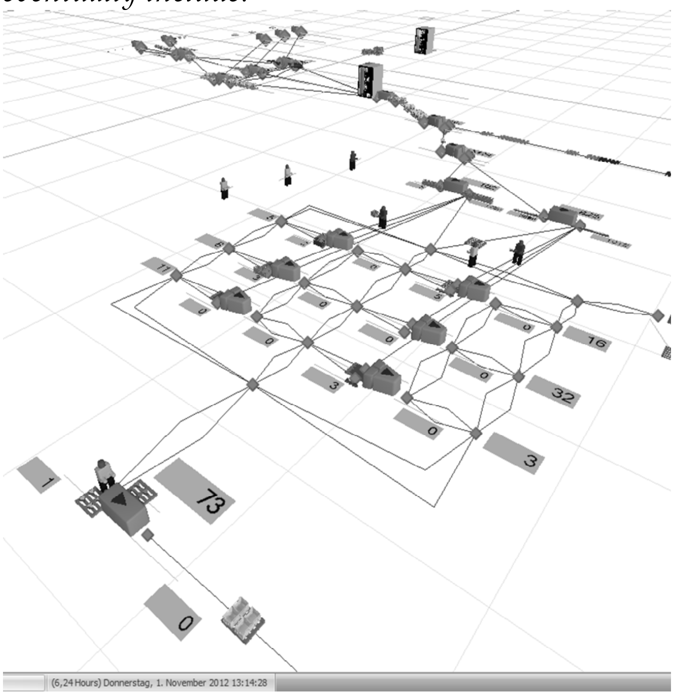

Figure 7 – container loop simulation model in Simio – in progress

Figure 7 shows a section of the basic simulation model layout derived from the work on the case study. It is implemented in the simulation program Simio, a popular commercial DES simulation environment for material flow applications. The current state of the simulation design has produced a simulation model that is able to reproduce the current state of the container loop quite accurately with regard to major variables and performance indicators. This is a key step on the way to test possible system variants including Auto-ID implantation as well as automatic cleanliness detection and a demand driven cleaning of containers. These variants are currently being modeled and tested.

Another element of the configurator concept that is currently in progress is the compilation of a standard generic process and process variants for container management loops, both including open and closed loops. The goal is to develop a standard set of processes and process variants that fits almost every container loop commonly found in real life applications. Figure 8 shows an example process variant for such a standard process. In this example the introduction of a demand driven initiation of the cleaning process for containers creates a transport path from the production plant directly to customers and suppliers. This transport path is shorter than the alternative of going via the external container-cleaning service provider. Therefore, every container that does not require cleaning can be transported directly to the supplier or customer, thus shortening the transport route and of course the resource consumption for the cleaning process. However, it is important to note that a direct transport from the production plant to the customers and suppliers is not always economically sound – if for example the container quantities per customer/supplier are too low, the containers have to be transported via transport hubs that are usually operated by logistics service providers – thus increasing the complexity of the transport logistics involved.

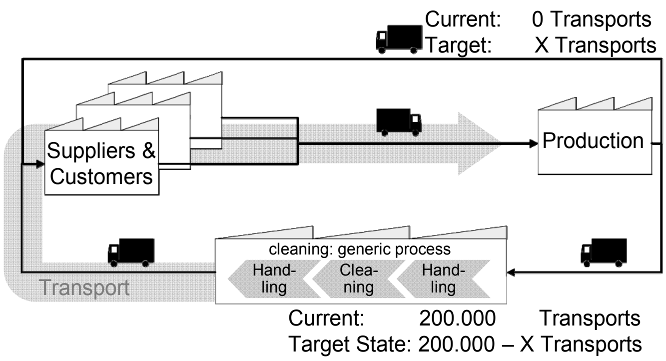

Figure 8 – example of a generic process description - container loop

The case study is being conducted in a production plant of a supplier in the automotive industry and will be focused on a particular set of products and the corresponding load carriers. The container inventory associated with the selected products amounts to approximately 300.000 units. Every day about 30.000 containers exit the production and have to be forwarded to the cleaning process that is executed by a third party logistics provider located in a considerable distance from the considered plant. In a first step to assess the potential of introducing a demand driven cleaning process, the container flow in the case study has been temporarily changed, so that workers assume the task of deciding whether the containers require cleaning and sorting them accordingly. In preliminary trials approximately 75% of the containers proved to be clean and could be directly forwarded to the suppliers and customers. Since the RFID system is not yet implemented, it is not possible to verify how often some of the containers have been used without being cleaned – first experiments indicate that most container types can be used multiple times before they have to be sent to cleaning. This would be equivalent to a reduction of cleaning efforts – including transportation and cleaning itself – of well over 75%. The first simulation experiments indicate that for most load carrier types the necessary inventory could be reduced by 20-30%, thus potentially lowering inventory costs.

CONCLUSIONS & OUTLOOK

Although still in the first half of the project duration, the research work has already produced preliminary results indicating that the savings potential is of considerable magnitude. The entirety of implications still has to be investigated but a reduction of the cleaning frequency of containers would greatly reduce the efforts and expenses associated with the cleaning process. Since the supply of containers would still be ensured, the efficiency of the reusable container loop would increase accordingly, with regard to the goal system of container loops.

The immediate next steps will be overcoming problems with the automatic measuring of the cleanliness status of the containers. Furthermore, the simulation experiments with system variants have to be finalized, thus producing empirical data for the effective configuration of container loops. Also, the process variants and the evaluation and assessment tools have to be developed into an accessible tool for practitioners. This will include trying to derive empirical data from the experiments, both with simulation and in real life trials, in the course of the case study, into generic formulae and reference tables, thus reducing the need for users of the configurator tool to adapt the simulation models to calculate the potential benefits and the proper configuration of their future state container loop as much as possible. Moreover, the real life trials have to be finalized and eventually the best system variants determined with the help of the simulation models have to be implemented in the case study application.

A combined optimization procedure and simulation could prove a promising way to further improve the results of the container management configurator – this could be the subject of future research in this field.

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VERIFICATION OF SHEET THICKNESS REDUCTION USING STEREO-PHOTOGRAMMETRY

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Abstract: *Deep drawing process is a complex process of significant planar deformation. Deformation in the thickness direction is a critical phenomenon in most cases regarding possible crack creation. Therefore, it is necessary to pay a special attention to its measuring. Direct measurement of the sheet metal thickness of parts is limited by complexity of their geometry. So it is necessary to evaluate it indirectly, e.g. by optical measuring of true strain using deformation networks. The digital photography method has been proven as effective but limited to only planar strain. Multiple images stereo-photogrammetry enables digitalizing the part surface into the three-dimensional model including real texture of deformation network. Strain measurements of individual network elements are accomplished only on the virtual model with no geometry restrictions. This contribution presents the way of verifying simulation results by photogrammetric measurement of thickness changes of B-pillar drawn by KUKA ENCO WERKZEUGBAU s.r.o.*
Keywords: *measuring, digital photography method, stereo-photogrammetry, deep drawing process*

INTRODUCTION

Deep drawing is one of the main technologies used in automotive industry. In the material there is a combined stress state, which result in planar strain, but also undesirable strain in the thickness direction, which has to be monitored due to the risk of cracking. Considering the complexity of the drawing process of complex parts, manufacturing of the parts has to be preceded by its thorough analysis in the FEM (Finite Element Method) software.

CONCEPT OF DRAWING TECHNOLOGY OF B-PILLAR

Concept of drawing technolgy of B-pillar and all parameters option has been carried out in the simulation software DYNAFORM. Using this simulation software first the blank geometry has been considered – material removals on the both sides of the blank have been designed. Another part of the simulations has been focused on optioning the appropriate distribution of the supporting forces (Fp=800kN) and the optimal location and geometry of the draw beads. These simulated parameters ensure a uniform material flow into the die and therefore the drawn part without critical thickness reduction and waves formation in the boundary areas is performed [1]. The Figure 1 shows distribution of the sheet metal thickness in different locations on the drawn part.

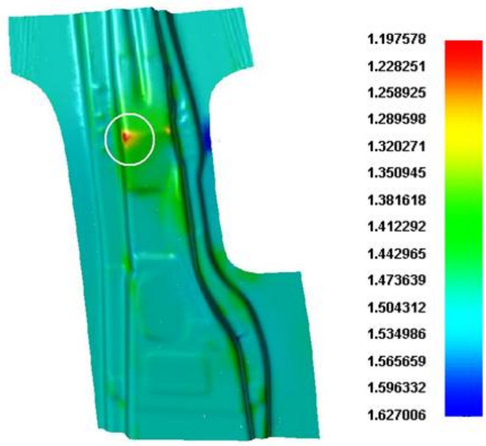

Figure 1. Sheet metal thickness of the drawn part [1]

STEREO-PHOTOGRAMMETRY SCANNING OF DRAWN PART

The 2D digital photography method (compared to the microscopic one) has been proven as effective *but limited to only planar strain. Multiple images stereo-photogrammetry enables digitalizing of the part surface into the three-dimensional model including real texture of deformation network. This enables determination of points' coordinates on general areas [2].*

We used the PhotoModeler Scanner software from EOS Systems Inc. to create the model from photogrammetric images. Stereo-couple of images is needed and after their orientation process, the software can create the point cloud and 3D surface of scanned surface. As a prerequisite, the surface has to provide sufficient textural information that enables detection and matching of homologous points [3]. Points' coordinates are calculated by image correlation and collinear conditions. Principle is based on supposition that each pixel of the image has its unique surrounding – pixel matrix by whose comparison the position of the point on the second image is identified. The bigger the dimension of comparing matrix is, the bigger probability of finding homologous couple of points and the longer computation will be [4].

Process of 3D surface model creation

First of all, the camera has to be calibrated in the PhotoModeler Scanner software. Calibration runs automatically by processing minimum eight images of testing calibration grid that contains coded targets (Figure 2) [2].

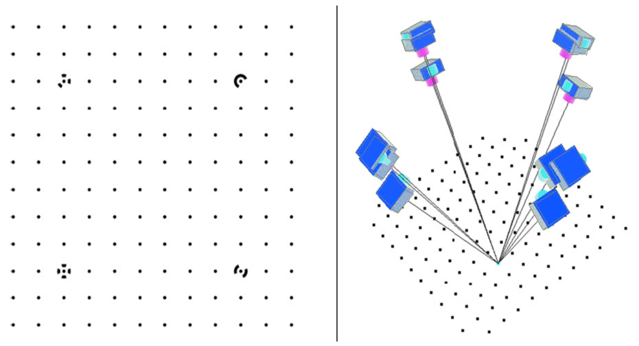

Figure 2. The calibration grid and its image processing during automatic calibration [5]

Image for the photogrammetric scanning process has to be made while keeping specific rules (Figure 3), that results from image correlation principle. Camera axis of the image couple should be slightly convergent (15°- 30°) and the proportion base/distatce (b/h) should be of range 0.1 ÷ 0.5 what ensures good coverage. Ideal proportion is 0.25. Noise and blur can cause problems to image correlation or even make it impossible. Therefore the smallest ISO sensitivity and tripod are used. The same lightening in images without flash is important. For mutual referencing it is suitable to use coded targets [2][5].

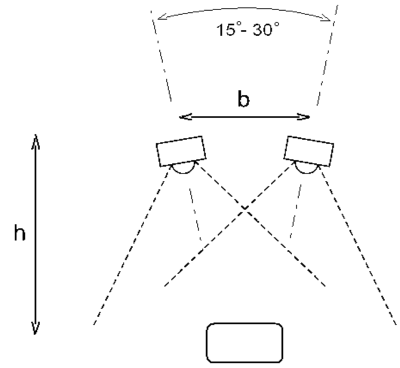

Figure 3. Image-taking conditions [5]

Two couples of images with axes convergence of 15° are used for processing (Figure 4, Figure 5). In the referencing mode we manually match the pairs of homologous points and then we process the project to orient the images and to calculate 3D coordinates of all the points. Mean error of all points' corrections has been 0.101px which corresponds to 0.005mm.

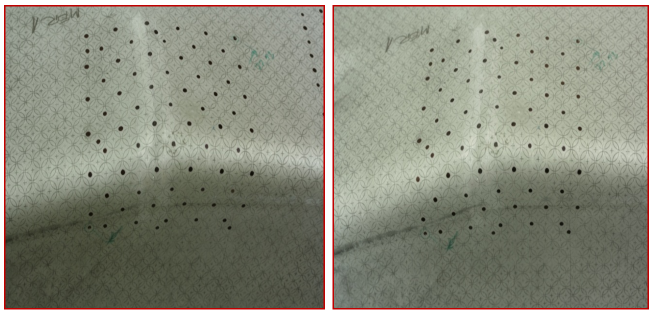

Figure 4. Couple of images used for 3D digitalizing of the top side of surface

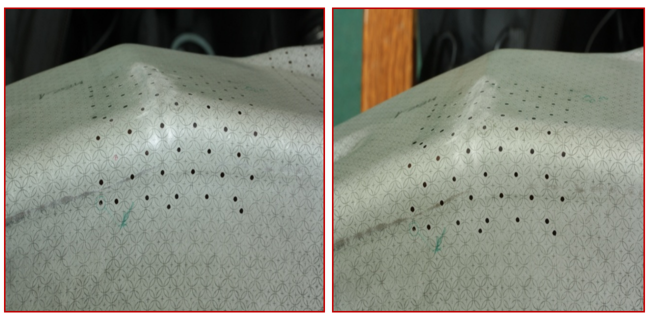

Figure 5. Couple of images used for 3D digitalizing of the side of surface

In the Dense Surface Modeling module a point cloud is generated on the principle of image correlation. Based on the calibration information the influence of image distortion caused by camera *lens has been eliminated and so that the photographs have been idealized before the final processing by means of Idealize Project module. The images have been resampled and the black trimmed regions have been obtained on each photograph [6]. By the function Trim boundary, the region of image corelation modeling could be selected and before calculation we could option these parametres:*

- *mages couple,*
- *sampling rate,*
- *depth range,*
- *sub-pixel,*
- *super-sampling factor,*
- *matching region-radius,*
- *texture type.*

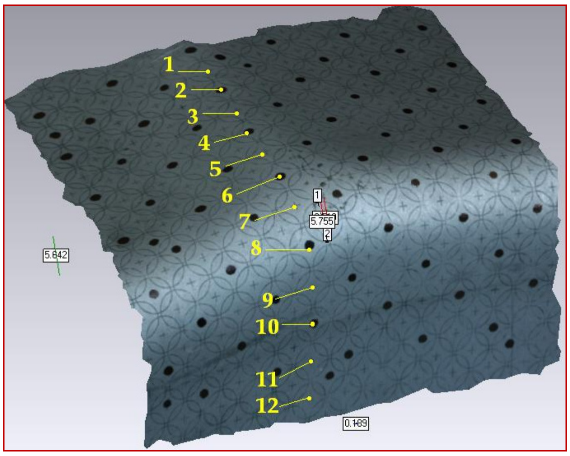

Figure 6. 3D visualization of generated part surface

The Figure 6 shows the final textured part surface. The regions where the software could not find homologous pixels by image correlation because of reflections from glossy metal surface have been trimmed. The surface is exportable into many formats that are widely used by current CAD software. After determination of the scale model, it is possible to measure the deformation network elements [2].

EXPERIMENTAL RESULTS

Direct measurement of the sheet metal thickness of parts is limited by the complexity of their geometry, so the true strain in the thickness direction in different locations can be determined indirectly based on planar strains from the equation [7]:

$$\varphi_2 = -(\varphi_1 + \varphi_2) \qquad (1)$$

where: φ_1 – major strain, φ_2 – minor strain, φ_3 – strain in the thickness direction

The value of sheet metal thickness can be determined from the equation:

$$\varphi_2 = \frac{\ln s_1}{s_0} \qquad (4.2)$$

where: s_1 – thickness after drawing process; s_0 – initial sheet metal thickness

Table 1. The value of true strains and thicknesses in different locations

Location	PhotoModeler Scanner			
	φ_1 [-]	φ_2 [-]	φ_3 [-]	s [mm]
1	0,102	0,024	-0,126	1,323
2	0,108	0,028	-0,136	1,309
3	0,122	0,032	-0,153	1,287
4	0,132	0,029	-0,161	1,276
5	0,135	0,029	-0,164	1,273
6	0,135	0,047	-0,181	1,251
7	0,129	0,071	-0,200	1,228
8	0,111	0,098	-0,210	1,216
9	0,141	0,069	-0,210	1,216
10	0,065	0,023	-0,088	1,373
11	0,055	-0,002	-0,053	1,423
12	0,105	-0,011	-0,094	1,366

Location	DYNAFORM			
	φ_1 [-]	φ_2 [-]	φ_3 [-]	s [mm]
1	0,071	0,021	-0,092	1,368
2	0,082	0,025	-0,107	1,348
3	0,093	0,029	-0,122	1,328
4	0,109	0,035	-0,144	1,299
5	0,131	0,044	-0,175	1,260
6	0,150	0,057	-0,207	1,220
7	0,147	0,081	-0,228	1,194
8	0,116	0,082	-0,198	1,231
9	0,082	0,046	-0,127	1,321
10	0,059	0,030	-0,089	1,372
11	0,042	0,022	-0,064	1,406
12	0,052	0,021	-0,072	1,395

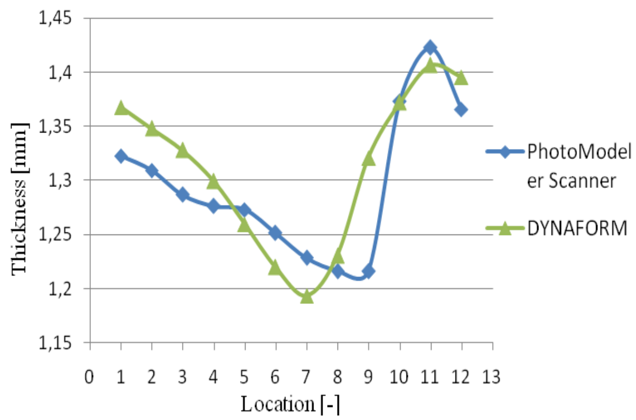

Figure 7. Comparison of dependences of thickness on location in PhotoModeler Scanner and DYNAFORM software

Table 1 contains the values of true strains and thicknesses in different locations evaluated by the PhotoModeler Scanner and DYNAFORM sofware. These results are depicted and compared in Figure 7 by the dependence of thickness on location [1].

CONCLUSION

While direct thickness measurement of sheet metal parts is limited by the complexity of their geometry, strain in the thickness direction can be evaluated also indirectly using stereo-photogrammetry. It allows us to specify the strain also on general surfaces, which are digitilized and so the measurement is made only on the 3D model. The simulation shows the possible location of the critical thickness reduction, and therefore it is necessary to check the dependence of the thickness on location. Stereo-photogrammetric measurement results confirm location of the critical thickness reduction, but without the risk of cracking. The dependence of the simulated thickness is very similar to results of stereo-photogrammetry, and thus confirmed the accuracy of the chosen approach.

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CONTROL SYSTEM OF THE RESCUE AND FIRE EXTINGUISHING ROBOT HARDY

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Abstract: *This paper presents the multipurpose service, emergency and rescue tracked mobile robot Hardy. The mechanical construction, technical solution, functions carried out by the robot and examples of potential applications are briefly explained in the beginning. Then follows description of the control system in the mobile robot and the operator's suitcase used for remote control. Presented are also experiences with modern electronic devices for control of hydraulic and electric motors in the robot based on the communication protocol SynqNET, implemented using technology from Robot System Integration (RSI). The next part of the paper deals with the user interface of the operator's application and some of the features that were designed to assist the operator, primarily the anti-collision system. The whole system is then critically evaluated using some experiences from practical use of the robot, even by a common user.*
Keywords: *Extinguishing robot, Hardy, control system, SynqNET, RSI*

DESCRIPTION OF THE ROBOT HARDY

Hardy is a remotely-controlled multipurpose service, emergency and rescue mobile robot designed for manipulations with objects of up to 300 kilograms of weight and also for other fire brigade and reconnaissance tasks. It is meant for use it emergency situations where a direct intervention of human rescuers or firemen is not safe. The robot is able to extinguish fire with a stream of water, with remotely adjustable shape of the stream.

The mobile robot consists of three main parts: a robust chassis providing perfect stability, a manipulation arm with high load capacity, and a multipurpose effector with three adjustable gripping fingers and integrated water jet. The tracked chassis has been taken from a mini-loader Bobcat, including the original diesel engine and hydraulic aggregate, which was then expanded by more hydraulic drives for the arm and effector. A new electric alternator was connected to the diesel engine, to provide enough energy for the control system electronics and for the 400-volts DC motors of the arm. The mechanical construction of the chassis was modified to secure mounting of the manipulator arm and other new devices and was also supplemented with further covering, a bumper (or optionally a ploughshare) in the front, and boxes for control system elements.

Figure 1: Robot Hardy

CONTROL SYSTEM OF THE LOCOMOTORY SUBSYSTEM

Locomotory subsystem is one of the most important modules of the robot and contains a tracked chassis powered by two rotational *hydraulic motors. Source of the pressure hydraulic media are hydraulic generators driven by the diesel engine. The locomotory subsystem is controlled by an electronic device (interface) designed for communication with the original control unit of the tracked chassis. The device simulates signals generated by the control joystick previously located in the driver's cabin.*

Control signals for driving are transmitted wirelessly from the operator's station (suitcase) via a separate communication channel on a lower frequency (866 MHz), in order to achieve higher range in industrial environment, because driving is the most crucial function of the robot. Directly on the chassis is realised service controlling, so that the robot can be moved in case of a failure.

The chassis from tracked loader Bobcat is driven by fully controllable tandem hydraulic piston pumps, which are powering two reversible hydraulic motors. Handling is realised by two joysticks, or the system can be reconfigured for just one joystick.

Remote control of driving could be done only by connecting to the original control system of the chassis. Direct regulation of the hydraulic motors would be very complicated, because it is necessary to control not only the mentioned hydraulic motors, but also the diesel engine and other components participating on the whole process.

A feasible way how to replace the original joystick with an electronic device proved to be to simulate the joystick angle by change of magnetic field over the corresponding sensors. Executed tests discovered, that reading of angles of the joystick is based on detection of magnetic field changes above the sensor board. These changes are induced by a permanent magnet located on the end of the moving stick. Magnetic fields around 4 sensors are measured and passed as an electric signal to other parts of the control module (see Figure 2).

This solution required an extensive analysis of magnetic values generated by the permanent magnet and their accurate imitation by a set of electromagnets (coils). The advantage of this approach is the fact, that the original electronics of the joystick is intact and the realisation is contactless.

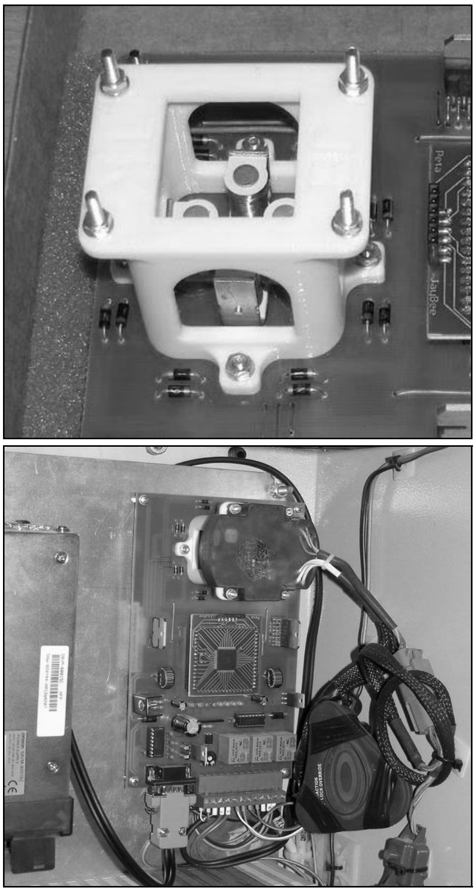

Figure 2: Components developed to replace the original driving controller

MANIPULATOR ARM

The manipulator has 5 degrees of freedom. The first two joints have rotational hydraulic motors and the next 3 joints use DC electromotors from the TGDrives Company. Lifting capacity of the arm corresponds to weight of the biggest existing pressure bottle, which is 300 kilograms. Gripper with three fingers powered by hydraulic cylinders can be set to one of two possible configurations: 3 fingers by 120 degrees or 2 fingers against one. This configuration change is automatic; the effector contains two Maxon DC motors for this function.

Figure 3: Effector detail

Through inner spaces of the arm, water is brought up to the effector and serves for cooling of the arm in case of operation in high temperatures, and also for fire extinguishing using the water jet located in the middle of the effector (between the gripper fingers). It is even possible to regulate the width (angle) of the water stream cone. This functionality is provided by another DC motor Maxon integrated into the effector. For cooling and protection of the whole robot near open fire or in high temperatures, the chassis contains water sprayers that create water mist around the robot.

ROBOT CONTROL SYSTEM

The whole control system consists of a part located directly on the robot and of an operator station. The operator has a suitcase with a computer running the operator application, by which is he using wirelessly all functions of the robot and has a visual feedback about the state of the robot. This feedback includes pictures from cameras (with optional stereovision), data from sensors and interactive 3D visualisation of the actual position of the arm and effector.

The application running on the operator's station is fully graphical, with stress laid on the camera pictures and comfortable control of all functions using a wireless gamepad and a touch screen.

The robot control system contains a durable industrial computer with an application executing commands from the operator – the bidirectional communication with the operator's computer is made via wi-fi.

Figure 4: Operator's station

Backbone of the system is a SynqNet bus [3] interconnecting three DC motor controllers for the arm motors and a Slice I/O module for analog and digital inputs and outputs for all auxiliary functions of the robot, communication with sensors and especially for control of the proportional hydraulic valves for arm and effector motors. The system also contains a CANOpen bus for the EPOS control units of Maxon motors located in the effector.

ANTI-COLLISION SYSTEM

The manipulation arm with strong motors could easily damage itself or some delicate components of the mobile robot (cameras, sensors, communication antennas …) situated in the operating area of the arm. When the robot is out of direct sight from operator, the operator has only very limited feedback from the robot in the form of video from robot camera(s). Actual angles of all arm joints usually are not clear from camera view and thus the operator cannot be fully responsible for prevention of collisions and the control system must assist him [2].

The collision detection is implemented using the separating axis algorithm [4] on pairs of bounding boxes enveloping individual mechanical parts of the robot [5, 6]. Finding an existing intersection between two OBBs would mean that the real arm already probably is in collision – which is too late. Algorithm in the control system of Hardy uses extrapolation of actual angular velocities of all arm joints to predict position of the joints after a chosen constant time. If a potential collision is detected, the arm is slowed. If the collision is imminent, the arm is completely stopped.

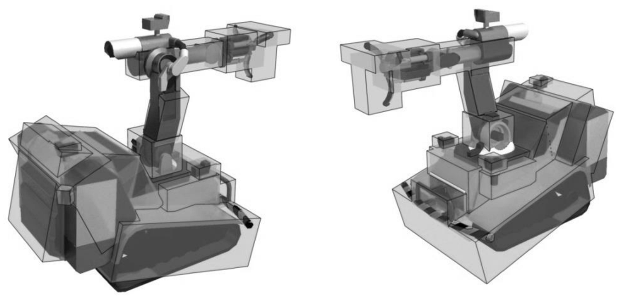

Figure 5: Collision boxes on a 3D model of the robot

CONCLUSION

During realisation of the emergency and rescue robotic system Hardy, it was necessary to solve a lot of technical problems and come with unique solutions of some components. One of the problems was how to control the original mini-loader (Bobcat T250) chassis by an external control *system. The Bobcat control unit communication bus and protocol are closed and even direct assistance of a service centre did not lead to a solution. Thus it was necessary to propose a way how to pass driving orders (speed, steering) without having to move the joysticks originally designed for control.*

Because of the extreme power of the robot and its remote control even without direct visibility from the operator, it was also necessary to design and implement many features assisting the operator during control and helping to prevent accidents. The anti-collision system with the separating axis theorem used to test intersections between pairs of oriented bounding boxes proved to be very efficient and requires insignificant amount of CPU processing time.

Many other problems were solved by a larger team of specialists and their description is not a part of this article.

ACKNOWLEDGEMENTS

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THE EFFECT OF THE PIPELINE BENDING ON THE SHAPE OF THE NATURAL GAS STREAM FIELD BEFORE THE INLET TO THE ORIFICE PLATE IN THE HIGH-PRESSURE PIPELINES

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Abstract: *Worldwide raising requirements for the heat and the energy have huge influence on decreasing amounts of the mineral resources and to increasing tendency of their prices. It is necessary to deal with them responsibly. One of these cases is using natural gas as an energy and heat source. Nowadays billions of normalized cubic meters of natural gas are transferred and used every day around the world. The most common flow measurement type, used in high-pressure pipelines, is measuring by pressure differential, which mainly uses orifice plates inserted in the pipelines. In this type of measurement it is very important to have a steady flow to avoid inaccuracies in the measurement. It could be difficult in the case of the measuring of the volumetric flow in the measuring stations, where one transit pipeline is dividing into the more pipelines of smaller diameters with lots of bendings in a small area. These bendings should have the impact on the stream field of the natural gas before the inlet to the orifice plate that could affect flowing of the gas behind the orifice plate and differential pressure measured on the orifice plate. The aim of this article is to show the magnitude of the impact of different pipeline bendings on the shape of the stream field in the high-pressure pipelines.*
Keywords: *orifice plate, high-pressure pipeline, natural gas, stream field, velocity profile*

INTRODUCTION

Natural gas flowing through the transit gas lines consists of seven major gases like methane, ethane, propane, butane, pentane, nitrogen and carbon dioxide. Majority of the volumetric percentage has methane with its 98.39 % Table 1.

Table 1. Composition of the natural gas in the volumetric percentage

gas	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	N_2	CO_2
[vol %]	98.39	0.44	0.16	0.07	0.03	0.84	0.07

For this reason the paper will assume, that the natural gas used in the analysis will have physical and chemical properties like pure methane due to their nearly identical chemical compositions. In the simulations it will behave as an ideal gas.

MODEL PREPARATION

The whole analysis is calculated in the ANSYS Workbench. The model consists of three parts, two straight pipes and one 90° elbow in the middle of them (Figure 1). In the outlet of the longer straight pipe, there is a space for connection of the orifice plate for the measuring of the volumetric flow.

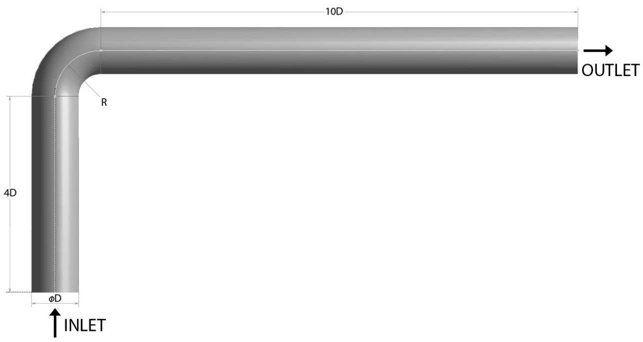

Figure 1. Geometry of the model

Four models with different dimensions were created. Diameter of the pipe was identical in the all cases D=730 mm. Inlet straight part lenght was set to four times diameter of the pipe, that is D=2920 mm. Outlet straight part lenght was set to 10D, that is D=7300 mm, as it is given in the standard ISO 5167-2:2003. The radius R of the *elbows were 700 mm, 600 mm, 500 mm and 400 mm.*

Mesh

The mesh of the body consists of 232566 tetrahedral cells and it has 96067 nodes. To gain better and more realistic behaviour of the gas flow near the walls was set an inflation. The inflation has 15 layers with the growth rate of 1.5 and it is bounded by the outer walls of all three parts of the model (Figure 2).

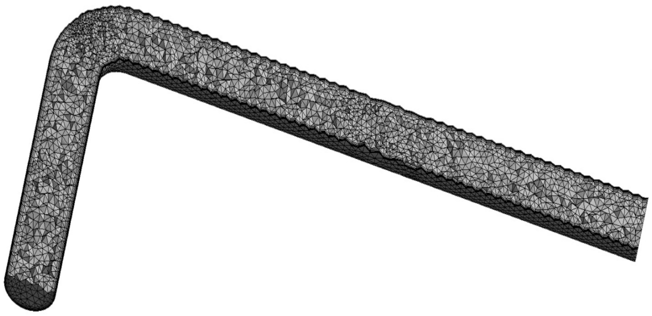

Figure 2. Meshing of the model

Boundary conditions and model solver

Behaviour of the model was set for the high-pressure pipeline with flowing methane as the fluid part. In the pipe methane behaves as the ideal gas. All boundary conditions in the inlet to the pipe are in the Table 2. Equivalent roughness of the surfaces of the pipes was set to Δ=0.1 mm. Boundary condition for the inlet was set to mass flow rate and for the outlet was set pressure outlet.

Table 2. Boundary conditions in the inlet to the pipe

Pressure	Temperature	Density	Mass flow rate
p [Pa]	T [K]	ρ [kg.m^{-3}]	m [kg.s^{-1}]
5.10^6	288.0	33.5	80.0

Density based model solver was selected due to the compressibility of the natural gas and because of the high Reynolds numbers and necessity of modelling flow near the wall was k-ω SST viscous model chosen.

ANALYSIS OF THE STREAM FIELD

The value of the bending radius has huge impact on the velocity profile as it is visible in the Figure 3. In all the models is maximum velocity value around the inner wall of the bending, where reaches up to 10.6 m.s^{-1}. Then the flow with the highest velocity continues flowing to the upper wall of the straight pipe part and in the lower wall appears flow with low velocity close to the zero value. The unstable flow behind the elbow has raising tendency with the decreasing radius value.

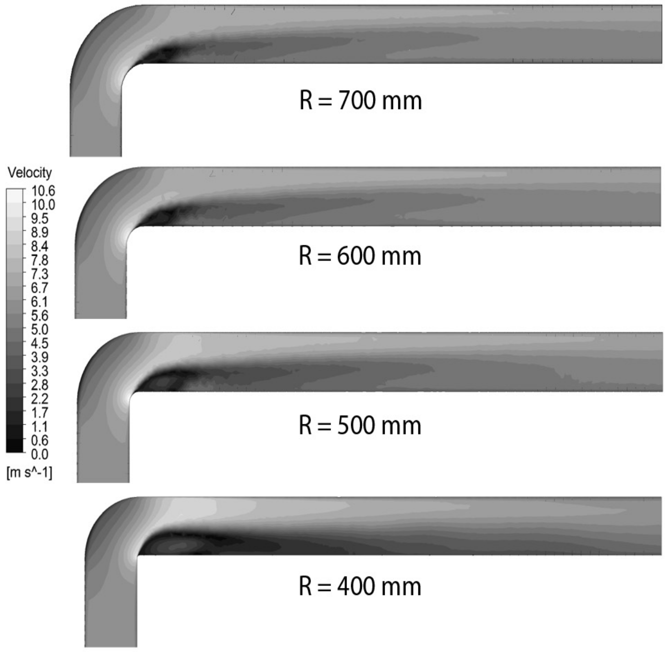

Figure 3. Velocity profiles in the sections through the models

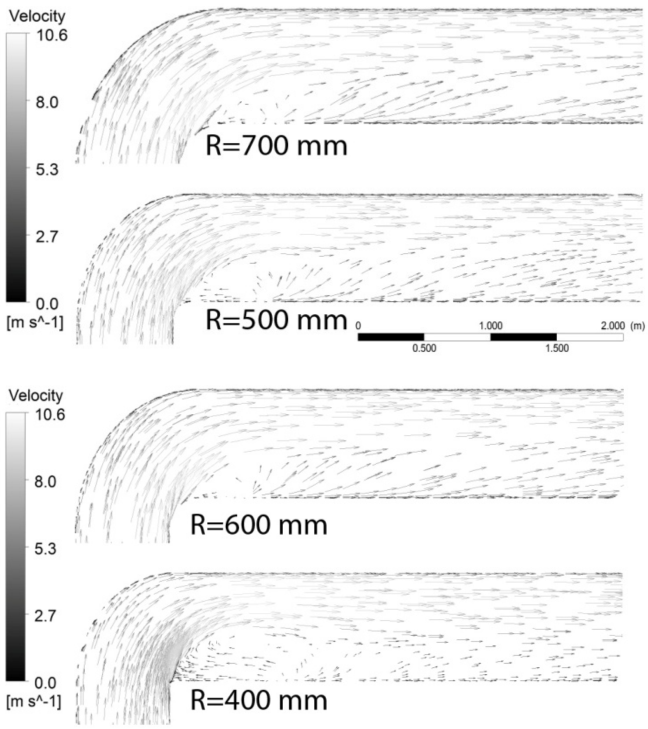

Figure 4 . Velocity vectors in the sections around the bending

With decreasing of the bending radius reverse flow near the lower wall becomes stronger and more visible (Figure 4). The stream field near the lower wall is more affected by the reverse flow and it takes longer distance to get stabilized with the *upper stream which is less affected by the bending radius.*

The standard ISO 5167-2:2003 mentions rules how to correctly measure by the orifice plates. For orifice plates with D and D/2 tappings , the spacing of the upstream pressure tapping is nominally equal to D. Velocity profiles in the distance of 1D from the outlet are shown in the Figure 5. The sections with the lower radius didn't reach the maximum velocity and their velocity profiles are more divided and influenced by the unstabilized flowing near the lower wall.

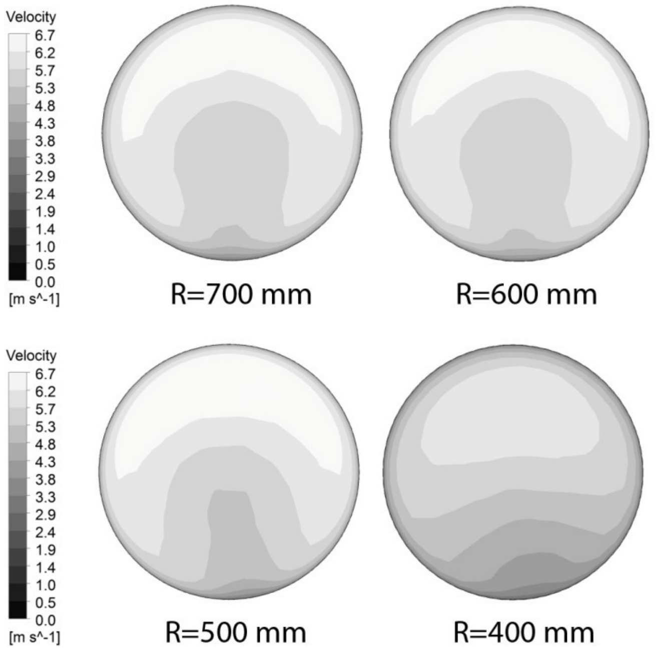

Figure 5. Velocity profiles in the sections in the distance of 1D from the outlet

CONCLUSION

The value of the radius has a big impact on the stream field in the high-pressure pipeline. The accuracy of the measurement could be affected if the flow has not had enough length to get stabilized all around the pipe. This knowledge could have a great importance in the measuring stations, where the natural gas is distributed in the pipeline system with lots of elbows and bendings in the small area. The final flow which is entering orifice plate can not be stabilized enough in the distance of ten times diameter of the pipe (lenght = 10D) as it is predicted in the standard ISO 5167-2:2003. Analyzing of the pressure fields in the pipeline system affected by the unstable velocity flow all around the pipe will be the next aim of the research.

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DESIGN OF LABORATORY 3-AXIS CNC MILLING MACHINE BY MODULAR APPROACH „LABROS 100S“

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Abstract: *In this paper, the results of the research of the modular approach to the design of lab 3-axis CNC milling machine, the basic module of the support structure including the drive systems and the measuring systems, module of the main spindle and the control unit are presented. The parameters of the support structure and of the main spindle of the lab milling machine are indentified, because of the modular approach to the desing of the machine. The goal of this research is to develop our own hardware and software system of the control unit that will enable direct entry and recognition of the G-code according to ISO 6983.*
Keywords: *CNC milling machine, modular approach, design*

INTRODUCTION

By developing and applying CNC machine tools a big progress, with an efficiency in preparation, organization and performance of manufacturing operation, is made. CNC machine tools are controlled by a computer, that is by a computerized control unit that is placed on the machine.

As the control unit contains of a computer, programs can be saved, modified and upgraded, and the results of these intervention can be simulated and verified instantly on the machine, before production begans. Programming of the CNC machine tool is made via a computer, and the program is most often transferred with a USB storage device or through a computer network.

There is aslo the possibility to program directly on the machine using the keyboard and screen, that are components of every CNC machine. The control unit support 3D geometric models as there are the basic of automatically generating of programs. The goal of this work is to desing a 3-axis CNC laboratory educational milling machine by using a modular approach.

MODULES OF THE CNC MACHINE TOOL

The structure of the CNC machine consists of the following systems: mechanical, drive, measuring and controlling. The modular approach in designing is the foundation of design of contemporary machine tools. The modules are constituent parts of the machine tool. The kinematic modules – a module of the main movement (module of the main spindle) and a module of the linear support movement in the direction of the NC coordinates have the most important role. These two modules allow the implementation of the basic function of the machine tool: the relative movement between the tool and the workpiece and the realization of the process. Onto the kinematic modules (supports, stands, bearing support system) functional systems are built in: drive systems, the system for leading (sliding and roller guides) and measuring systems for circular and linear movement.

Most of the functional systems can be found on the market as ready-made and can be adjusted fast, with some modification, to the requirements of the projected machining system. This fact in designing of the mechanical system of the 3-axis CNC milling machine was used, therefore the design of the control unit of the 3-axis CNC milling machine was the brunt of this work.

Thus, when designing the module of the linear movement in the direction of the NC coordinate axes BOSCH profiles with corresponding cross *section and BOSCH guides are used. The relative movement between the modules is realized over wormshaft and nut rack with recirculating ball bearing. Step motors with rotational movement with precisely determined functional characteristics are used to drive the bandages spindle (support linear movement).*

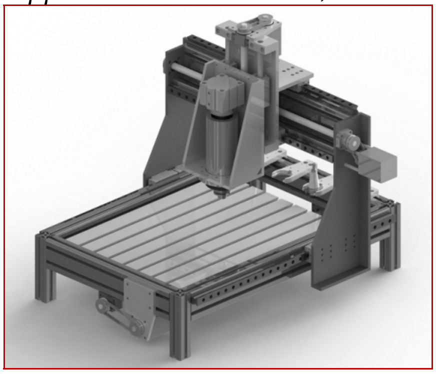

Figure 1. 3D model of the lab 3-axis CNC milling machine

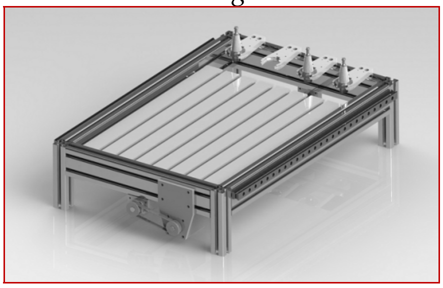

Figure 2. The module of the X axis (basic module of the support structure)

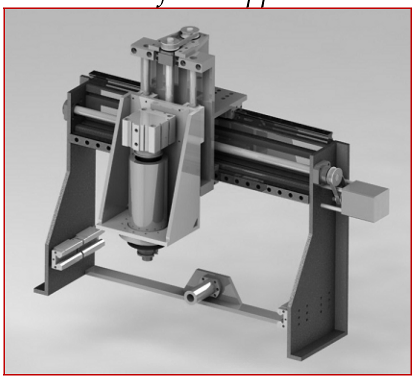

Figure 3. The module of the Y axis (gantry module)

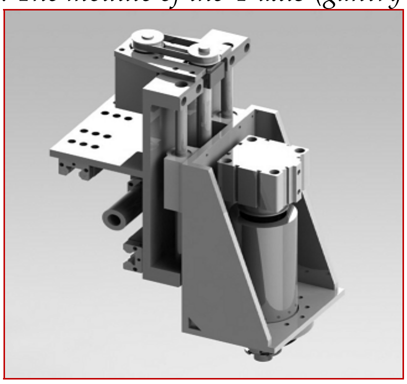

Figure 4. The module of the Z axis

The module of the main spindle consists of several basic functional parts: housing, spindle shaft, axially spaced roller bearings, electric drive motor, system for clamping and releasing tools and internal cooling system.

CONTROL UNIT

The control unit is to enable direct entry of the G-code and reading of the codes over USB interfaces, and to generate control signals for step motors based on the code. The control unit is based on a PC platform along with ARDUINO microcontrollers for every controlled axis. The interface between a machine and an operator is realized over controlling tasters and industrial LCD screen, and with the help of the interface the operator can access different regimes of programming and work of the machine, but also access and control auxiliary functions of the machine.

The relative movement between the tool and workpiece of the CNC machine is defined with the resultant which consists of the components of the movements in direction of axes of the coordinate system of the machine. According to the Figure 1, the relative movement of the tool in regard to the workpiece should follow the contour of the workpiece that is marked with the line A-B.

The real path of the tool, thus the real shape of the contour of the workpiece will not follow the contour marked with the line A-B, because in reality this is not achievable. The real path of the tool, thus the real shape of the contour of the workpiece are replaced with an approximate contour of polygonal shape. The interpolation of the real contour, by using contours of polyginal shape, is realized in the Interpolator of the CNC machine. The Intepolator is placed in the control unit. The Interpolator coordinates the movement in the direction of the axes of the machine so that the resulting movement coincide with the directions of the tangent in certain points of the contour.

Linear movement

In the structure of the G-code two basic types of linear movement are differed: rapid motion mode and the linear movement during the processing (feed motion mode). Two standard codes are used to set up these motion modes: G00 specifies rapid motion mode and G01 specifies feed motion mode.

The machine is placed in the wanted position in the shortest route with the maximum speed by using the function of the rapid motion mode. The function of the rapid motion mode is realized by giving the coordinates of the last point of the trajectory. Giving the coordinates of the last point of the trajectory the direction of the relative movement is defined and the number of the signals on the step motor, with the maximum frequency, is generated, thus the maximum speed of the step motor is achieved. This movement is realized for every axis individually (without interpolation) and lasts till the moment of the achievement of the wanted position on every axis.

⌑ ***The linear interpolation***

According to the Figure 6 the movement of the tool from point A to point B is realized in a straight line with the speed V. The distance between the points is marked with D and has the value:

$$D=\sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2} \qquad (1)$$

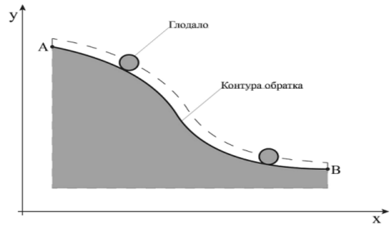

Figure 5. The movement of the tool in regard to the workpiece

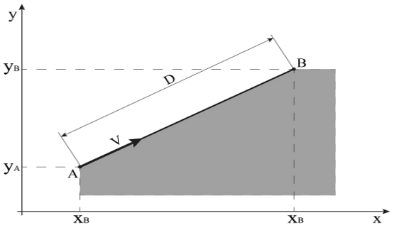

Figure 6. Process of the linear interpolation

The time interval in which the tool moves from A to B, by knowing the distance D that the tool has to exceed with the speed V, can be found: T=D/V

The movement is projected onto the coordinate axes, and the current coordinates of the tool can be expressed in the function of time:

$$x(t) = x_A + \int_0^t x dt = x_A + \int_0^t \frac{x_B - x_B}{T} dt$$
$$y(t) = y_A + \int_0^t y dt = y_A + \int_0^t \frac{y_B - y_B}{T} dt \qquad (2)$$
$$z(t) = z_A + \int_0^t z dt = z_A + \int_0^t \frac{z_B - z_B}{T} dt$$

If the time interval T is devided in a large number of little intervals N, the time interval has then the value Δt = T/N, and the expressions for the current coordinates of the tool become :

$$x(t) = x(n\,\Delta t) = x_A + \frac{x_B - x_A}{N} n$$
$$y(t) = y(n\,\Delta t) = y_A + \frac{y_B - y_A}{N} n \qquad (3)$$
$$z(t) = z(n\,\Delta t) = z_A + \frac{z_B - z_A}{N} n$$

where is : n = 1,2...N

According to this, the tool makes an elementary move in the direction of the axes x, y and z for every elementary step. The accuracy of the interpolation is conditioned by the maximum size of the elementary move. The maximum values of the elementary movements are given with these expressions:

$$\left|\frac{x_B - x_A}{N}\right|;\ \left|\frac{y_B - y_A}{N}\right|;\ \left|\frac{z_B - z_A}{N}\right| \qquad (4)$$

⌑ ***The circular interpolation***

The interpolation of a circular path is realized by defining the coordinates of the points of the circle in the function of time. This is done by the Interpolator. The controls of the G-code for doing the circular interpolation are: G02 - for the circular interpolation clockwise (CW) and G03 for the circular interpolation counterclockwise (CCW). There are defined with ISO 6983. Geometrical parameters that are given with these functions are: the current position of the machine (known from the previous line of the G-code): XA, YA and ZA, the coordinates of the last point of the arc: XB, YB and ZB and the value of the radius of the interpolated circle R. The value of R can be given with a positive or negative sign, so there are two solutions: two possible arcs.

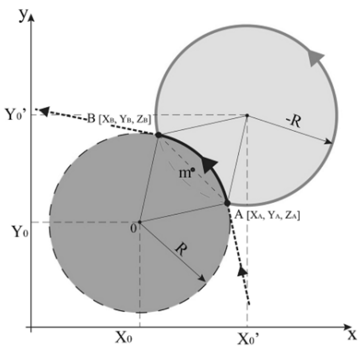

Figure 7. The circular interpolation CCW; G03

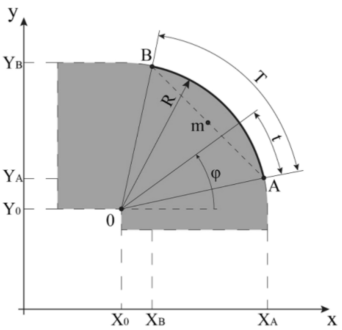

Figure 8. The process of the circular interpolation

In the formulas for parametric description of the arc values of the coordinates of the centar of the circle: X_0 and Y_0 figures. These values are defined by using the previous defined values of the coordinates of the first and the last point and the value or the radius of the arc. The relations between these mentioned parameteres are given with these following relations:

1. For the positive sign of the radius R (Figure 7 and Figure 8):

$$x_0 = x_m + \sqrt{R^2 - (D/2)^2}\,\frac{Y_A - Y_B}{D} \quad (5)$$

$$y_0 = y_m + \sqrt{R^2 - (D/2)^2}\,\frac{x_A - x_B}{D}$$

2. For the negative sign of the radius R (Figure 7 and Figure 8):

$$x_0 = x_m - \sqrt{R^2 - (D/2)^2}\,\frac{Y_A - Y_B}{D} \quad (6)$$

$$y_0 = y_m - \sqrt{R^2 - (D/2)^2}\,\frac{x_A - x_B}{D}$$

where X_m and Y_m are the coordinates of the centar of the straight line which connect the points A and B:

$$X_m = \frac{X_B - X_A}{2};\ Y_m = \frac{Y_B - Y_A}{2} \quad (7)$$

D is the shortest distance between the points A and B:

$$D = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \quad (8)$$

and the value of the radius R of the interpolated arc is taken as the absolute value.

According to the Figure 8 the relations of the parameterization of the arc are:

$$x = x_0 + R\cos\varphi;\ y = y_0 + R\sin\varphi \quad (9)$$

As it is $\varphi = \frac{2\pi}{T}t$, it will become

$$x = x_0 + R\cos(\frac{2\pi}{T}t);\ y = y_0 + R\sin(\frac{2\pi}{T}t) \quad (10)$$

DRIVE SYSTEM

The drive system provides the drive of: the main spindle, of the support of the tool, of the support movement and of the other systems and devices that are parts of the structure of the machine. According to the principles of the control in the machining process of the CNC machines the drive of the main movement and the drive of the support movement are separated, thus the conditions for an autonomously control of some drives are made.

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THE COMPARISON OF YIELD OF DEPOSITION OF FUNCTIONALLY GRADED CERMET LAYERS Ni-ZrO_2-8Y, Ni -TiB_2 AND Ni-Al_2O_3 DEPOSITED BY ELECTROPHORETIC DEPOSITION

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Abstract: This paper deals with comparison of yield deposition for functionally graded cermet layers Ni-ZrO_2, Ni-TiB_2 and Ni-Al_2O_3 which were obtained by electrophoretic deposition (EPD) in benzene alcohol-based suspension. The cermet has very interesting properties which can be achieved by a combination of different materials. The yield of deposition for FG cermet layers Ni-ZrO_2-8Y, Ni-TiB_2 and Ni-Al_2O_3 has a significant influence for final powder deposition. On the base of evaluation of results, the yield of deposition was the highest in case of FG cermet Ni-Al_2O_3 followed by Ni-ZrO_2-8Y and Ni-TiB_2. The highest possible yield of deposition leads to the resulting materials with the desired properties.
Keywords: cermet layers, Ni-ZrO_2, Ni-TiB_2, Ni-Al_2O_3, electrophoretic deposition (EPD)

INTRODUCTION

Currently there is a huge challenge when combining the mutually incompatible properties into one material such as hardness at high temperature and stiffness at low temperature. One of the ways to obtain these properties in one material is to create a functionally graded material (FGM). FGM offers a solution of how to prepare for instance FGM with tough core and hard surface in one material.

The FGM is a two component composite characterized by a compositional gradient from one component to the other. The properties are extremely important, especially in materials such as cermet with gradually changing structure. Functionally graded cermet is a structural material composed of a ceramic hard phase and a metal binding phase, in which approximately equiaxed fine grains of the ceramics, which constitute approximately 15-85% by volume, are embedded in a matrix of metal or alloy binder.

For FG cermets Ni-ZrO_2-8Y, Ni-TiB_2 and Ni-Al_2O_3 the combination of metal and ceramic can lead to desired and exceptional properties as opposed to conventional hard metals. All three ceramic powders have very high hardness, low toughness and excellent wear resistance. TiB_2 has very good thermal, electrical conductivity and hardness and can be used as a refractory protective layer on heat-resistance alloys.

With an excellent combination of properties (high strength and stiffness) of Al_2O_3 and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications. The usage of ZrO_2-8Y instead of ZrO_2 was chosen because adding small percentages of yttria eliminates phase changes and the resulting material can be used as a heat-insulating coating. The mating of these mutually incompatible properties in one material system (cermet) can lead to improving the life span of cutting tools.

The yields of depositions for preparation of FG cermet layers were obtained by method of EPD, which is very suitable for preparing such as materials. The method of EPD was chosen for its versatility when using different kinds of powders (metals, ceramics) and for its cost effectiveness. In order to prepare the green body by means of EPD it is necessary to have stable suspension, which was obtained in our case by electrostatic repulsion only affected the pH values.

EXPERIMENT

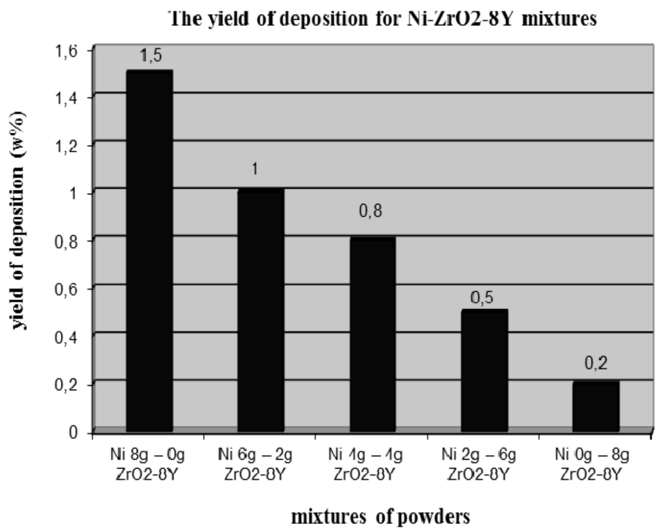
The commercially available powders used in this experiment were Ni with an average particle size of 30 μm, and SSA 15 m²/g, TiB_2 with an average particle size of 14 μm and SSA 45 m²/g, ZrO_2-8Y with an average particle size of 20 – 30 nm and SSA 50 m²/g and Al_2O_3 with average particle size of 150 nm and SSA 10 m²/g. All types of suspensions consisted of 60 ml of benzene alcohol C_2H_6O 96% (ethanol min.96%, benzine 1%). All powders had constant value of 8g (starting value). In all experiments the 0.3 ml of 65% HNO_3 were used. For the EPD experiment, the Ni electrodes (deposition and counter) were used. Ni electrodes were cleaned in an ultrasonically pured acetone, isopropyl alcohol and distilled water bath and the distance between the electrodes was set to 8 cm. The setting parameters for EPD were constant in all experiments, I=150mA, U=120V, P=10kW (maximum limiting performance), t=5min. All suspensions were treated by ultrasound for 5 minutes in order to disperse. According to the measured values of pH (1 – 1.4) suspension was stable and positively charged.

The yields of depositions were calculated after 5 minutes of drying of powder for all presented nanopowders. The EPD device can operate at the temperature range of 0–40°C. In our case the temperature was adjusted to 25°C and pH values was measured at 25°C on pH meter 730.

The yield of deposition was investigated for powder mixtures with different weights of powders. The five measurements of yield of deposition were performed for each material system. The starting value of Ni powders was 8g which was gradually change to 8g of ZrO_2-8Y, TiB_2 and Al_2O_3. The yield of deposition was obtained as follows: for the first deposition, the 8g of Ni were disperse in 60 ml of benzene alcohol + 0.3 ml of 65% HNO_3. After 5 minutes of EPD the Ni electrodes were pulled out and the deposited powders were dried for 5 minutes. Afterwards the electrode with the deposited powders was immersed into the second suspension with 6g of Ni and 2g ZrO_2-8Y and this procedure continued until the suspension of 8g of ZrO_2-8Y. This procedure was the same for Ni-TiB_2 and Ni- Al_2O_3 cermets. The details of EPD parameters, suspensions, pH and yield of deposition are shown on tab. 1-3.

Table 1. EPD parameters, pH and yield of deposition in benzene alcohol–based suspension for Ni–ZrO_2-8Y

Setting parameters	Suspension	pH	Yield of deposition [w%]
I= 150 mA U= 120 V P= 10 W tdep= 5 min T= 25°C	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 8g – 0g ZrO_2-8Y	1.1	1.5
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 6g – 2g ZrO_2-8Y	1.2	1
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 4g – 4g ZrO_2-8Y	1.2	0.8
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 2g –6g ZrO_2-8Y	1.3	0.5
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 0g – 8g ZrO_2-8Y	1.5	0.2
Overall yield of deposition			4



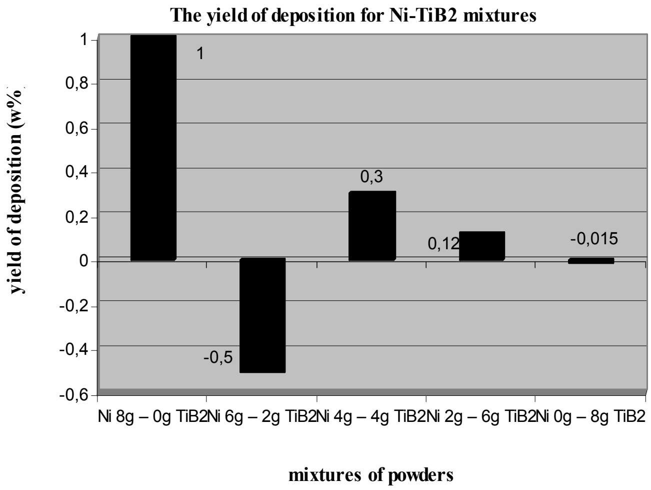
Graph 1. The yield of deposition or Ni-ZrO_2-8Y mixtures

Table 2. EPD parameters, pH and yield of deposition in benzene alcohol–based suspension for Ni–TiB_2

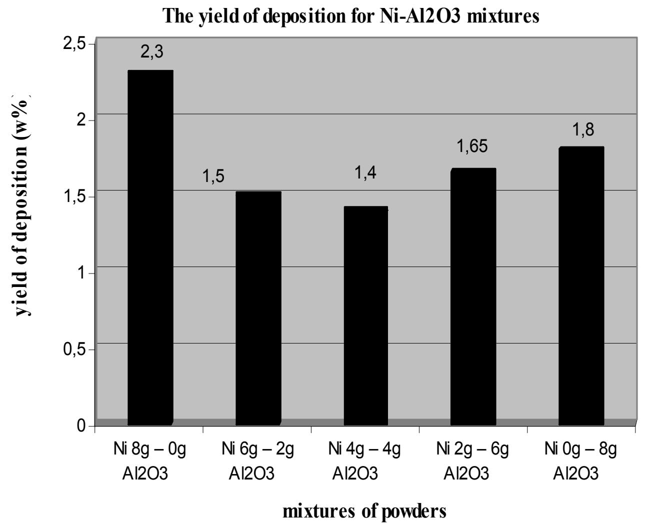
Setting parameters	Suspension	pH	Yield of deposition [w%]
I= 150 mA U= 120 V P= 10 W tdep= 5 min T= 25°C	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 8g –0g TiB_2	1.1	1
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 6g –2g TiB_2	1.2	-0.5
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 4g – 4g TiB_2	1.1	0.3
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 2g – 6g TiB_2	1.1	0.12
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 0g – 8g TiB_2	1.2	-0.015
Overall yield of deposition			0.9

Table 3. EPD parameters, pH and yield of deposition in benzene alcohol–based suspension for Ni – Al_2O_3

Setting parameters	Suspension	pH	Yield of deposition [w%]
I= 150 mA U= 120 V P= 10 W tdep= 5 min T= 25°C	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 8g – 0g Al_2O_3	1.1	2.3
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 6g – 2g Al_2O_3	1.2	1.5
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ Ni 4g – 4g Al_2O_3	1.1	1.4
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 2g – 6g Al_2O_3	1.1	1.65
	60 ml of benzine alcohol + 0,3 ml of $HN0_3$ + Ni 0g – 8g Al_2O_3	1.2	1.8
Overall yield of deposition			8.7



Graph 2. The yield of deposition for Ni-TiB_2 mixtures



Graph 3. The yield of deposition for Ni-Al_2O_3 mixtures

DISCUSSION

The challenge of preparing such cermet layers by means of EPD is complicated. The first problem is that stability suspension is hard to achieve by electrostatic repulsion.

In this paper the electrostatic repulsion was done by affected the ph values by adding the HNO_3. The proof of suspension stability could be done by the zeta potential measurement. As shown on graph 1, the yield of deposition decreased almost linearly with adding of ZrO_2-8Y nanopowders.

The highest yield of deposition occurred in FG cermet Ni-Al_2O_3. The overall yield of deposition was 8.7 compare to 4 w% for Ni-ZrO_2-8Y and 0.9 w% for Ni – TiB_2 which is too low for obtaining the material of desired properties. As can be seen on graph 3, the yield of deposition was almost the same for pure Ni and Al_2O_3 and the gradient profile is the most convenient when compared to Ni–TiB_2 and Ni-ZrO_2-8Y. For this reason the FG cermet Ni-Al_2O_3 seems to be the best solution in the case of yield of deposition.

The second problem was to adhere the coating on the deposition electrode. As seen on graph 2, with the second immersion of the electrode and after 5 minutes of running the EPD process, the decrease in yield of deposition occurred, the value was -0.5 w%. The same decrease occurred even for the last deposition – 0.015 w%. There is an assumption *that this can happen because of weak forces among individual particles deposited on the electrode and the applying of electric field disturbed the deposit. This is a very rare situation which has a negative impact on the resulting yield of deposition and final powder compact.*

CONCLUSION

Based on the demonstrated results, it is possible to confirm the possibility to prepare the functionally graded cermet´s layers of Ni-ZrO_2-Y8 Ni-TiB_2 and Ni-Al_2O_3. It was shown that the higher yield of deposition was for Ni-ZrO_2-Y8 followed by Ni-Al_2O_3 and Ni- TiB_2.

All these experiments are good indicators not only for preparing the FGMs but also for preparation suspension and determination of parameters of EPD. In the future for preparation of cermet layers by means of EPD, there is a need to optimize the EPD parameters for given characteristics of deposited powders and the type of used suspension.

All these experiments were carried out in laboratories of the Institute of Technologies and Materials, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava.

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MICROMILLING USING PNEUMATIC SPINDLE – EXPERIMENTS AND APPLICATION

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Abstract: Pneumatic high speed spindle is a response to ever increasing demands on machine tools. Designers of contemporary products require machining of smaller details of higher shape complexity. This means that smaller tools have to be used for machining. To be able to keep the defined cutting speed of a smaller tool we have to increase spindle speed. There is a limit, however, of standard machining spindles. To overcome this problem a pneumatic spindle has been introduced as an accessory device applicable to any machine tool. With speed of up to ten times higher than the speed of regular spindle we are now able to effectively machine complicated shapes using tools of diameter as small as 0.1 mm. This paper presents practical results of high speed pneumatic spindle application for real industrial products. Furthermore there are results of experimental testing and machining introduced to give a better perspective of behaviour of pneumatic spindle during cutting process. These experiments show reactions of spindle speed to extreme cutting conditions. The practical applications show production of radial turbines and distributors, making a groove with depth of 10xD and more.
Keywords: high speed pneumatic spindle, application, cutting process, experimental testing

INTRODUCTION

Contemporary machining applications have been increasing their demands of shape complexity of the final product. The reason is clear. The market asks for innovative products to satisfy increasing customers' needs. This fact would apply mainly to electronics market where designers are coming up with new looks of mobile phones, tablets or laptops with an overwhelming speed. To keep up with such a standard, machine tools have to be constantly innovated. To satisfy such requirements, smaller machining tools have to be used so as to fit in smaller gaps. When we consider a technological point of view we find out that with decreasing diameter of the tool we have to increase spindle speed to meet the defined cutting speed for certain tool and material. These facts have initiated a development of a high speed pneumatic spindle.

DESCRIPTION OF PNEUMATIC SPINDLE

The pneumatic spindle has been designed in Research Center of Manufacturing Technology (RCMT) at Czech Technical University (CTU) in Prague. The first working sample was ready in 2008. It has been subjected to various testing and experiments. Based on test results a new generation of the high speed pneumatic spindle has been designed [1]. This new generation emerged in 2011.

The spindle is capable of reaching 142 000 RPM at its maximum. It is driven by a radial pneumatic turbine and fitted with ball bearings with ceramic rolling elements. The turbine runs under standard air pressure of 6 bars. There is also a control unit that is capable of setting and keeping the spindle's speed at a constant value.

The second generation spindle (see Figure 1) has been subjected to even more tests and experiments. Furthermore it has been used in many practical applications. Results of such tests are described in this paper.

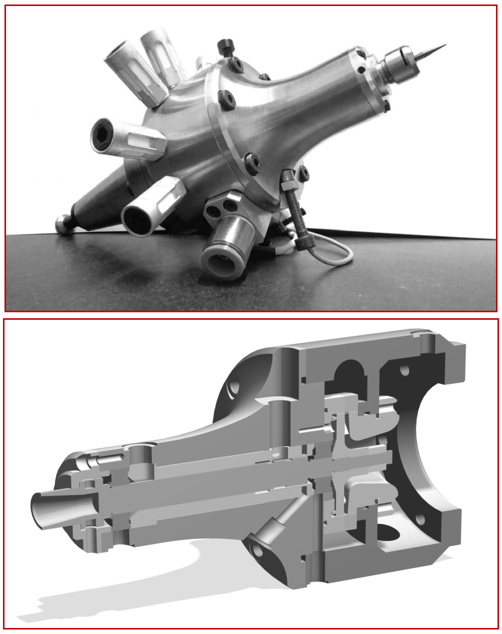

Figure 1: The second generation of high speed pneumatic spindle

DESCRIPTION OF EXPERIMENTS

As mentioned above the pneumatic spindle has been subjected to various experiments which were to find maximum speed [2], control parameters [3], maximum performance and torque [4], resonance vibrations [5], etc. Although all these tests have shown good results of the pneumatic spindle's overall theoretical performance the practical application was yet to be undergone.

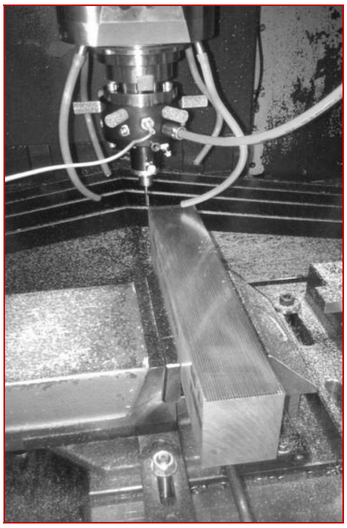

Figure 2: Machine-tool setup for real machining testing

The machine-tool setup for real machining testing is shown in Figure 2. The high-speed pneumatic spindle was clamped in the machine-tool's main spindle. The main spindle was held stopped by its electromagnetic brake. To be able to find out the possibilities of the pneumatic spindle an extreme cutting conditions have been chosen. The tool was a 4 mm flat-end mill with 4 flutes. Material for machining tests was a high durable aluminium alloy (7075) and the cutting conditions can be found in Table 1.

Table 1: Cutting conditions for experimental machining

Tool	Material	Speed	Feedrate	a_z	a_r
4mm flat-end carbide mill	Aluminium Alloy 7075	60 000 rpm	4500 mm/min 0.02 mm/tooth	0.3 mm	1.75 mm

The experiment procedure consisted of machining the whole surface of a large aluminium block (300 x 60 mm) for various cutting conditions. The conditions mentioned here are the most extreme. When we notice the value of feedrate in Table 1, 4500 mm/min is quite high. Thanks to the speed of the spindle we can use such value. If we calculate the feed per tooth (see eq. 1) we get a generally recommended value:

$$ft = \frac{f_{min}}{4n_n} = \frac{4500}{4 * 60000} \approx 0.02 \text{ mm/tooth} \quad (1)$$

where:

f_t	feed per 1 tooth of the tool	[mm/tooth]
f_{min}	feed per minute	[mm.min^{-1}]
n_n	nominal speed	[RPM]

The exceptionally high value of feedrate has to be taken into account because in some cases we might reach a limit of an ordinary machine-tool. In our case we used a 3-axis milling center with linear mangetic motors which have the capability of high speed and acceleration.

EVALUATION

The results of machining test can be seen in Figure 3, the upper diagram shows the overall test which took 3 minutes and the lower diagram is a magnification of a certain part of the record to be able to distinguish speed behaviour clearly. We can notice a drop of speed when the cutting tool enters the material. This drop is about 2.5% which can be considered negligible.

The experiments have proven the spindle to be capable of handling machining processes with relatively large tools applying high performance cutting conditions.

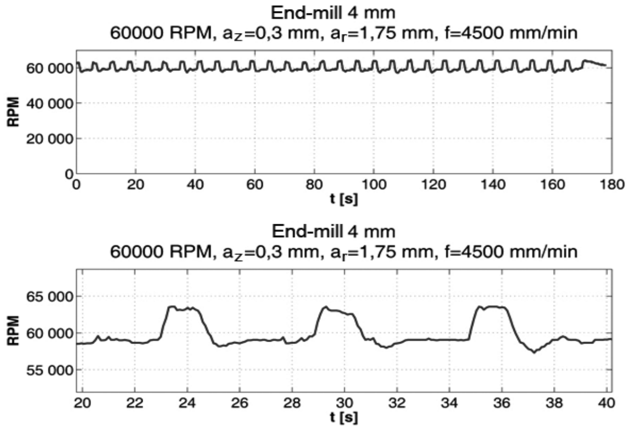

Figure 3: Machining test results

PRACTICAL APPLICATIONS

There have been many practical applications for the university's purposes and for industrial companies already performed using the high-speed pneumatic spindle. A selection of these applications is mentioned further in this paper.

Radial Turbines, Radial Air Distributors

The turbines and distributors have been produced in RCMT on a vertical milling center using the pneumatic high-speed spindle instead of the ordinary machine-tool's spindle.

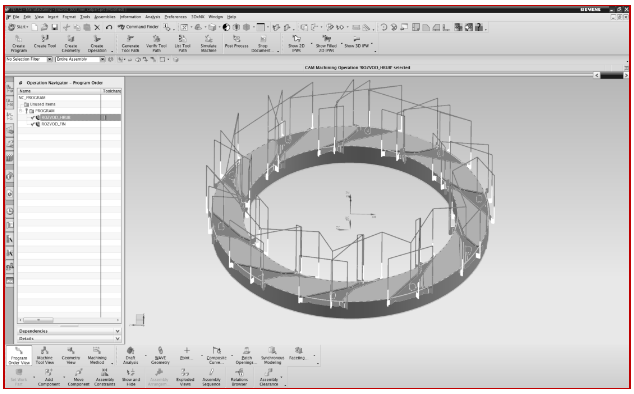

Figure 4. The turbines and distributors

Figure 5: Production of radial air turbine and distributor

Table 3: Cutting conditions for turbines and distributors machining

Tool	Material	Speed	Feedrate	a_z	a_r
1mm flat-end carbide mill	Aluminium Alloy 7075	60 000 rpm	2400 mm/min 0.02 mm/tooth	0.2 mm	0.35 mm

Both turbines and distributors are to be used in the pneumatic spindle itself. The difference from the current ones is changed design and different pressure and flow characteristics.

If we compare machining time for 1 mm 2 tooth end-mill when using a regular machining spindle and the high-speed pneumatic spindle we can easily conclude the following relation for a 10 000 RPM regular spindle:

$$f_{min} = f_t * n * 2 = 0.02 * 10000 * 2 = 400 \text{ mm/min} \quad (2)$$

Now let's compare the feedrate applied for pneumatic spindle in Table 3 which is 2400 mm/min and the feedrate for regular spindle from (2) which equals 400 mm/min. Clearly the difference is a multiple of 6.

The machining time for a turbine was 7 minutes with the pneumatic spindle. It means that a regular spindle would take 42 minutes to manufacture the same part.

Deep Groove

A challenging practical application has arisen on demand of a Czech machine-tools builder. They were seeking for a method to replace electro-erosion technology with a faster process. The task was to produce a slot which is 0.8 mm in width and 8 mm deep. We had the opportunity to put our high-speed pneumatic spindle to test in this application.

A machine tool setup can be seen in Figure 6 on the left. Due to the length of the tool which was 10xD we had to use cutting conditions according to increased fragility of the tool.

Table 4: Cutting conditions for machining the deep groove

Tool	Material	Speed	Feedrate	a_z	a_r
0.8 mm flat-end carbide mill, 10xD	Aluminium Alloy 7075	80 000 rpm	1000 mm/min 0.006 mm/tooth	0.05 mm	0.8 mm

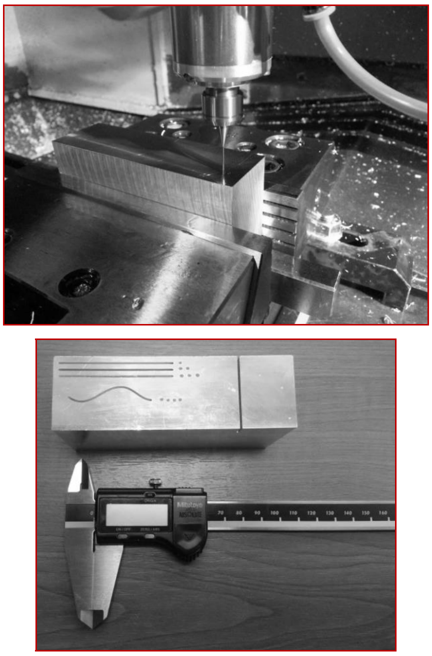

Figure 6: Deep groove. A machine tool setup and the result

The cutting conditions are in Table 4. The final result was very satisfactory. It is pictured in Figure 6. An 80 mm long groove took 8 minutes to produce. Time was a challenge as well. In competition with the electro-erosion the micromachining was about twice as fast.

The production of the grooves has also been tested in the industrial partner's workshop. The tests were very successful. This fact proved the high speed spindle to be very flexible and applicable on wide spectra of machine tools.

CONCLUSION

The high-speed pneumatic spindle has proven its use in a series of experiments and practical applications conducted at university laboratories as well as in real life workshops. There were much more practical applications performed using the spindle. For example there was a raster of micro holes produced for Czech Science Academy. The holes were 0.15 mm in diameter and 0.02 in depth.

There are more experiments and tests to undergo in the future development. At this time there is also a new version of the spindle being prepared.

The increased demand for high speed spindles can be clearly noted in research field. There are both electrical [6, 7] and pneumatic [8] spindles designs. If we take a look at pneumatic spindles there's still a room for improvement especially when we are concerned with speed control. The high speed pneumatic spindle developed at RCMT can fill in this gap and offer a competitive design along with the speed control.

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THE ROBUST CONTROL OF DISTRIBUTED PARAMETER SYSTEMS

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Abstract: This contribution describes dynamic properties of the temperature fields in casting die, as the system with distributed parameters. The dynamics of systems with distributed parameters with lumped-input/distributed-output are solved by finite element numerical method, which is conducted in a COMSOL Multiphysics software environment. In the theoretical part of this work are introduced the basic properties of systems with distributed parameters, IMC controllers and explained the programs, which are applied during this work. The last part of this presented work deals with control of the temperature field in the casting die with robust IMC controllers.
Keywords: modeling, robust control, distributed parameter systems

INTRODUCTION

In the world wide scale the numerical analysis of the machines and casting processes are highly used. The performed numerical software environments such as MATLAB, COMSOL Multiphysics and others take place nowadays.

The aim of these numerical analysis to investigate technological and production processes as a dynamic systems, involved in the prescribed definition domain, to secure maximum productivity, without distortion under the highest outside and inside quality in the means of lower costs. The main core of these numerical analysis is to find the solution for the nonlinear partial differential equations tasks located on geometrical complex space definition domain.

From the system and control theory point of view, distributed parameter systems (DPS) here are involved. Acquired dynamic characteristics could define and resolve the controlling tasks of these distributed systems, what open new possibilities of technical innovations, new design approaches by the creation of new technologies in the matter of machines construction.

DPS CONTROL LOOP WITH IMC CONTROLLERS

A robust control system for LDS can be designed, for example using the Internal Model Control (IMC) structure see Figure 1, [1]. This well-known structure is incorporated into the time synthesis (TS) block of DPS feedback control system, see Fig. 2. The relation between feedback controller R and IMC controller Q for the nominal model of the system $\tilde{S}$ is prescribed by the formula:

$$Q = \frac{R}{1+\tilde{S}\,R}\,; \qquad R = \frac{Q}{1-\tilde{S}\,Q} \tag{1}$$

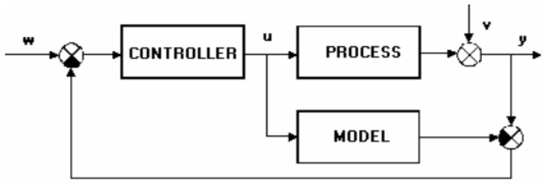

Figure 1 . Internal model control structure

The use of IMC structure at the DPS controling synthesis is interesting in the way of good control loop stability, dynamic response and robustness. Many practical design approaches of IMC controlers has been developed. These approaches further describe how to transform them into the classical feedback controllers, respect with the *aplication to the different class of dynamic systems, including DPS [2],[3].*

The structure of the control loop DPS based on IMC is depicted on the Figure 2.

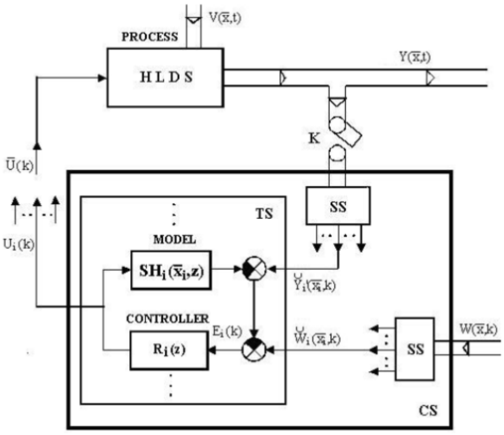

Figure 2. Distributed parameter feedback robust control system

In the continued section, the design method on the control loops with IMC structure in the time control synthesis block of IMC $Q_i^*(z)$ controllers is presented. As a nominal transfer functions, representing the process model, are in the particular control loops considered the identified transfer functions $\{SH_i(\bar{x}_i,z)\}_{i=1,n}$.

H_2 optimal controllers $Q_i^*(z)$ for the input $\breve{W}_i(k)$ in the form of step function $\gamma^*(z)=\dfrac{z}{z-1}$ are defined by minimization the criterion:

$$\min_{Q_i^*(z)}\left\| E_i(\bar{x}_i,z)\right\|_2=\min_{Q_i^*(z)}\left\|\left(1-SH_i(\bar{x}_i,z)Q_i^*(z)\right)\gamma^*(z)\right\|_2 \quad (1.1)$$

Discrete IMC controller $Q_i^*(z)$ is then in the form:

$$Q_i^*(z)=SH_{iM}(\bar{x}_i,z)^{-1} \quad (1.2)$$

Final result of the discrete IMC controller $Q_{iF}^*(z)$ with the filter is then in the form:

$$Q_{iF}^*(z)=Q_i^*(z)F_i^*(z)=Q_i^*(z)\frac{(1-\alpha_i)}{z-\alpha_i} \quad (1.3)$$

For $SH_i(\bar{x}_i,z)$ = $SH_{iM}(\bar{x}_i,z)$ and discrete filter $F_i^*(z)$ will be $R_i^*(z)$ in the simple feedback control loop of time element synthesis in the discrete form:

$$R_i^*(z)=\frac{SH_{iM}(\bar{x}_i,z)^{-1}F_i^*(z)}{1-SH_i(\bar{x}_i,z)SH_{iM}(\bar{x}_i,z)^{-1}F_i^*(z)}=$$

$$=\frac{1}{SH_{iM}(\bar{x}_i,z)}\cdot\frac{F_i^*(z)}{1-F_i^*(z)} \quad (1.4)$$

And then:

$$R_i^*(z)=\frac{1}{SH_{iM}(\bar{x}_i,z)}\cdot\frac{1-\alpha_i}{z-1} \quad (1.5)$$

We establish the filter parameters α_i by solving the optimization problem, in order to accomplish the robust stability and robust performance conditions.

MODELING OF TEMPERATURE FIELDS IN CASTING DIE

A significant software tool for numerical modeling based on finite element method (FEM) is the COMSOL Multiphysics environment. The casting die is one of the critical factors affecting on result quality of the cast as a product, mainly from the view of the die distributed temperature thermal filed. For the thermal fields analyze purposes in the die body the thermal modeling of the casting die field in the COMSOL Multiphysics environment was performed. Layout diagram of heating elements, cooling bodies, and thermocouples in the lower part of the mould is shown in Figure 3.

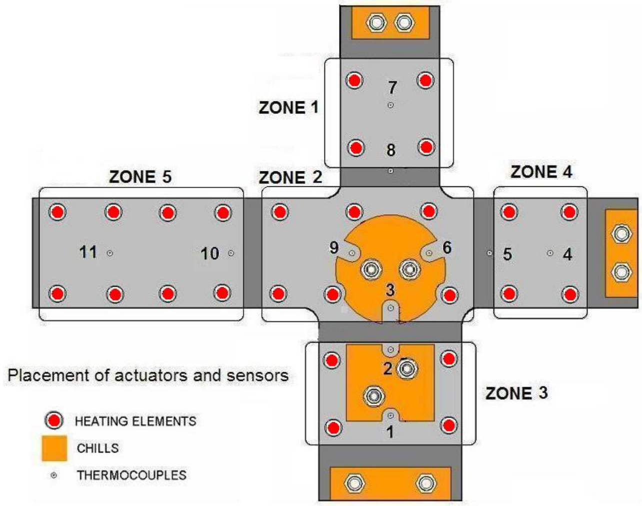

Figure 3. Bottom side of the steel casting mould

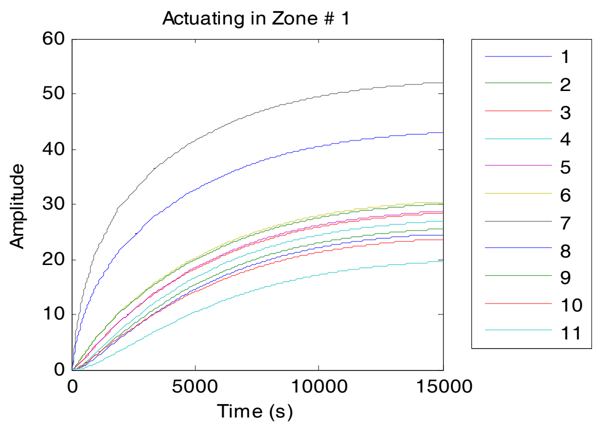

Figure 4. Temperature courses at given points of the mould

3D geometry of the casting die model was modeled in CAD environment and after that imported to COMSOL Multiphysics. PDR parameters, boundary condition specifications, heat sources at individual zones, FEM conditions, plot results and many other result animations performed by GUI were set in the menu Physics, Mesh, Solve, Postprocessing, File and so on. Temperature fields were analyzed in 11-points where thermocouples are placed in molds physical model. Temperatures of FEM modeling are obtained in the above 11-points are shown in Figure 4.

CONTROL OF TEMPERATURE FIELDS IN CASTING DIE WITH IMC CONTROLLERS

For the zone heating in casting die as DPS, the feedback control loops circuit with 5 time-discrete robust controllers $\left\{R_i^*(z)\right\}_{i=1,5}$ with blocks of DPS Blockset , [4], [5] was created, Figure 5.

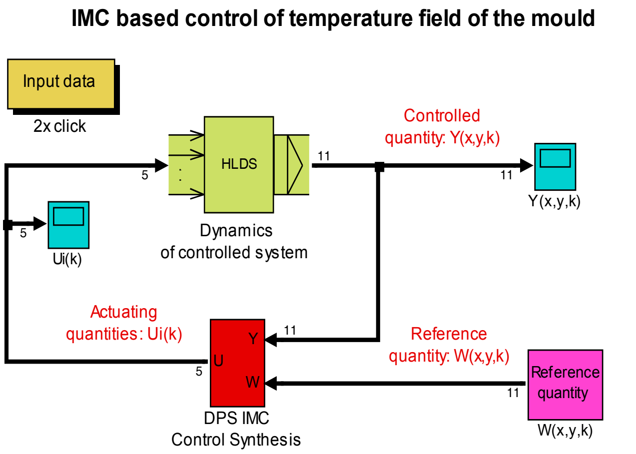

Figure 5. Feedback control loop of the casting die preheating simulation in DPS Blockset

Approximation result for 5 DPS control loops are the approximation coefficients of distributed output quantity and distributed reference quantity $\left\{\breve{Y}_i(k)\right\}_{i=1,5}$, $\left\{\breve{W}_i(k)\right\}_{i=1,5}$. Their difference $\breve{E}_i(k)=\breve{W}_i(k)-\breve{Y}_i(k)$ input into the time control synthesis component block as a control error.

Time variation of quadratic norm of distributed control error $\left\|E(\bar{x},k)\right\|$ is total data of control quality, not in the space dependency $\bar{x}$, but also in the time dependency k, what can be used by the quadratic function formulation for the parameters optimization of controllers for DPS control.

$$J=\min_{\alpha_i}\sum_{k=0}^{N}\left\|W(\bar{x},k)-Y(\bar{x},k)\right\| \tag{3}$$

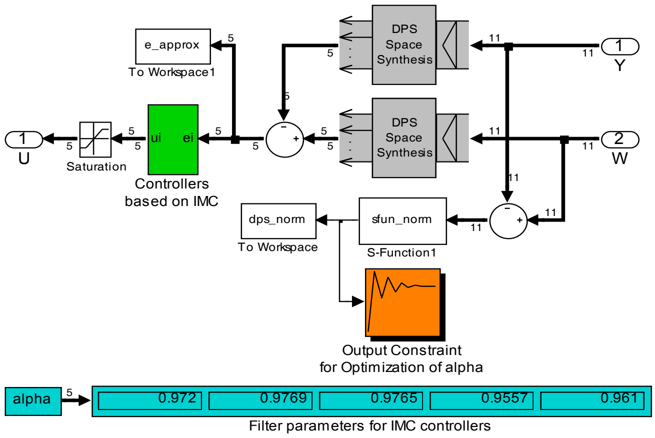

Figure 6. Structure of IMC controlling synthesis block of DPS

Simulation results of the control process for distributed reference quantity W are depicted on Figure 7 and Figure 8.

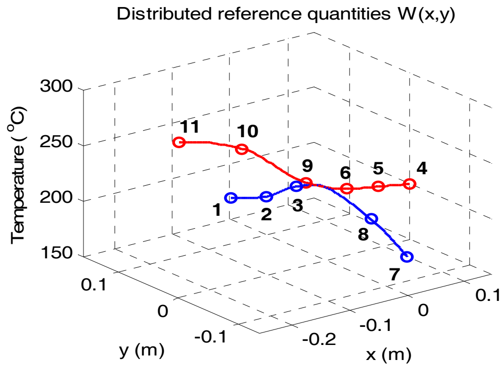

Figure 7. Distributed reference quantity

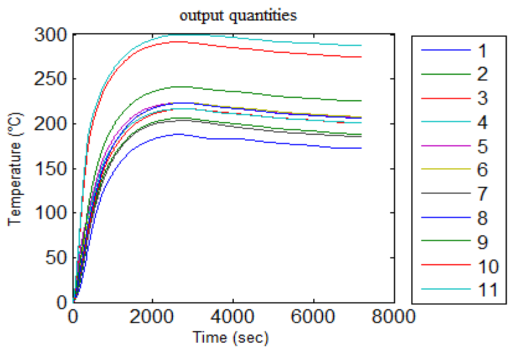

Figure 8. Output quantities in the points 1-11

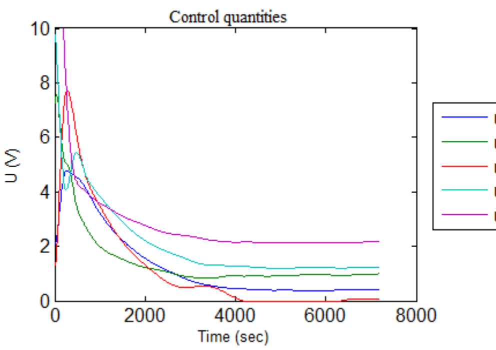

Figure 9. Control quantities in the zones 1-5

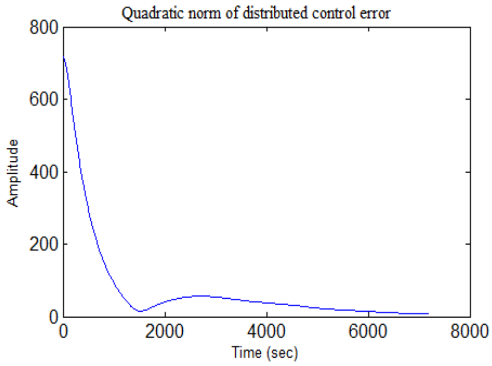

Figure 10. Quadratic norm of distributed control error

4. CONCLUSION

In this paper, the problems of the proposal was robust controllers for robust control mould temperature field as a system with distributed parameters. Next, we examined the proposal robust control based on IMC control structure of the control loop. Identified continuous and discrete transfer functions of temperature fields obtained FEM modeling in COMSOL Multiphysics were exported to MATLAB & Simulink to determine distributed and lumped models. The presented methodology of robust control DPS-based LDS reflecting the uncertainty of dynamic models in time synthesis domain and space synthesis domain.

ACKNOWLEDGMENT

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FLOWER PURCHASE BEHAVIOUR IN HUNGARY IN 2013

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Abstract: A quantitative survey was conducted to find up-to-date information about today's dry flower purchasing behaviour in Hungary. 130 questionnaires were filled in Kecskemet and in Hortus Hungaricus flower exhibition in Budapest. The data was analyzed by SPSS 11.5 statistical package program. Frequencies and cross tabs were calculated. Multivariate statistics (factor, correspondence analysis) were applied to find latent variables. ANOVA model revealed significant statistic differences. The questionnaires were filled mostly by women. The age and income were evenly distributed in the sample. Another goal of our research was to deep interview wholesaler and retailers. In the conclusions practical management suggestions are provided to both wholesalers and retailers, small and big shops alike. Up to date catalogues, direct marketing, wide choice are the key issues that retailers should consider.
Keywords: dry flower, consumer behaviour, questionnaire, SPSS, deep interview

INTRODUCTION

Short-cut flowers can provide fleeting pleasure of the flower lovers, but dried plants can play aesthetic pleasure too (Lévai et al., 2012/a). Dried flowers, crops have always been present in Hungary. They were used mostly in medication in different ways. In particular medicine, they are used in different ways (Levai, 2004). Special drying plants for home decoration are also used. People in the past always collected plants and flowers, leaves for home-made healing. In the 1960s the number of pharmacies and herbarium pharmacies increased thus the interest in dried flowers decreased. In the 70s national dry flower centres were formed in Szeged, Kecskemét, Pannonhalma and the town of Gyor (Wenszky, 1993).

More goods are produced in Hungary that is being sold abroad. Today, dry flower became fashionable in the decorations. Dry flower makes the environment more friendly and enjoyable. They are not only durable, but fewer problems occur. Natural flowers often have to be replaced.

Today the Netherlands and tropical Asian countries affect commercial supply of dry flower (Lévai et al.,2012/b). In Hungary, in the last 10 to 15 years dry flower varieties have been completely changed according to the supply. Many companies are specialised in dry flower growing and a special market for them has been formed. The demand for dry flower varieties varies from year to year, according to the fashion (Horváth, 2001). The currently dominant fashion of clothes colour is reflected the flower colours as well.

In this article we assessed dry flower purchasing behaviour in Hungary. We applied a primer research through questionnaires. Also some retailers have been deep interviewed.

MATERIAL AND METHODS

At the end of the questionnaire socio-demographic questions were asked. This helped us analyze data according to sex, income etc.

Figures 1-2 show describes the socio-demographic composition of the survey. It is important to emphasize that usually results are averages. No specific conclusions can be made from these findings. Therefore it is essential to differentiate the information according to sex, income, place of living etc.

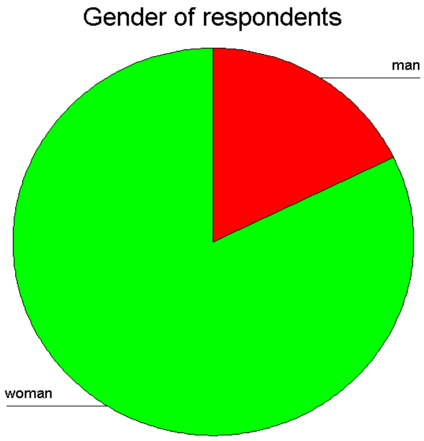

Figure 1: Genders in the sample

According to Figure 1, questions were mostly filled by women. They are – as usual – more willing to answer questions.

The age histogram shows that age was evenly distributed with the exception of the age category of 45-60.

Quantitative survey is the most common practice in domestic market research. Our questionnaire was filled by 130 respondents. The results were differentiated according to socio-demographic criteria (gender, age, education, occupation, place of living and income). The questionnaires were mostly filled by residents of Kecskemét and Szigetszentmiklós Flora Hungarian Wholesale Flower Market.

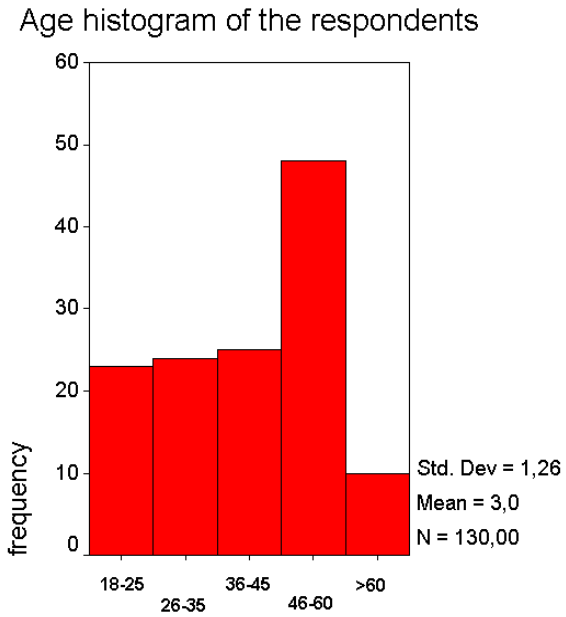

Figure 2. Age distribution in the sample

The answers to written questions received were recorded in the questionnaire. From the data obtained numerical data were created. SPSS ver. 11.5 software was used to evaluate questionnaire data. This statistic package consists of many different statistical models that were made by different independent research institutes. The program package makes it possible to calculate multivariate statistic relations, like factor, cluster, MDS, correspondence, ANOVA and homogeneity analysis. A variety of graphics and charts visualize the information and results.

Questionnaire is the most widely used tool in marketing research. The questionnaire is designed to provide various types of qualified consumers' responses. The questionnaire related to the logical order of questions. Many topics are included. The different types of questions and provide information on a variety of question types. Questions are grouped in different ways, depending on what kind of results you want to get the survey form. The questions should be grouped by purpose and the questionnaire should be appropriate. Frequencies are simple summaries of answer values. It is important to emphasize that these data are average values that include ages, incomes, place of living etc.

In cross tabs values of two variables are shown together. We can see the result data obtained according to another variable. Thus multi-response relationships can be obtained.

RESULT

ANOVA statistical model is used when significant differences are calculated. The program calculates standard deviations and analyzes their correlation.

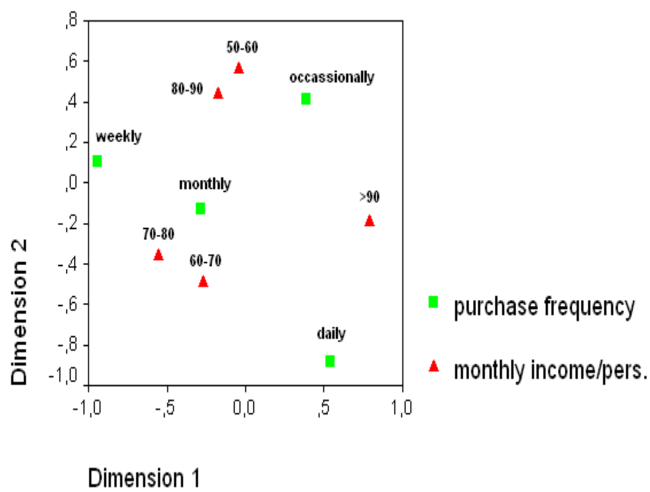

Figure 3.: Correlation between purchase frequencies and net monthly income by applying correspondence analysis

Factor analysis is a multivariate statistics that is used to calculate the correlation between answer values. Latent variables, so called factors were created by the factor correlation coefficients. In this way we can segment the respondents according to their behaviour.

Correspondence analysis model shows the correlation of two variables on a map (Naresh, 2005).

According to Figure 3., purchase frequency is related to monthly income. Interestingly, medium monthly income resulted in the highest purchase frequency.

Factor analysis calculates latent variables from variables of the questionnaire. Thus it creates segments. Members of the segments are homogeneous in their behaviour and completely different from other segments. The factor coefficients are shown in Figure 7. By assessing high coefficient statements (coloured with red), segments can be named. SPSS cannot give name to segments. It is the researcher's task.

In this case 3 segments were separated:

The first segment is called dry flower buyers who were raised in their family who used to buy dry flowers. In the second segment customers are very individual and creative. The like unusual forms and create interesting dry flower compositions. Customers of the third segment prefer fresh cut flowers and potted flowers.

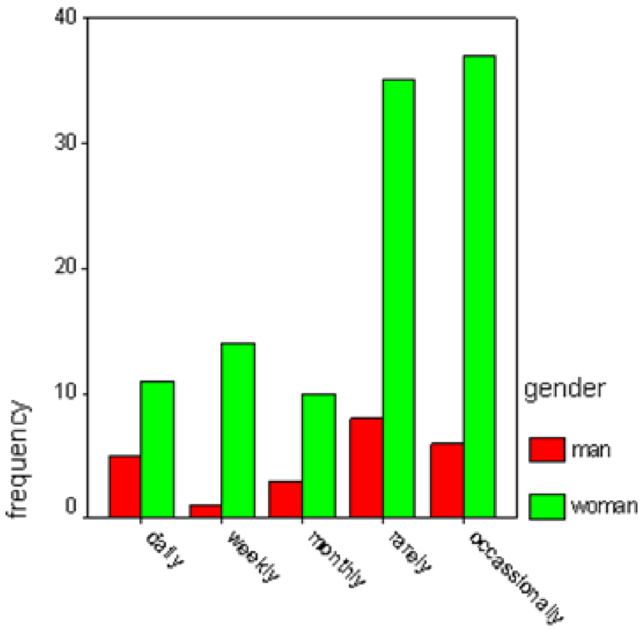

Figure 6.: Frequency of purchase according to gender

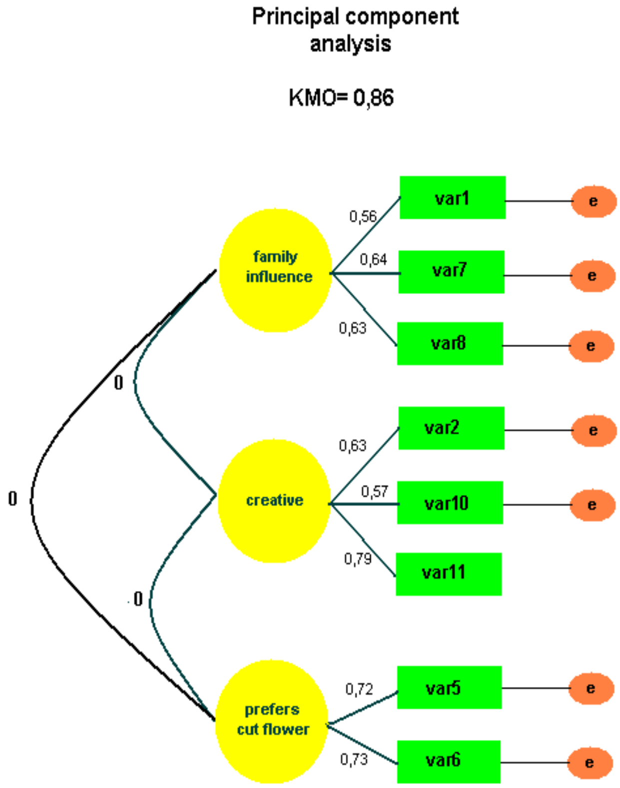

Figure 7: Segmentation by factor analysis

CONCLUSIONS

- *Dry flower is mostly bought by women*
- *Income is not necessary associated with the frequency of purchase. Segments above average net income buy dry flower mostly*
- *There are three segments are outlined in the survey:*
  - a. *family tradition*
  - b. *creative, innovative*
  - c. *prefers cut flower*
- *Respondents can be divided to three groups: family influenced, creative and cut flower buyers*
- *Small flower shops are satisfied with the choice of other flower stores.*
- *The dry flower wholesalers that we examined have a much wider choice of dry flowers (Treerné, 2006).*
- *Virtually each florist is interested in selling dry flower in a reasonable price. They also try to sell the best quality possible.*
- *Florist should sell the newest and most fashionable dry flowers in all colour tints.*
- *Small flower shops sell less dry flowers. They should have small packaging sizes. In this way they can increase their choice.*

- *Bigger flower shops like shrink plaster packaging as it is more economic.*
- *In wholesaling consumers were satisfied with the subordinates. They were attentive, kind and helpful.*
- *Ongoing information needs to be given to customers about discounts, promotions and new products.*
- *The information shall be made by mail or electronic mail.*
- *Up to date catalogue should made to provide adequate information about new dry flowers, crops and supplies.*
- *Direct mail can be an effective way to communicate with potential buyers.*

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COMPARISON OF THE CHARACTERISTICS BETWEEN SERIAL AND PARALLEL ROBOTS

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Abstract: This paper gives survey of the position analysis, jacobian and singularity analysis, stiffness analysis, dynamics and applications of serial and parallel robots. Also a detailed comparison of the characteristics of serial and parallel robots and their advantages and disadvantages are presented.
Keywords: serial robots, parallel robots, comparison

INTRODUCTION - Introduction to robotics

Robotics is a field of modern technology that crosses traditional engineering boundaries. Understanding the complexity of robots and their applications requires knowledge of mechanical engineering, electrical engineering, systems and industrial engineering, computer science, economics, and mathematics.

The term robot was first introduced into vocabulary by the Czech playwright Karel Capek in his 1920 play Rossum's Universal Robots, the word "robota" being the Czech word for work. Since then the term has been applied to a great variety of mechanical devices, such as teleoperators, under-water vehicles, autonomous land rovers, etc. Virtually anything that operates with some degree of autonomy, usually under computer control, has at some point been called a robot.

There are many definitions for what a robot is and this often leads to discrepancies between statistics quoted about robots. An official definition for a robot comes from the Robot Institute of America (RIA): A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

The commonly accepted definition in the UK is that provided by the British Robot Association which is as follows: An industrial robot is a re-programmable device designed to both manipulate and transport parts, tools, or specialised manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks.

The definition of a robot used by the Japanese Industrial Robot Association widens these definitions in order to include arms controlled directly by humans and also fixed sequence manipulators which are not re-programmable.

The key element in the above definitions is the re-programmability of robots. It is the computer brain that gives the robot its utility and adaptability. The so-called robotics revolution is, in fact, part of the larger computer revolution. Even this restricted version of a robot has several features that make it attractive in an industrial environment. Among the advantages often cited in favour of the introduction of robots are decreased labour costs, increased precision and productivity, increased flexibility compared with specialized machines, and more humane working conditions as dull, repetitive, or hazardous jobs are performed by robots.

The robot, as it is defined, was born out with integration of two earlier technologies: teleoperators and numerically controlled milling machines. Teleoperators, or master-slave devices, were developed during the Second World War to handle radioactive materials. Computer numerical control (CNC) was developed because of the high precision required in the machining of certain items, such as components of high performance aircrafts.

The first robots essentially combined the mechanical linkages of the teleoperator with the autonomy and programmability of CNC machines.

The first successful applications of robot manipulators generally involved some sort of material transfer, such as injection moulding or stamping, where the robot merely attends a press to unload and either transfer or stack the finished parts. These first robots could be programmed to execute a sequence of movements, such as moving to a location A, closing a gripper, moving to a location B, etc., but had no external sensor capability. More complex applications, such as welding, grinding, deburring, and assembly require not only more complex motion but also some form of external sensing such as vision, tactile, or force-sensing, due to the increased interaction of the robot with its environment.

It should be pointed out that the important applications of robots are by no means limited to those industrial jobs where the robot is directly replacing a human worker. There are many other applications of robotics in areas where the use of humans is impractical or undesirable. Among these are undersea and planetary exploration, satellite retrieval and repair, the defusing of explosive devices, and work in radioactive environments. Finally, prostheses, such as artificial limbs, are themselves robotic devices requiring methods of analysis and design similar to those of industrial manipulators.

One modern robotics system usually consists of a mechanical manipulator, an end-efector, a microprocessor-based controller, a computer and internal and external sensors/sensing devices (contact or noncontact).

Classification of robots (robotic manipulators)

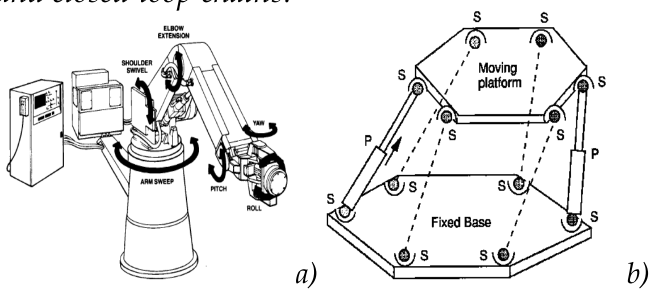
Robots can be classified according various criteria, such as degrees of freedom, kinematic structure, drive technology, workspace geometry, motion characteristics, control.

Degrees of freedom

One obvious classification scheme is to categorize robots according to their degrees of freedom. In ideal case, a manipulator should posses 6 degrees of freedom in order to manipulate an object freely in three-dimensional space. From this point of view, we call a robot a general-purpose robot if it possesses 6 degrees of freedom, a redundant robot if it possesses more than 6 degrees of freedom, and a deficient robot if it possesses less than 6 degrees of freedom

Kinematic structure

Another classification of robots is according to their structural topologies. A robot is said to be a serial robot (fig.1.1 a) or serial (open-loop) manipulator if its kinematic structure takes the form of an open loop-chain, a parallel manipulator (fig.1.1 b) if it is made of a closed-loop chain, and hybrid manipulator if it is consists of both open- and closed-loop chains.



a) b)

Figure 1.1 a) Serial robot (manipulator) b) parallel manipulator

Drive technology

Typically, robots (manipulators) are electrically, hydraulically, or pneumatically driven. Most robots use DC- or AC-servo motors or stepper motors, because they are cleaner, cheaper, quieter and relatively easy to control.

Hydraulic drives have no rival in their speed of response and torque producing capability. Therefore hydraulic robots are used primarily for lifting heavy loads. The drawbacks of hydraulic robots are that they tend to leak hydraulic fluid, require much more peripheral equipment (such as pumps, which require more maintenance), and they are noisy. Pneumatic robots are inexpensive and simple but cannot be controlled precisely, because air is a compressible fluid. As a result, pneumatic robots are limited in their range of applications and popularity.

Workspace geometry

The workspace of a manipulator is defined as the volume of space the end effector can reach. A reachable workspace is the volume of space within which every point can be reached by the end effector in at least one orientation. A dextrous workspace is the volume of space within which *every point can be reached by the end effector in all possible orientations. Dextrous workspace is a subset of the reachable workspace.*

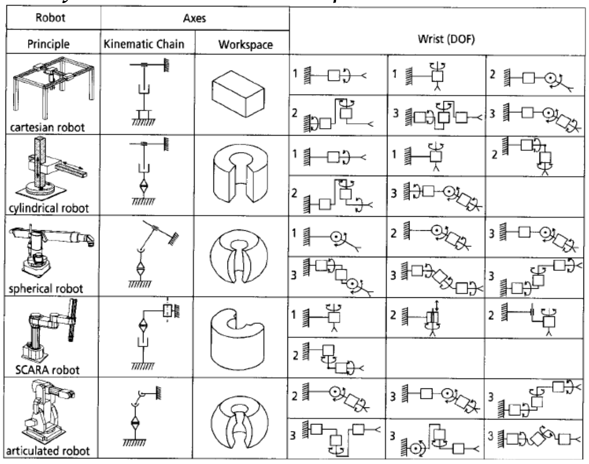


Figure 1.2 Five most common types of robots geometry [5]

Most industrial robots (manipulators) at the present time have six or fewer degrees-of-freedom. These robots are usually classified kinematically on the basis of the first three joints of the arm (R-revolute or P-prismatic) used for manipulating the position, while the rest of joints associated with the wrist are for controlling the orientation.

The majority of these robots (manipulatators) fall into one of five geometric types: Cartesian (PPP), cylindrical (RPP), spherical (RRP), SCARA (selective compliance assembly robot arm) (RRP), articulated (RRR) (fig.1.2). Each of these five manipulator arms are serial link robots. A sixth distinct class of manipulators consists of the so-called parallel robot. In a parallel manipulator, as we mentioned before, the links are arranged in a closed rather than open kinematic chain.

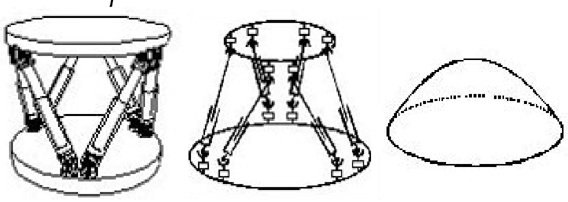


Figure 1.3 Principle, kinematic chain and workspace of parallel robot

Motion characteristics

Robot manipulators can also be classified according to their nature of motion in planar, spherical and spatial.

A manipulator is called a planar manipulator if its mechanism is a planar mechanism (fig.1.4 a). A manipulator is called a spherical manipulator if it is made of a spherical mechanism (fig.1.4 b). A manipulator is called a spatial manipulator if at least one of the moving links in the mechanism possesses a general spatial motion (fig.1.1 b).

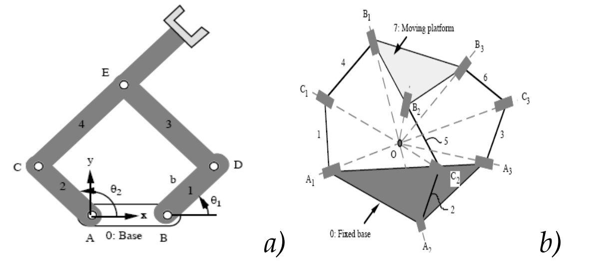


Figure 1.4 a) Planar parallel manipulator) b) spherical parallel manipulator

Control

Robots are classified by control method into servo and non-servo robots.

The earliest robots were non-servo robots. These robots are essentially open-loop devices whose movement is limited to predetermined mechanical stops, and they are useful primarily for materials transfer. In fact, according to the definition given previously, fixed stop robots can hardly qualify as robots.

Servo robots use closed-loop computer control to determine their motion and are thus capable of being truly multifunctional, reprogrammable devices. Servo controlled robots are further classified according to the method that the controller uses to guide the end-effector. The simplest type of robot in this class is the point-to-point robot. A point-to-point robot can be taught with a discrete set of points, but there is no control on the path of the end-effector in between taught points. Such robots are usually taught a series of points with a teach pendant. The points are then stored and played back. Point-to-point robots are severely limited in their range of applications. In continuous path robots, on the other hand, the entire path of the end-effector can be controlled. For example, the robot end-effector can be taught to follow a straight line between two points or even to follow a contour such as a welding seam. In addition, the velocity and/or acceleration of the end-effector can often be controlled. These are the most advanced robots and require the most sophisticated computer controllers and software development.

Accuracy and repeatability

The accuracy of a manipulator is a measure of how close the manipulator can come to a given point within its workspace. Repeatability is a measure of *how close a manipulator can return to a previously taught point.*

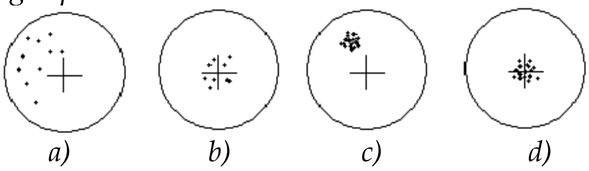


Figure 1.5. a) low accuracy, low repeatability b) high accuracy, low repeatability c) low accuracy, high repeatability d) high accuracy, high repeatability

In this target analogy each dot represents an attempt to get to the central cross. The size of the cluster shows the spread in the result, and the closeness of the centre of the cluster to the cross is measure of accuracy [44].

The primary method of sensing positioning errors in most cases is with position encoders located at the joints, either on the shaft of the motor that actuates the joint or on the joint itself. There is typically no direct measurement of the end-effector position and orientation. One must rely on the assumed geometry of the manipulator and its rigidity to calculate the end-effector position from the measured joint positions. Accuracy is affected therefore by computational errors, machining accuracy in the construction of the manipulator, flexibility effects such as the bending of the links under gravitational and other loads, gear and joint backlash, and an existing of other static and dynamic effects. It is primarily for this reason that robots are designed with extremely high rigidity. Without high rigidity, accuracy can only be improved by some sort of direct sensing of the end-effector position, such as with vision.

Once a point is taught to the manipulator, however, say with a teach pendant, the above effects are taken into account and the proper encoder values necessary to return to the given point are stored by the controlling computer. Repeatability therefore is affected primarily by the controller resolution. Controller resolution means the smallest increment of motion that the controller can sense. The resolution is computed as the total distance traveled by the tip divided by 2^n, where n is the number of bits of encoder accuracy. In this context, linear axes, that is, prismatic joints typically have higher resolution than revolute joints, since the straight line distance traversed by the tip of a linear axis between two points is less than the corresponding arc length traced by the tip of a rotational link. In addition rotational axes usually result in a large amount of kinematic and dynamic coupling among the links with a resultant accumulation of errors and a more difficult control problem. One may wonder then what the advantages of revolute joints are in manipulator design. The answer lies primarily in the increased dexterity and compactness of revolute joint designs. For example, Figure 1.6 shows that for the same range of motion d, a rotational link can be made much smaller than a link with linear motion. Thus manipulators made from revolute joints occupy a smaller working volume than manipulators with linear axes. This increases the ability of the manipulator to work in the same space with other robots, machines, and people. At the same time revolute joint manipulators are better able to manuver around obstacles and have a wider range of possible applications.

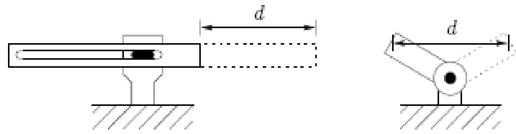


Figure 1.6 Linear vs. rotational link motion.

Accuracy and repeatability are usually of the same order, typically millimetre for very large robots, tenths of millimetre for general purpose robots and hundredths of millimetre for the most accurate assembly robots.

SERIAL ROBOTS - Position analysis

A serial robot consists of several links connected in series by various types of joints, typically revolute and prismatic. One end of the robot is attached to the ground and the other end is free to move in space. The fixed link is called base, and the free end where a gripper or a mechanical hand is attached, the end effector.

For a robot to perform a specific task, the location of the end effector relative to the base should be established first. This is called position analysis problem. There are two types of position analysis problems: direct position or direct kinematics and inverse position or inverse kinematics problems. For direct kinematics, the joint variables are given and the problem is to find the location of the end effector. For inverse kinematics, the location of the end effector is given and the problem is to find the *joint variables necessary to bring end effector to the desired position. For a serial robot direct kinematics is fairly straightforward, whereas inverse kinematics becomes very difficult. For a deficient robot the end efector can not be positioned freely in space, and for the redundant robot there may be several infinitudes of inverse kinematics solutions corresponding to a given end-effector location, depending on the degrees of redundancy. In solving the inverse kinematics problem, we are often interested in obtaining a closed-form solution, that is, in reducing the problem to an algebraic eqution relating the end-effector location to a single joint variable. In this way, all possible solutions and manipulator postures can be accounted for.*

To achieve this goal, various methods of formulation have been proposed: vector algebra method, geometric method, 4x4 matrix method (Denavit-Hartenberg), 3x3 dual matrix method, iterative method, screw algebra method and quarternian algebra method [45].

The number of possible inverse kinematics solutions depends on the type and location of a robot manipulator. In general, closed-form solutions can be found for robot manipulators with simple geometry, such as manipulators with three consecutive joint axes intersecting at a common point or three consecutive joint axes parallel to one another. For manipulator of general geometry, the inverse kinematics problem becomes an extremely difficult task.

Two commonly used methods for kinematics analysis of serial robot manipulators are Denavit and Hartenberg's method and the method of successive screw displacements.

Jacobian and singularity analysis

For some applications, such as spray painting (fig. 2.1), it is necessary to move the end effector of the robotic manipulator along some desired paths with prescribed speed. To achieve this goal, the motion of the individual joints must be carefully coordinated. There two types of velocity coordination problems, called direct velocity and inverse velocity problems. For the direct velocity problem, the input joint rates are given and the objective is to find the velocity state of the end effector. For the inverse velocity problem, the velocity state of the end effector is given, and the input joint rates required to produce desired velocity are to be found.

Figure 2.1 Spray painting robots [57]

Vector space spanned by the joint variables is called joint space, and the vector space spanned by the end-effector location, the end-effector space. For robot manipulators, the Jacobian matrix, or simply Jacobian, is defined as the matrix that transforms the joint rates in the actuator space to velocity state in the end effector state. The Jacobaian matrix is a critical component for generating trajectories of prescribed geometry in the end effector-space. Most coordination algorithms used by industrial robots avoid numerical inversion of the Jacobain matrix by deriving analytical inverse solutions on an ad hoc basis. Therefore, it is important that efficient algorithm be developed.

Since the velocity state of the end-effecor can be defined in various ways, a variety of Jacobian matrices and consequently, different methods of formulation have appeared in the literature. The most frequently used in practice are a conventional Jacobian and screw-based Jacobian [45].

For a serial robot solving direct velocity problem is relatively easy, whereas inverse velocity problem becomes very difficult, especially for robots of general geometry.

The Jacobian matrix is also useful in other applications. For some manipulator configurations, the Jacobian matrix may lose its full rank. Such conditions are called singular conditions or singular configurations. Physically this implies that the instantaneous screws spanning the n-dimensional space of the Jacobian matrix became linearly dependent. Therefore, at a singular condition, a serial robot manipulator may lose one or more degrees of freedom, and it will not be able to move in some directions in the end-effector space.

Singularity configurations can found by setting the determinant of the Jacobian matrix to zero. In *general, this will result in a single algebraic equation. For serial robot manipulators, the singular condition is a function of the intermediate joint variables, not of the first and the last joint variables. This is because the presence of the singularity depends solely on the relative locations of the joint axes. Rotations of the entire manipulator about the first axis not change the relative locations of the joint axes. Similarly, rotation of the end effector about the last joint axis does not affect the location of any joint axis. Therefore, the first and the last joint variables do not appear in the determinant of Jacobian matrix.*

There two types of singularities for a serial robot manipulator: boundary singularity and interior singularity. A boundary singularity occurs when the end effector is on the surface of the workspace boundary, and it usually happens when the manipulator is either in a fully stretched-out or a folded-back configuration. Boundary singularity can also occur when one of its actuators reaches its mechanical limit. An interior singularity occurs inside the workspace boundary. Several conditions may lead to an interior singularity. For example, when two or more joint axes line up on a straight line, the effects of a rotation about one joint axis can be cancelled by counterrotation about another joint axis. Thus the end effector remains stationary even though the intermediate links of the robot manipulator may move in space. Another example of interior singularity occurs when four revolute joint axes are parallel to one another or intersect in common point.. For a manipulator of general geometry, the problem of identifying interior singularities becomes a much more complex problem. Basically, an interior singularity occurs whenever the screws of two or more joint axes become linearly dependent. Boundary singularities are not particularly serious, since they can always be avoided by arranging the task of manipulation far away from the workspace boundary. Interior singularity is more troublesome because it is more difficult to predict during the path planning process.

Stiffness analysis of serial robots

When a robot manipulator performs a given task, the end effector exerts some force and/or moment on its environment. This contact force and/or moment will cause the end effector to be deflected away from its desired location. Intuitively, the amount of deflection is a function of the applied force and the stiffness of the manipulator. Thus the stiffness of a robot manipulator has a direct impact on the position accuracy. Furthermore some advanced control strategies use the stiffness characteristics for feedback control of a robot manipulator.

The overall stiffness of a robot manipulator depends on several factors, including the size of and material used for the links, the mechanical transmission mechanisms, the actuators and the controller. As the links become longer and more slender. Link compliance becomes the major source of deflection. This is particularly true for space robots, for which light weight and compactness are the major concern. (fig. 2.2)

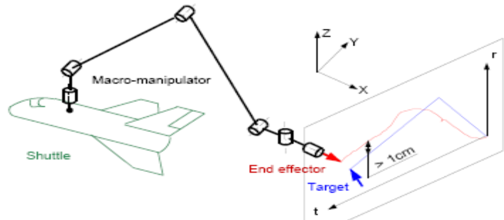


Figure 2.2. Serial space robotic manipulator [1]

Most of the modern serial industrial robots are constructed with fairly rigid links, and the major sources of compliances come from the mechanical transmission mechanisms and control system.

For a serial robot manipulator, each joint is typically driven by an actuator through a multiple-stage speed reducer along several drive shafts. The speed reducer and the drive shafts may deflect when torque or force is transmitted. Further, the drive torque or force generated by a servo system usually depends on the position and error signals and its feedback gains. The stiffness of the speed reducer, the drive shafts, and the servo system may be combined into an equivalent stiffness.

Dynamics of serial robots

For some applications, such as arc welding, (fig.2.3), it is necessary to move the end effector of manipulator from point to point rapidly.

The dynamics of the robot manipulator plays an important role in achieving such high-speed performance. The development of dynamical model is important in several ways. First, a dynamical model can be used for computer simulation of a *robotic system. By examining the behaviour of the model under various operating conditions, it is possible to predict how a robotic system will behave when it is built. Various automation tasks can be examined without the need of real system. Second, it can be used for the development of suitable control strategies. A sophisticated controller requires the use of a realistic dynamical model to achieve optimal performance under high-speed operations. Some control schemes rely directly on a dynamic model to compute actuator torques required to follow a desired trajectory. Third, the dynamic analysis of the manipulator reveals all the joint reaction forces (and moments) needed for the design and sizing of links, bearings and actuators.*

There are two types of dynamical problems: direct dynamics and inverse dynamics. The direct dynamic problem is to find the response of a robot arm corresponding to some applied torques and/or forces. That is, given a vector of joint torques or forces, we wish to compute the resulting motion of the robot manipulator as a function of time. The inverse dynamic problem is to find the actuator torques and/or forces required to generate a desired trajectory of the manipulator. The problem can be formulated in joint space, or the end effector space. The two formulations are related by the Jacobian matrix and its time derivative. In general, the efficiency of computation for direct dynamics is not as critical since it is used primarily for computer simulations of a manipulator. On the other hand an efficient inverse dynamical model becomes extremely important for real-time feedforward control of a robot manipulator.

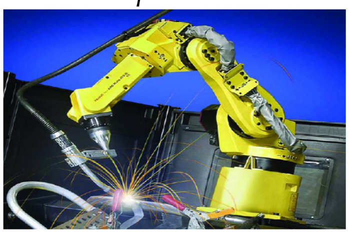


Figure 2.3. Arc welding robot [57]

The dynamical equations of motions can be formulated by several methods. The most frequently used are the application of the Newton and Euler laws and the Langranges's equations of motion.

Applications of serial robots

Robots, basically serial robots, are used in applications that require repetitive tasks over long periods of time, operations in hazardous environments (like nuclear radiation, under water, space exploration, etc.), and precision work with high degree of reliability. They can also be used by handicapped persons to overcome some of their physical disabilities.

Some examples of use of industrial robots are following: machine loading and unloading (fig 2.4), palletizing, die casting, forging, press work, arc welding and spot welding (fig.2.5), heat treatment, spraying (paint, enamel, epoxy resin and other coatings), deburring, grinding, polishing, injection moulding, cutting (laser, plasma), inspection, assembly (fig.2.6), packaging (fig.2.7), material handling (fig.2.8), etc.

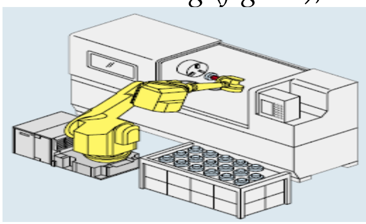


Figure 2.4 Robot application in machine loading and unloading [56]

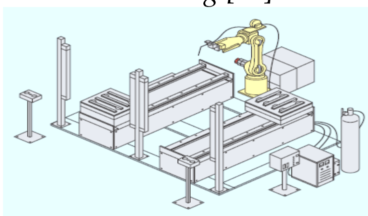


Figure 2.5. Application of robot in welding process [56]

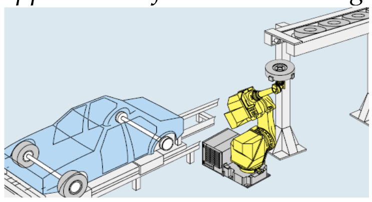


Figure 2.6 Robot application in assembly [56]

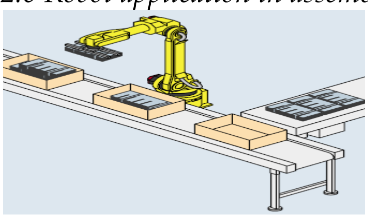


Figure 2.7 Application of robot in packaging [56]

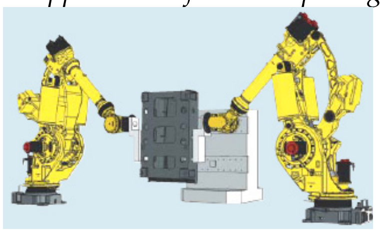


Figure 2.8 Application of two robots in handling heavy objects (materials) [56]

According to the International Federation of Robotics (IFR) of all installed industrial robots, approximately 33% are in assembly, 25% are used in different welding applications, 2,8% in packaging/palletizing, but with intention to grow-up, etc.

Main characteristics of the serial robots are given in the table below:

Table 2.1. Characteristics of serial robots

Feature	Serial robot
Workspace	Large
Solving forward kinematics	Easy
Solving inverse kinematics	Difficult
Position error	Accumulates
Force error	Averages
Maximum force	Limited by minimum actuator force
Stiffness	Low
Dynamics characteristics	Poor, especially with increasing the size
Modelling and solving dynamics	Relatively simple
Inertia	Large
Areas of application	A great number in different areas, especially in industry
Payload/weight ratio	Low
Speed and acceleration	Low
Accuracy	Low
Uniformity of components	Low
Calibration	Relatively simple
Workspace/robot size ratio	High

PARALLEL ROBOTS - Position analysis

A parallel robot manipulator is composed of two or more closed-loop kinematic chains in which the end-effector (mobile platform) is connected to the fixed base platform by at least two independent kinematic chains. Between the base and end-effector platforms are serial chains (called limbs or legs). (fig.3.1)

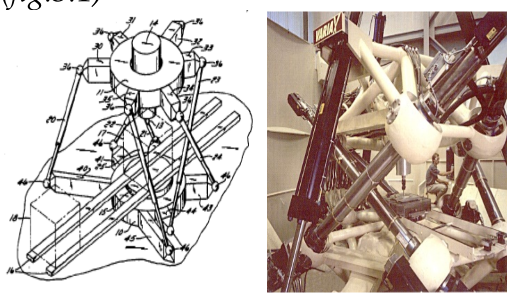


Figure 3.1 Example of parallel robot manipulator, Patent US 5388935: VARIAX machining center, (Courtesy: Giddings & Lewis, Inc., Fond du Lac, WI)

Typically, the number of limbs is equal to the number of degrees of freedom such that every limb is controlled by one actuator and all actuators can be mounted at or near the fixed base. For this reason , parallel manipulators are sometimes called platform manipulators. Because the external load can be shared by the actuators, parallel manipulators tend to have a large load-carrying capacity.

Parallel manipulators have been used in applications like airplane simulators [43], adjustable articulated trusses [40], mining machines [4], pointing devices [22],, walking machines [46], machining centres [20], etc.

The development of parallel manipulators can be dated back to the early 1960's when Gough and Whitehall [23], first devised a six-linear jack system for use as a universal tire testing machine. Later, Stewart [43] developed a platform manipulator for use as an aircraft simulator. Hunt [26] first made a systematic study of the structural kinematics of parallel manipulators.

Since then, parallel manipulators have been studied by numerous researches [45]. More than 100 different mechanical architectures of parallel robots have already been proposed.

Most of the 6-DOF parallel manipulators studied to date consist of six extensible limbs. These parallel manipulators possess the advantages of high stiffness, low inertia and large payload capacity. However, they suffer the problems of relatively small useful workspace, design difficulties and difficult control.

For parallel robot manipulators two position analysis problems have to be solved: direct kinematics and indirect kinematics. A parallel robot indirect kinematics is fairly straightforward, whereas direct kinematics is very difficult problem. Perhaps, the only six limbed 6 DOF parallel manipulators for which closed-form direct kinematics solutions have been reported in the literature are special forms of the Stewart-Gough platform. As to the general Stewart-Gough platform, research has to resort to numerical techniques for the solutions.

Parallel robot manipulators can be classified as planar (fig.3.2 a), spherical (fig. 1.4 b), or spatial (fig.3.2 b) manipulators in accordance with their motion characteristics.

Position analysis of planar and spherical parallel robot manipulators is easier than position analysis *of parallel robot manipulators, or if the spatial manipulator has less than 6 DOF, or if the parallel manipulator is symmetrical.*

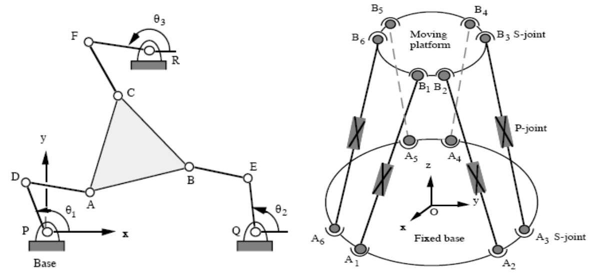


Figure 3.2 a) planar parallel robot manipulator b) spatial parallel robot manipulator

The parallel manipulator is symmetrical if it satisfied the following conditions:

1. The number of limbs is equal to the numbers of degrees of freedom of the moving platform.

2. The type and number of joints in all the limbs are arranged in an identical pattern.

3. The number and location of actuated joints in all the limbs are the same.

When the conditions above are not satisfied, the manipulator is called asymmetrical.

For position analysis (direct and indirect kinematics) for parallel manipulators, both vector and algebraic techniques are used.

Details about position analysis for different types of planar parallel robot manipulators are given by [49, 48, 12, 24] and for different types of spatial parallel robot manipulators [37, 15, 35, 65, 66, 13, 8, 31, 67, 27, 11, 19, 41] etc.

Jacobian and singularity analysis

The Jacobian analysis of parallel manipulators is a much more difficult problem than that of serial manipulators because they are many links that form a number of closed loops.

An important limitation of parallel manipulator is that singular configurations may exist within its workspace where the manipulator gains one or more degrees of freedom and therefore loses its stiffness completely. This property has attracted the attention of several researches. For example, Gosselin & Angeles [21] studied the singularities of closed-loop mechanisms and suggested a separation of the Jacobian matrix into two matrices: one associated with the direct kinematics and the other with the inverse kinematics. Depending on which matrix is singular, a closed-loop mechanism may be at a direct kinematic singular congiguration, an inverse kinematic singular configuration, or both.

The most widely used methods for Jacobian analysis for parallel robot manipulators are the method of velocity vector-loop equations and the method of reciprocal screws.

A parallel manipulator such as VARIAX machining center shown in fig 3.1 typically consists of a moving platform and a fixed base connected by several limbs. This moving platform serves as the end effector. Because of the closed-loop construction, not all joints can be controlled independently. Thus some of the joints are driven by actuators, whereas others are passive. In general, the number of actuated joints should be equal to the number of degrees of freedom of the manipulator.

Let the actuated joint variables be denoted by a vector q and the location of the moving platform be described by vector x. Then the kinematic constrains imposed by limbs can be written in the general form

$$f(x,q)=0 \qquad (3.1)$$

where f is an n-dimensional implicit function of q and x and 0 is n-dimensional zero vector.

Differentiating equation (3.1) with respect to time, we obtain a relationship between the input joint rates and the end-effector output velocity as follows:

$$J_x \dot{x} = J_q \dot{q} \qquad (3.2)$$

where $J_x = \frac{\partial f}{\partial x}$ *and* $J_q = -\frac{\partial f}{\partial q}$

The derivation above leads to two separate Jacobian matrices. Hence the overall Jacobian matrix, J, can be written as,

$$\dot{q} = J \dot{x} \qquad (3.3)$$

where $J = J_q^{-1} J_x$. *Jacobian matrix defined in equation 3.3 for a parallel manipulator corresponds to the inverse Jacobian of a serial manipulator.*

Due to the existence of two Jacobian matrices, a parallel robot manipulator is said to be at singular configuration when either Jx or Jq or both are singular.

An inverse kinematic singularity occurs when the determinant of Jq goes to zero, namely,

$$\det(J_q)=0 \qquad (3.4)$$

When Jq is singular ant the null space of Jq is not empty, there exist some nonzero $\dot{q}$ *vectors that* *result in zero $\dot{x}$ vectors. Infinitesimal motion of the moving platform along certain directions cannot be accomplished. On the other hand, at the inverse kinematic singular configuration, a parallel manipulator can resist forces or moments in some directions with zero actuator forces or torques.*

Inverse kinematic singularities usually occur at the workspace boundary, where different branches of the inverse kinematic solutions converge. It is similar to that of serial manipulator.

A direct kinematic singularity occurs when the determinant Jx is equal to zero, namely

$$\det(Jx)= 0 \qquad (3.5)$$

Assuming that in presence of such a singular condition the null space of Jx is not empty, there exist some nonzero $\dot{x}$ vectors that result in zero $\dot{q}$ vectors. That is, the moving platform cans posses infinitesimal motion in some directions while all actuators are completely locked. Hence the moving platform gains one or more degrees of freedom. This is in contradiction with the serial manipulator, which loses one or more degrees of freedom [47]. In other words, at a direct kinematic singular configuration, the manipulator cannot resist forces or moments in some directions. In those directions the stiffness is zero. Direct kinematic singularities usually occur where different branches of direct kinematic solutions meet.

A combined singularity occurs when the determinants of Jx and Jq are both zero. Generally, this type of singularity can occur only for manipulators with special kinematic architecture. At a combined singular configuration, equation (3.1) will degenerate. The moving platform can undergo some infinitesimal motions while all the actuators are locked. On the other hand, it can also remain stationary while actuators undergo some infinitesimal motions.

Singularity analyses for different types of parallel robot manipulators are presented by [30, 13, 65, 66, 63, 64, 62, 2, 3, 31, 68, 69, 33, 28] etc.

Dynamics of parallel robots

While the kinematic of parallel robot manipulators have been extensively studied during the last two decades, fewer papers can be found on the dynamic of parallel manipulators [45]. The dynamic analysis of parallel manipulators is complicated by the existence of multiple closed loop chains. Several approaches have been proposed, including the Newton-Euler formulation the Langrangian formulation and the principle of virtual work. Details about dynamic modelling of parallel robots are given by [14, 34, 29, 36, 63, 64, 32, 25, 18] etc.

The traditional Newton-Euler formulation requires the equations of motion to be written once for each body of the manipulator, which inevitably leads to a large numbers of equations and results in poor computational efficiency. The Lagrangian formulation eliminates all of the unwanted reaction forces and moments at the outset. It is more efficient than the Newton-Euler formulation. However, because of the numerous constrains imposed by closed loops of a parallel manipulator, deriving explicit equations of motion in terms of a set of independent generalized coordinates becomes a prohibitive task. To simplify the problem additional coordinates along with set of Lagrangian multipliers are often introduced. In some cases, limbs are approximated by point masses by arguing that such approximation does not introduce significant modelling errors. In this regard, the principle of virtual work appears to be the most efficient method of analysis.

Applications of parallel robots

After spending almost 20 years in the laboratories for preliminary studies parallel robots are now used in real-life applications. This interest for parallel robots come from the potentially interesting features of parallel mechanisms: high accuracy, rigidity, speed and large load carrying capability, which in a very large number of cases may overcome the drawbacks of the more complex kinematics, dynamics and smaller workspace.

But a fact is that these advantages are only potential and any real parallel robot will present in practice impressing performances only if all its components (either hardware or software) present a high level of performance.

The current applications of parallel robots are in domains such as fine positioning devices (fig.3.3 and fig.3.4), simulators (fig. 3.5), motion generators (platforms) (fig. 3.6), ultra-fast pick and place robots (fig.3.7), machine-tools (fig. 3.8, fig.3.9 and fig.3.10), medical applications (fig.3.11, fig.3.12), haptic devices (fig.3.13), entertainment, *force sensors, micro-robots (fig. 3.14), articulated trusses, etc.*

Figure 3.3 Application of parallel robots for fine positioning UKIRT (United Kingdom Infrared Telescope), collaboration between Royal Observatory Edinburgh and Max-Planck-Institut für Astronomie Heidelberg [61]

Figure 3.4 Parallel robots for fine positioning [60]

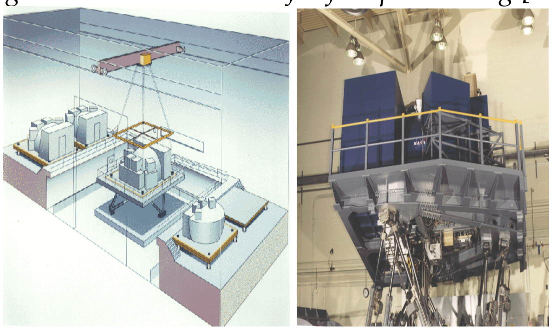


Figure 3.5 Application of parallel robots as simulators NASA LARC-simulator [61]

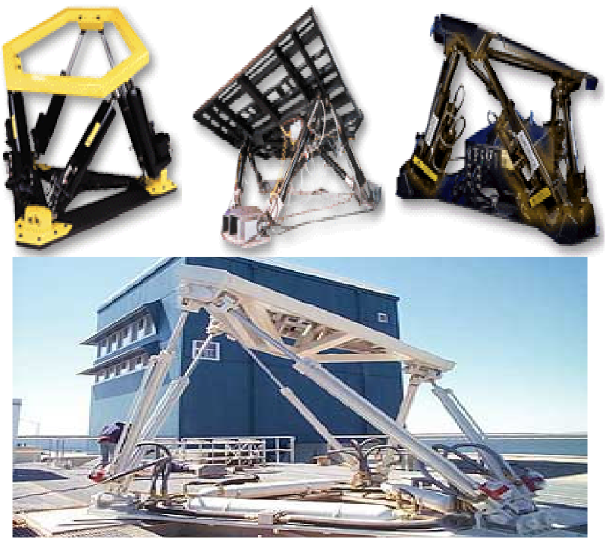


Figure 3.6 Parallel robots as motion platforms [55],[53]

Figure 3.7 Ultra-fast pick and place robot ABB-Flex Picker IRB 340 [50]

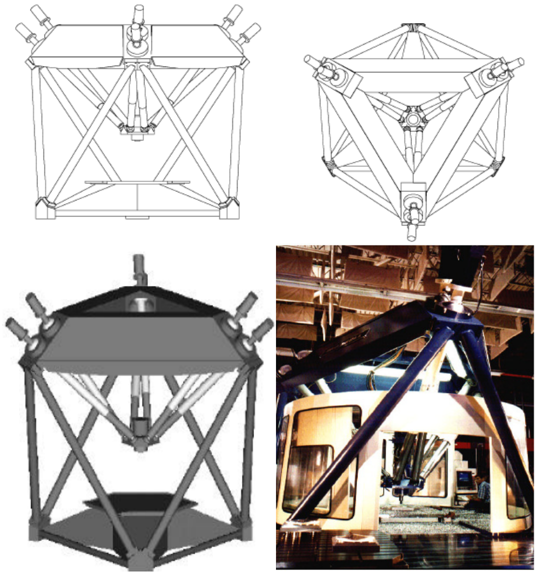


Figure 3.8 Side and top view, solid model and photo of Ingersoll Octahedral Hexapod machine tool installed at NIST [16]

Figure 3.9 Hexapod parallel robot based machine tool [6]

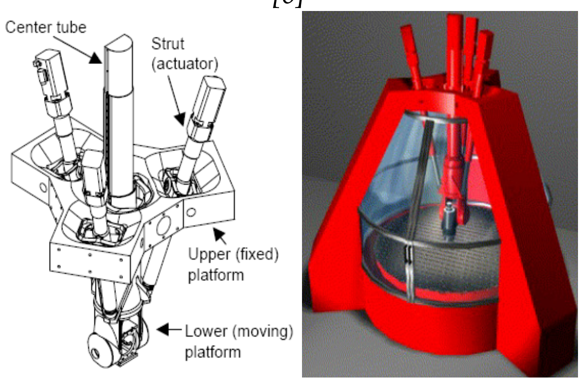


Figure 3.10, Hybrid parallel-serial robot Tricept 805 tripod and a complete machining center [42]

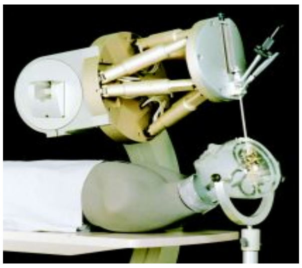


Figure 3.11 Hexapod for brain surgery. Photo courtesy of IPA [59]

Figure 3.12 Parallel robot SurgiScope in action at the Surgical Robotics Lab, Humboldt-University at Berlin (courtesy of Prof. Dr. Tim C. Lueth) [58]

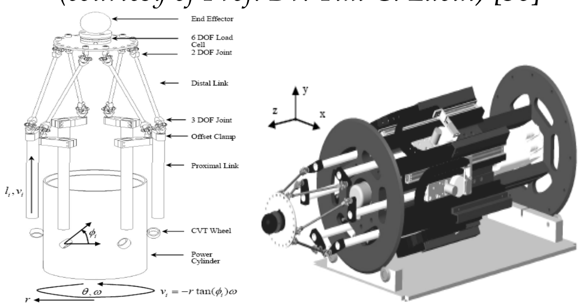


Figure 3.13 Cobotic parallel platform [17]

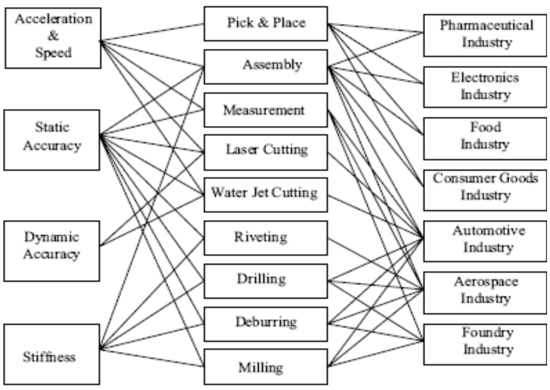
Figure 3.14 Parallel micro robot [52]

But in spite of above given examples and high performance potential of parallel robots, this technology has not yet made a dramatic impact on industrial automation. However, there is an interesting trend towards the use of general purpose industrial serial robots for applications with higher demands on accuracy, stiffness, natural frequency, cycle time etc.

Thus, significant efforts are now being made to use industrial robots for such applications as measurements, laser cutting, laser welding, high precision assembly, grinding, deburring, milling etc. Because of the inefficient robot performance for these applications, several compensation methods are used, which add cost and make installation, programming, maintenance etc., difficult [9].

Moreover, in most cases the industrial serial robots of today probably will never reach the application requirements for high performance applications. One way to solve these problems could be using of robots based on parallel kinematics. But it is not easy to challenge and change the mature industrial robot technology, even if some successful structures find increasing market shares today, too. Parallel kinematic structures provide such high performance potential, but it is very important for the research community to come up with concepts and technologies which will make parallel kinematic robots a natural choice when flexible automation systems are designed.

One example of a successful parallel kinematic robot structure is the Delta structure (fig. 3.7), designed in 80's from Prof. Reymond Clavel (professor at EPFL – École Polytechnique Fédérale de Lausanne). The reason for this success is that the features of this structure fit into applications requiring very fast handling of light weight products, for example in the consumer goods, food and electronics industries. Thus, to be successful with the transfer of results from parallel kinematics robots research to industrial product development, it is very important to understand the application requirements. Morever, it is important to understand what advantages parallel kinematics robots features, provide in potential applications.



Parallel robot features Applications End Users

Figure 3.15 Diagram exemplifying the relations between potential performance features of a parallel kinematic robot and the applications and industries needing this performance for improved flexible automation [9]

For example, parallel kinematic robot structures may give higher speed and acceleration, higher *static and dynamic accuracy and higher stiffness than what is possible with the serial industrial robots used today. Starting with these competitive features, potential applications and end users can be evaluated, like the example diagram given in fig. 3.15. For each application and for each type of installation in the manufacturing plants of the end users, a detailed study is needed to find out if the parallel kinematic robot will satisfy all requirements.*

Several examples of sucessful parallel robots

- ***Delta parallel robot***

It is in the early 80's when Reymond Clavel (professor at EPFL – École Polytechnique Fédérale de Lausanne) comes up with the brilliant idea of using parallelograms to build a parallel robot with three translational and one rotational degree of freedom. Latter called his creation the Delta robot (fig.3.16), without suspecting that at the turn of the century, it will establish itself as one of the most successful parallel robot designs, with several hundreds active robots worldwide.

The basic idea behind the Delta robot design is the use of parallelograms. A parallelogram allows an output link to remain at a fixed orientation with respect to an input link. The use of three such parallelograms restrain completely the orientation of the mobile platform which remains only with three purely translational degrees of freedom. The input links of the three parallelograms are mounted on rotating levers via revolute joints. The revolute joints of the rotating levers are actuated in two different ways: with rotational (DC or AC servo) motors or with linear actuators. Finally, a fourth leg is used to transmit rotary motion from the base to an end-effector mounted on the mobile platform.

The use of base-mounted actuators and low-mass links allows the mobile platform to achieve accelerations of up to 50 G in experimental environments and 12 G in industrial applications. This makes the Delta robot a perfect candidate for pick and place operations of light objects (from 10 gr to 1 kg). Ideally, its workspace is the intersection of three right circular tori. The Delta robots available on the market operate typically in a cylindrical workspace which is 1 m in diameter and 0.2 m high.

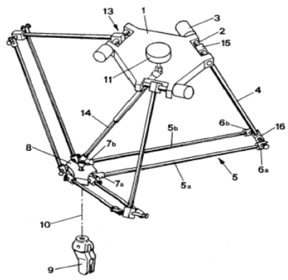


Figure 3.16 Schematic of the Delta robot (from US patent No. 4,976,582) [51]

As simple as it is, the design of the Delta robot is covered by a family of 36 patents of which the most important are the WIPO patent issued on June 18, 1987 (WO 87/03528), the US patent issued on December 11, 1990 (US 4,976,582), and the European patent issued on July 17, 1991 (EP 0 250 470). Overall, these patents protect the invention in USA, Canada, Japan, and most West European countries. The patents do not specify the way in which the Delta structure is actuated in order to incorporate the basic design as well as its variants [7].

The Delta robot is mostly used as a pick-and-place robot (C33 and CE33 Robots, fig.3.17, from SIG pack Systems-from 2004 part of Packaging Technology division of Bosch and IRB 340 Flex Picker Robot from ABB Automation fig. 3.7), although there exist some other applications in medicine (SurgiScope fig.3.12)- and machine tools (Krause & Mauser Group Quickstep 3-axis milling machine is in fact Delta robot with linear motors, fig. 3.18).

The Delta robot was licensed to various companies. In addition, some machine tool manufacturers managed to get their own patents and have built parallel kinematics machines based on the Delta robot architecture.

Figure 3.17 Two of the three Delta robot models offered by SIG Pack Systems, C33 and CE33 (courtesy of SIG Pack Systems-now Bosch Packaging Technology division)

Figure 3.18 The Quickstep 3-axis machining center and Quickstep's kinematic structure [58]

– ***FANUC parallel robot***

Another sucssesful type of parallel robot is F-200iB (fig 3.19) a product of FANUC Robotics North America of Rochester Hills, MI. The F-200iB is a six degrees of freedom servo-driven parallel link robot designed for use in a variety of manufacturing and automotive assembly processes.

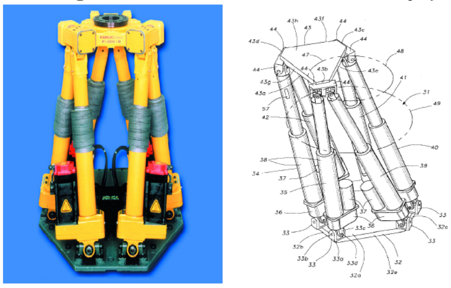


Figure 3.19 A FANUC parallel robot F-200iB [57] (US patent No. 5987726) [51]

The F-200iB is engineered for applications requiring extreme rigidity and exceptional repeatability in a compact, powerful package. F-200iB, the solution for: sub-compact robot welding, pedestal welding, part loading/positioning, nut running, vehicle lift and locate, flexible/convertible fixturing, material removal, dispense. The F-200i is very rigid when compared to serial linked robots. There is less flexing of the arms and high repeatability. With serial linked robots, the end-of-arm flexing errors are cumulative. In a parallel link structure they are averaged. Compared to a serial link machine, this type of robot has a small range of motion due to the configuration of the axes, although it has a broad mix of applications. It has motion speed in vertical z axis 300 (mm/sec), in horizontal x and y axes 1500 (mm/sec) and repeatability ± 0.1(mm).

Other atypical applications for the F-200iB include education, medical and scientific research uses.

– ***TRICEPT robot***

In 1987 a new type of robot, the 3 DOF parallel kinematic robot, was designed and built by Karl-Erik Neumann (fig.3.20). This type of robot has three or more linear axes which function parallel to one another. It has three prismatic actuators which control two rotational and one translational degree of freedom of the mobile platform. A conventional wrist is additionally mounted on the mobile platform (fig.3.21)

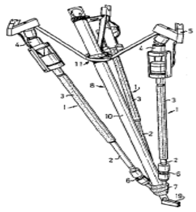


Figure 3.20 3-DOF Parallel kinematic robot Tricept (US Patent No.: US 4,732,525) [51]

Figure 3.21 Parallel kinematic robot Tricept IRB 940 [50]

The initial challenge for this system was that it required computer power that was unavailable at the time. Karl-Erik Neumann, the inventor of the Tricept robot, explains: ''There was no control system to run the machine until 1992 when the company Comau Pico launched the first multiprocessor controller. That, and open architecture, made it so we could adapt its complex kinematics [10].

Neumann founded Neos Robotics in Sweden. Neos Robotics has purchased another Swedish machining company, and strated to go under the name of SMT Tricept. Now SMT Tricept is in a strategic alliance with ABB robotics.

The Tricept robot is the system that greatly influenced the parallel kinematic robot phenomenon. Although initially designed as an assembly robot, the demands from the market transformed it into a machine tool. This market demand led introduction in 1999 of Tricept model 805, a larger version of Tricept. This was developed as a machine tool robot, which combined the flexibility of a robot with the stiffness of a machine tool. The last few years, the biggest application of Tricept is metal cutting. The Tricept can also be used to hold laser and saw cutting tools, as well as friction welders. Customers who use Tricept robots *include automobile makers in Europe and North America: Peugeot, Ford, Renault, Volvo, General Motors, BMW, and Volkswagen. The aerospace industry uses Tricept robots for fabricating propellers, turbine blades, impellers and any other item that requires a considerable amount of contouring. Other applications for the Tricept include assembly with thrust, deburring, polishing, woodworking, water-jet cutting and spot-welding.*

In October 2002 ABB and SMT Tricept launched the last type of an exceptionally powerful and stiff Tricept robot IRB 940 - for heavy-duty cleaning and pre-machining of aluminium parts (vertical machining power of 1300 kg, horizontal machining power of 350 kg, accuracy ± 0.2 mm, and repeatability of ± 0.02 mm).

IRB 940 Tricept is designed to form an integrated part of optimized production lines, teaming up with traditional arm robots and CNC machine tools. Arm robots handle material, machine tending and light cleaning. Tricept robots then take over to do heavy-duty cleaning and pre-machining, while CNC machines put the finishing touches to cleaning and part processing.

Main characteristics of the parallel robots are given in the table below:

Table 3.1. Characteristics of parallel

Feature	Parallel robot
Workspace	Small and complex
Solving forward kinematics	Very difficult
Solving inverse kinematic	Easy
Position error	Averages
Force error	Accumulates
Maximum force	Summation of all actuator forces
Stiffness	High
Dynamics characteristics	Very high
Modelling and solving dynamics	Very complex
Inertia	Small
Areas of application	Currently limited, especially in industry
Payload/weight ratio	High
Speed and acceleration	High
Accuracy	High
Uniformity of components	High
Calibration	Complicated
Workspace/robot size ratio	Low

Comparison of the characteristics of serial and parallel robots

Table below gives comparison between main characteristics of serial and parallel robots:

Table 4.1. Caracteristics of serial and parallel robots

Feature	Serial robot	Parallel robot
Workspace	Large	Small and complex
Solving forward kinematics	Easy	Very difficult
Solving inverse kinematics	Difficult	Easy
Position error	Accumulates	Averages
Force error	Averages	Accumulates
Maximum force	Limited by minimum actuator force	Summation of all actuator forces
Stiffness	Low	High
Dynamics characteristics	Poor, especially with increasing the size	Very high
Modelling and solving dynamics	Relatively simple	Very complex
Inertia	Large	Small
Areas of application	A great number in different areas, especially in industry	Currently limited, especially in industry
Payload/weight ratio	Low	High
Speed and acceleration	Low	High
Accuracy	Low	High
Uniformity of components	Low	High
Calibration	Relatively simple	Complicated
Workspace/robot size ratio	High	Low

CONCLUSION

If we analyse the table 4.1 we will see that the both types of robots have advantages and disadvantages. For example parallel robots offer potential advantages compared with serial, with higher overall stiffness, higher precision, low inertia, and higher operating speeds and accelerations. However these advantages could be easy relativised by reduced workspace, difficult mechanical design, and more complex kinematics and control algorithms.

It is really very difficult to say what kind of robot is better, serial or parallel. A robot selection procedure is very difficult and complex activity. It depends on many different factors like type of application (dangerous, repetitive and boring, precise, etc.), task requirements (DOF, speed, accuracy, repeatability), load requirements, workspace, economic justification, programming time, maintaining, etc.

Parallel robots are most successful in applications like motion simulators, ultra precision positioning devices, medical applications, ultra-fast pick and *place robots and micro-robots. But serial robots dominate almost in all manufacturing applications. Probably this will change with continuously solving of the open problems in parallel robotics given in [38, 39] or using hybrid structures. Hybrid structures are in fact compromise between advantages and disadvantages of both robot structures, serial and parallel. The two most successful manufacturing applications of parallel robots are in fact hybrid structures. First one, Tricept robot is (parallel-serial) structure, 3-axis parallel machine tool-robot plus 2-axis, conventional serial wrist. The second, Sprint Z3 3-axis parallel kinematic tool head by DS Technologie (fig.5.1) that may advance in Z and tilt in all directions, and may be mounted on a conventional XY stage. The machining centre lines ECOSPEED and ECOLINER equipped with the Sprint Z3 tool head are in fact hybrid structures (serial-parallel).*

This two robot structures probably will live parallel a long years. If we compare about 20 years research in parallel mechanisms and more than 200 years in research to reach the current level of knowledge for serial mechanisms, it is easy to conclude that this process of solving problems in parallel robotics will be long term.

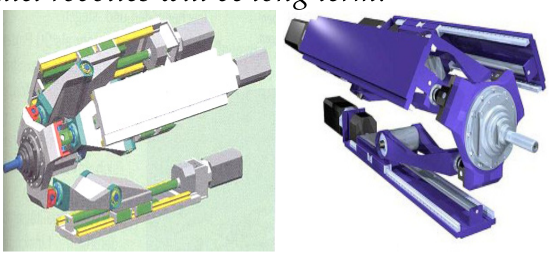


Figure 5.1. Sprint Z3 parallel kinematic tool head [54]

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1. Audun RØNNING SANDERUD, 2. Trygve THOMESSEN

RELEASING THE SYNERGY OF HUMAN-ROBOT COLLABORATION – REDUNDANT ROBOTICS IN PRACTICE

1-2. Productive Programming Methods AS (PPM AS) Trondheim, NORWAY

Abstract: *The later year's evolvement to a more commonly open innovation model [1] have laid a fundament for a rapid growth of Small and Medium Enterprises (SMEs). While large enterprises often have large production lines with low variation, the task for the industrial robot is predictable and highly repetitive, SMEs have more often small batch production with high variation. The SMEs have in the most recent years begun to adopt industrial robots in their production. While SMEs rarely have their own expertise on robotic installation the use has been made possible by more user friendly program editors and remote service and operations. To further enhance the flexibility and overcome the challenges of complex niche production, redundant industrial robots should be introduced to a larger extent. The challenges with redundant industrial robots have so far been the complexity related to solving the inverse kinematics with reasonable secondary tasks. This paper presents advantages of using redundant industrial robots, and aim to motivate more research on user friendly, "easy-to-use" redundancy resolutions for redundant industrial robots.*
Keywords: *Redundant Industrial Robots, Human-Robot Collaboration, Industrial Applications, SMEs*

INTRODUCTION

As an effect of the rise of the SMEs more robotics companies have developed, and started to offer more user-friendly systems, and systems that bring the humans closer to the robot. Rethink Robotics™ have developed the Baxter system [2]. Baxter is a double seven-axes arm, with a fully integrated control system. It can be installed in one hour and does not require any safety installations beyond the built-in safety system. But with only 2.3 kg payload per arm the work is limited to very light operations. ABB have introduced the SafeMove system which is designed to bring the operator closer to the industrial robot [3]. SafeMove operate with zones in which the operator can move safely, and allow a more efficient use of the robot. The robot will automatically slow down as the operator approaches, and go to a full stop if the operator is too close. The SMErobots™ initiative have done extensive research on, and developed systems to simplify both the programming of and safety issues related to industrial robot installations [4]. However, the challenge for many SMEs is still the complexity of the product in low volume series. Processes that involved work pieces with complex geometry that require accurate processing with heavy tools are at best cumbersome to automate and the long term effects of having a human operator do the task may result in serious injuries. A system where the repeatability and strength of the robot is combined with the sensing and flexibility of the human is combined is therefore still longed for. This would require a safety system good enough to have the operator work besides the robot. A sensor system must not only protect the operator but give enough information about what is going on in the robot's environment for it to make a decision on how to configure its arm.

IMPROVING WITH REDUNDANT ROBOTICS

In many applications, there is no need for more than a six-axes robot, as it is sufficient to define any pose of the end-effector in space. The gains of having more than six axes can mostly be attributed to more flexibility in the robot arm configuration referred to as self-motion (Figure 1). In terms of *using a seven-axes robot, it can increase the working space of which the robot is able to operate, i.e. easily grind under a table or picking and placing in more complex environments. This also reduces the environmental space needed for the industrial robot since it can reach further in a complex environment. In addition, by introducing more joints, one can distribute the total joint motion on more joint. This way it is possible to reduce cases where some joints would move considerably more than others.*

The level of redundancy R, defined as R=N-6 where N is the number of available joints, always is a limiting factor when introducing secondary tasks. One should always assign priorities between the primary and secondary tasks to ensure the desired behavior.

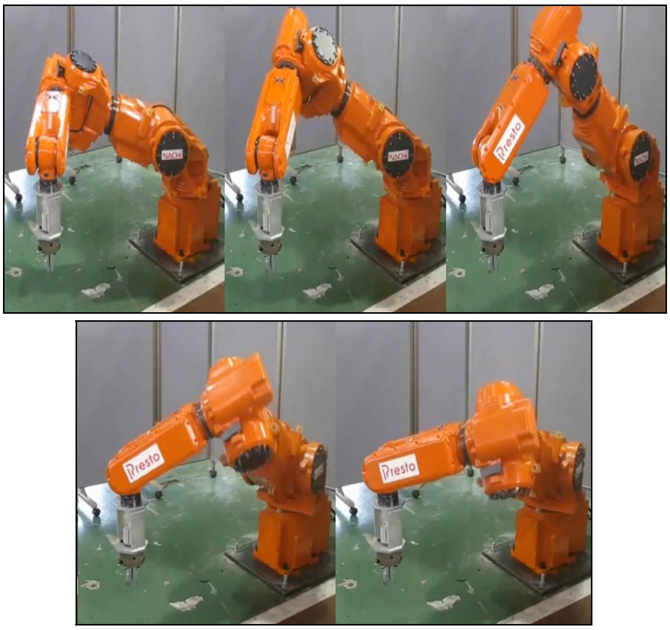

Figure 1. The NACHI MR20 performing self-motion [5].

Human interaction

Human interaction with robots is to some extent in use in the industry today as seen in Figure 2. When an industrial robot is being used as a third hand for a worker, use of a redundant robot will further increase the flexibility of the system. The robot will be able to, for instance, hold a work piece in the same position with several different configurations as it can be seen in Figure 3. This would ease the workers accessibility to the workpiece. This may also reduce the number of required gripping, which in turn reduces time in production.

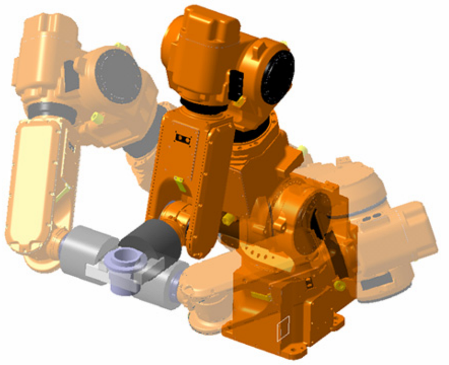

Figure 2. The NACHI MR20 holding the work piece with different configurations [5].

Figure 3. Two workers collaborating and working together with traditional six-axis robots [6] [7].

Process control

Since a redundant robot has more degrees of freedom than it needs to perform its primary task it introduces several new possibilities when it comes to implementation of secondary tasks. Axes can also be transfers from the primary task to increase the capabilities of the secondary task. These may include the following.

- *Obstacle Avoidance: Obstacle avoidance that does not affect the task at hand is simply not possible with only six-degrees of freedom. The redundant robots self-motion ability gives it* *the flexibility it needs to keep the tool stationary while reconfiguring its arm to avoid an obstacle. This allows a redundant robot to reconfigure to reach places unreachable for a six-axis robot as seen in*

- *Singularity Avoidance: The same reasoning may be applied to singularity avoidance as to obstacle avoidance. While jogging, the control system may detect a possible upcoming singularity, and then reconfigure the arm in a fashion so that the robots configuration never reaches its singular pose. With a six axes robot, there simply no way around the singular configuration.*
- *Joint Limit Avoidance: Due to the extra joint the robot is able to select such an arm configuration throughout a predefined path, so that it does not encounter any joint limits. This will leave the robot more robust to unforeseen motion caused by dynamic tasks.*
- *Energy and Torque Optimization: To reduce the energy consumption of the larger joints the smaller joints may be prioritized when using redundant robots. If the robot is performing short-ranged tasks, it may use the smaller and less energy consuming, ones. When moving heavier objects may the larger joints be used more to reduce the torque and stress in the smaller joints, thus prolonging their lifetime. Reducing stress on the smaller joints can also be achieved through keeping the greater component of the reaction forces parallel to the rotation axis of the smaller joints.*

Space efficiency

Redundant industrial robots also have a great advantage when it comes to required space. A robot with seven axes used in a loading system can be placed on the side of the machines door, as opposed to directly in front of it as a traditional six axis robot would require (see Figure 4). This feature reduces the space required in front of the machine and gives easier access for the operator for maintenance and operation. This also reduces the necessary reach for the robot, allowing a smaller robot to be used. According to NACHI, their MR20 seven-axes industrial robot can reduce the requirement for space in front of the machine with 70% [5].

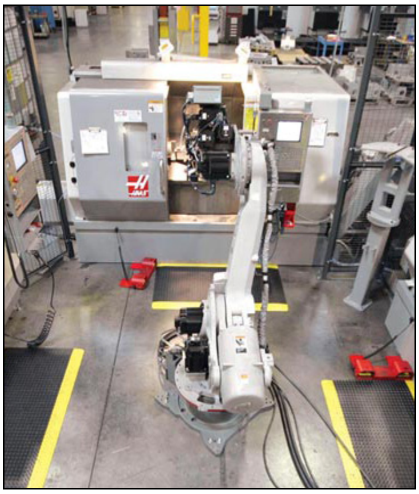

Figure 4. A six axis (left) and a seven axis (right) industrial robot used to load and unload parts [8] [5].

CONCLUSION

There is a definitive trend towards safer and more user-friendly industrial robot systems mainly aimed at SMEs. Most of the available systems are aimed at simplified robot programming and closing the gap between the operator and the robot, targeting a lower threshold for a company to invest in an industrial robot However, more research is required before the necessary equality between human and robot is achieved. To fully exploit the potential in human-robot collaboration redundant robots should be used. This will extend the flexibility and allow the operator to give more focus on the task, rather than the robot.

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LIGHTWEIGHT DESIGN OF VEHICLE BODY A CONTRIBUTION TOWARD GREENER ENVIRONMENT

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Abstract: *The vehicle mass experienced a period of progressive increase. Nowadays as it is essential to decrease both the fuel consumption and the CO_2 production, lightweight design becomes a relevant target for car manufacturer. One of the considered strategy toward lightweight is the substitution of the material used for manufacturing the different parts of the car body. Together with the new developed HSS steels, aluminium and magnesium are considerded. Recently composite material solutions have gained a lot of attention due to their very interesting characteristic. The paper discusses some the relevant aspects when developing a new material solution from the material production to the end-of-life. The paper includes one example of results that can be achieved with properly oriented light weight design procedure.*
Keywords: *lightweight design, car body, HS steel, light alloys, composite materials*

INTRODUCTION

The design of modern cars must meet many requirements in terms of transport performance, comfort, active and passive safety, fuel consumption and costs, quality and reliability, environmental impact and end-of-life destination. To satisfy these goals and to match legislation prescriptions and costumer expectations, continuous evolution of technology and multidisciplinary approach to the design are required. Most of these design aspects intersect each other in a number of even more complicated multidisciplinary views. This complexity asks for anticipation of the design choices at the very beginning of the design process, when the alternatives are explored and compared in order to define the solutions to be implemented in the new vehicle.

Nowadays, one of the main concern about automotive industry is related to the reduction of fuel consumption and exhaust emissions. In the last years, vehicle weight has progressively increased in order to guarantee higher vehicle performance, passenger comfort, safety and emission standards but, on the other hand, this has penalised the fuel consumption and the CO_2 emissions. In Europe as well as in US and in the far east countries governments have decided to force a change in this trends and new generation cars need to ensure lower emission levels. Particular attention is devoted to the Greenhouse Gas (GHG) production as they are considered the main responsible for the climate changes and the progressive world heating.

The EU government has put ambitious reduction targets and lightweight design can give an important contribution to achieve these targets.

The carbon dioxide production is directly related to the fuel consumption of the vehicle because it is a product of combustion chemical reaction. Therefore, taking into account that the combustion efficiency has already reached very high values, the only way to limit the CO_2 production is to decrease the fuel consumption. Even little reductions of the fuel consumption of each car would result in an overall big reduction of CO_2 emissions. A weight reduction of 100 kg, including secondary effects, leads to a reduction in fuel consumption of approximately from 0.3 to 0.5 litres per 100 km. This goes along with a reduction of CO_2 emission *of from 8 to 11 grams per kilometre [1]. If all cars in Europe (210 million vehicles) would save a quarter litres per 100 kilometres, the CO_2 emissions would be reduced by 17,344 million tons each year [2].*

In the last decades of the previous century, the rate of weight increase was steeper (figure 1). This high gradient can be explained by evident market trends toward larger vehicle and engine dimensions as well as higher performance requirements. At the same time, even enhanced vehicle features are responsible for the weight increase. In particular, safety and pollution control subsystems as well as comfort-related subsystems and equipments provide important contributions. The Figure 1 shows the tendency of weight increase for B-segment vehicles over the model years. In 40 years, weight increase is about 700 kg.

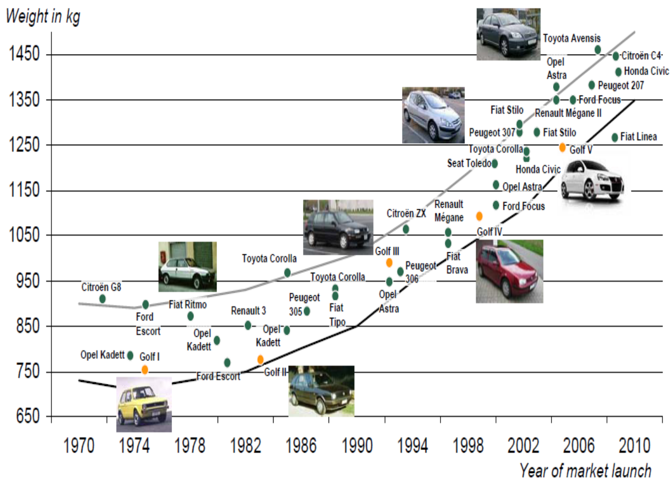

Figure 1. Comparison of curb weight trend of common B-segment vehicles [3]

The vehicle mass (m_F) is the dominant driving-resistance since it is present in three of four parts of the power demand equation (Eq. 1) and thus has direct influence on the fuel consumption. The benefits of weight reduction in this regard become clear by a simple analysis of the power demand P for vehicle riding:

$$P = P_{ac} + P_{cl} + P_{roll} + P_{aer} = \\ (e_i + m_F + m_{Zu}) \cdot a \cdot v + (m_F + m_{Zu}) \cdot g \cdot \sin(\alpha_{St}) \cdot v + \\ (m_F + m_{Zu}) \cdot g \cdot \cos(\alpha_{St}) \cdot f_R \cdot v + 0,5 \cdot \rho_L \cdot c_w \cdot A \cdot (v - v_w)^2 \cdot v \quad (1)$$

Except for the aerodynamic drag resistance, every addend of equation 1 contains the mass of the full vehicle. In city traffic, the drag resistance and climbing resistance contributions are quite low while the acceleration phases are considered to cause up to 40 % of the total fuel consumption.

Specific studies demonstrated that gains in terms of CO_2 emissions can be achieved by acting in particular on lightweight design and by adopting all the strategies and devices that lead to an increment in the internal combustion engine efficiency, in order to pursue the objective values of about 4,7 l/100km in fuel consumption, on the basis of fleet average [4].

A decrease in vehicle weight can be obtained by architectural and structural measures and by the use of alternative materials with better weight-specific properties than conventional mild steel. These two paths of lightweight design cannot be strictly separated, as changes in component material usually requires changes in the component design, too. In the following sections some perspective and results will be briefly presented and discussed for both the above mentioned paths.

TRENDS OF LIGHTWEIGHT MATERIALS FOR CAR BODY CONSTRUCTIONS

The use of unconventional materials offers a vast number of alternatives and at the same time proposes big challenge to designers, which, to meet the various, sometimes contradictory, requirements and goals, must face puzzling problems: new manufacturing technologies for parts production, different assembly methodologies, mounting techniques, compatibility issues, recycling deeds, always paying the attention to a problem of paramount importance: cost. Material costs, design development and prototype testing costs, production costs, tooling costs and whatever operation costs affect the cost of every single vehicle.

A simple evaluation of the advantages of substituting the universally adopted deep drawing mild steel with other materials can be performed by using simple engineering formulas for structural parts behaviour. There are many criteria with which it is possible to rank the material for specific application and target. An efficient practice is to plot one property versus one or more competing properties (for instance Young modulus or strength versus density and cost) to get bi- or tri-dimensional maps [5,6].

A multi material structure is the outcome of the best possible design able to meet the environment and legislation conditions, but also able to mantain the costs at acceptable levels. This problem has been widely studied in a number of EU-Projects, we would like to mention one of these projects: Super Light Car (SLC) with the example of a vehicle of the B-class segment.

The aim of the SLC-Project was the development of lightweight body structures in multi material design, which could be 30% lighter than the actual reference vehicle that is based on a extensive steel construction. This aim was only achieved with the exact evaluation of different material combinations, the development of new designs, simulations methods and joining techniques. In order to obtain in a credible way the evaluation of costs and the sustainability of innovative multi material design, appropriate methods for lightweight vehicles have been used.

The multi disciplinary analysis within the SLC-project deals with the manufacturing of new solutions based on hybrid, multi-material compounds (see figure 2a). The design of these innovative solutions asks also for innovative joining technologies (particularly in the case of multi material design) and innovative manufacturing process [5,8].

The SLC project leaded to a body concept (as shown in figure 2a) with a decrement of 82 kg (about 29% of that of the reference vehicle), with an estimated increment of costs of less than 5 € / kg.

In Figure 2b, it is possible to see paths related to material use for car body concepts, as defined by Audi [7]. The steel unibody is the reference design solution. According to the first path, the evolution of the traditional steel construction will include some innovative production technologies such as roll forming and thin casting technology, which lead to steel spaceframe and stainless steel spaceframe. The aluminium construction is the second path which has already been used for the production of aluminium shell construction and aluminium spaceframe (the typical example is Audi R8, completely made of aluminium with small use of carbon fibre reinforcements). The third path is the plastic material construction, mainly described by use of fibre reinforced plastics which leads to the so-called body-in-black. The mixed construction is considering the multi-material design. As shown in figure 2a, the final choice has been defined as a hybrid structure which includes mostly steel, aluminium, magnesium and fibre reinforced plastics.

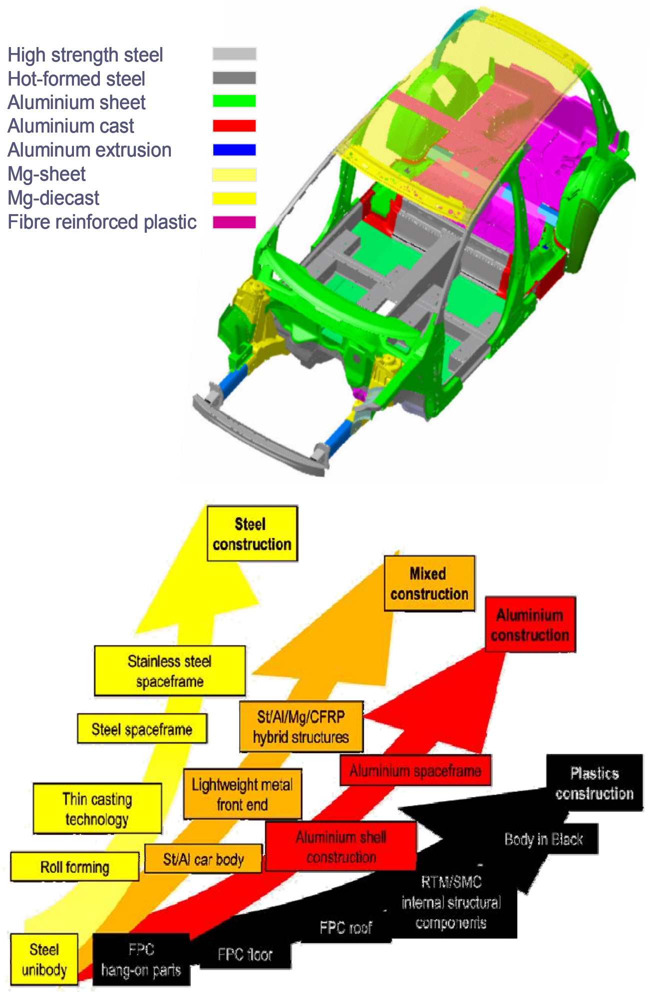

Figure 2 a) final concept for the SLC multimaterial body; b) paths for car body concepts [4]

ONE EXAMPLE OF LIGHTWEIGHT STRUCUTRAL SOLUTIONS

In this paragraph one example is presented of possible structural solutions aimed to lightweight but, obviously, able to match all the other structural requirements so that a full substitution of the normal production subassembly with newly designed one could be possible. The application is related to a front bonnet of a medium/high class car [8]. Different solutions in terms of material and shape of the inner structure have been studied by means of virtual analysis. The most interesting solution in terms of weight and performance has been prototyped [8]. Validation has been made by experimental tests, in particular to confirm the pedestrian head impact performance. The other types of performance of the bonnet (different type of stiffness and denting resistance) have to be maintained unchanged as they were in the original solution.

The reference bonnet is completely made of steel. The external shape of the skin could not be changed because it was defined by aesthetic style. For this reason, only the material and not the shape of the skin could be changed, while for the inner structure variations of both shape and material were possible. The structure of the reference bonnet is shown in figure 3.

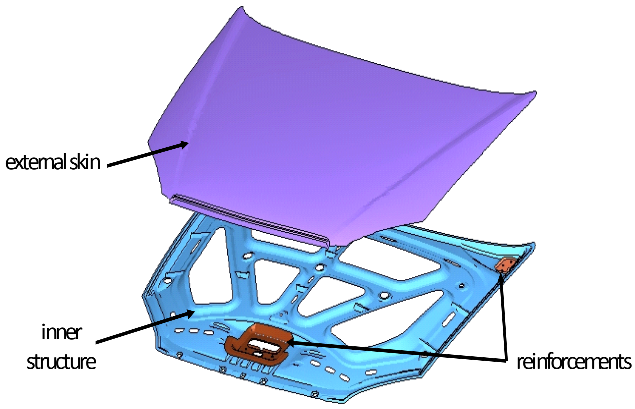

Figure 3. Structure of the reference steel bonnet

To reduce the weight of the bonnet the use of thermoplastic materials has been considered; their low density and good recyclability have been taken into account. The Noryl GTX has been selected as a possible solution, its quite good mechanical properties are reported in table 1.

Table 1: Properties of the Noryl GTX thermoplastic material

Property	Value	Property	Value
Density (g/cm³)	1.20	Flexural modulus (GPa)	4.00
Ultimate tensile strength (MPa)	80	Flexural yield strength (MPa)	135
Yield tensile strength (MPa)	85	Izod impact (unnotched, 23°C, kJ/m²)	45
Elongation at break (%)	6	CTE linear (µm/m/°C)	55
Elongation at yield (%)	3	HDT (66 psi, °C)	190
Tensile modulus (GPa)	4.30	Vicat softening point (°C)	230

Two different designs for the inner structure have been proposed [8] as shown in figure 4. Both are characterized by a regular structure with local ribs. They are aimed to reduce the weight and to distribute in a more efficient way the energy in case of impact against a pedestrian head, and at the same time to ensure sufficient bending and torsional stiffness. The studied solutions have been completed by an external aluminium skin and reinforcements still made of steel.

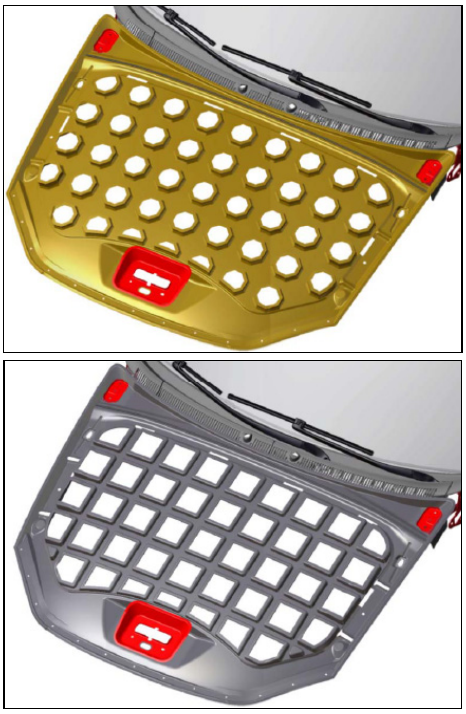

Figure 4 . Different designs considered for the thermoplastic inner structure [8]

Table 2: Numerical results of the pedestrian head impact test. [8].

Solution	Weight (%)	HIC_{15} (%)	Deformation (%)
Aluminium	-32.5	-10.0	14.7
Noryl (skin 2.5 mm)	-27.8	0.5	-3.8

Table 3: Numerical results of the stiffness tests. [8].

Solution	Weight (%)	K_t side (%)	K central (%)
Aluminium	-32.5	26.1	20.1
Noryl (inner structure 3.5 mm)	-31.1	-70.0	-61.5

A third solution has been developed with the same geometry of the reference one, but completely in aluminium (6016-T4 for the skin; 6181-T6 for the inner structure). Both lightweight solutions, with aluminium and thermoplastics, allow for a weight *reduction of about 30% if compared to the reference solution in steel.*

The results of the numerical tests are summarized in tables 2 and 3, where the HIC_{15} for the pedestrian impact test and the vertical deformation have been reported as variation with respect to the reference (steel) solution. Both the aluminium and the Noryl solutions show good potential to obtain the same improved performance for the pedestrian head impact.

CONCLUSIONS

The lightweight design is becoming rapidly one of the main targets in the development of a new car. This is countertendency with the trend of the last decades, when the mass of the vehicle has increased progressively.

The reduction of the mass of the vehicle is of great importance from two linked points of view: the reduction of the fuel consumption and the reduction of the CO_2 production. The reduction of the mass of the vehicle can be obtained by optimising the structure of the vehicle, in particular the body, by substituting the commonly used deep drawing steel with other materials such as aluminium or magnesium. This alternative is asking for relevant changes in the manufacturing process and there are also some questions related to the technologies to be adopted for joining parts made of different materials.

Another possibility is the use of composite materials. This is the clear trend in the aeronautical industry and this can be the near future also for the automotive industry, although a number of problems are still open and ask for practicable answers. Some new results have already been published and ask for verification of their practicability.

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APPLICATION OF GEAR REDUCER OILS IN FOOD PROCESSING INDUSTRY

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Abstract: *Technological production systems within food processing industry use machines which have specific requirements regarding the lubrication of particular components that come into contact with raw processing material. To satisfy stringent requirements, different types of lubricants have been developed. The problem of lubricating components and assemblies in the processing and packaging machines lies in the fact that the lubricant must possess qualities which allow it to come into contact with tobacco without compromising its safety. This paper gives an example of a synthetic ester-based gear oil used in tobacco industry. This paper reviews an example of gear reducer oil in a circulation system used for lubrication of working components of a cigarette filter making machine - Filter Maker.*
Keywords: *tobacco industry, gear oil, lubrication*

INTRODUCTION

Application of food-grade lubricants in food processing industry demands special types of base oils and additives which must meet stringent requirements set by the NSF (National Sanitation Foundation) Class H1 standard. NSF was established as early as 1944 as the national foundation for standardization, setting special requirements for lubricants used in food industry on American market. The H1 specification refers to food-grade lubricants used in food-processing environments where there is the possibility of incidental food contact [1].

In addition to the discussed criteria, food-grade lubricants meet other international standards in food-processing industry, such as:

- *Kosher, and*
- *Halal – food-safety standards.*

Beside requirements related to food-processing compatibility, food-grade lubricants must also meet certain requirements regarding physical/chemical and exploitation characteristics.

Depending on the mode of application (liquid, semi-liquid, solid or aerosol), food-grade lubricants must often meet stringent requirements of machine exploitation, while remaining safe in contact with processed food [2].

This paper reviews an example of gear reducer oil in a circulation system used for lubrication of working components of a cigarette filter making machine - Filter Maker.

GEAR REDUCER OILS IN TOBACCO INDUSTRY

Machines used for processing and packaging in tobacco industry are specific both design- and application-wise. The problem of lubricating components and assemblies in these machines lies in the fact that the lubricant must possess qualities which allow it to come into contact with tobacco without compromising its safety. Furthermore, just as with other types of standard industrial lubricating oils, all other physical/chemical properties food-grade lubricants must match the quality of conventional mineral oils.

The base oils which are used in food-grade gear reducer oils are manufactured according to HF1 and are predominantly of ester type [3]. The majority of synthetic esters (among various types) *are quickly biologically degradable, almost matching vegetable oils in that respect, as proven by numerous experiments [2,3,4]. However, the advantage of synthetic esters lies in their better oil oxidation properties and flow point at low temperatures. Another advantage is their ability to mix with mineral oils.*

Base oils of synthetic esters are used for manufacture of various types of products, including: hydraulic oils, oils for two-stroke gasoline engines, oil mixtures for Diesel engines used in ecologically sensitive environments (forestry, river and lake shipping, etc.), gear reducer oils and all other industrial oils which must meet ecological and food-safety requirements [5].

Generally, the synthetic ester base oils perform exquisitely in comparison with their mineral base counterparts, regarding:

- *thermal stability,*
- *oxidation stability,*
- *replacement intervals (longer, compared to mineral oils)*
- *viscosity index (VI) - temperature properties,*
- *flow properties at low temperatures,*
- *operating temperature limitations,*
- *resistance to radiation,*
- *resistance to flame.*

As regards chemical characteristics, gear reducer oils used in tobacco industry must meet following requirements:

- *Good corrosion properties, ASTM D-130 copper corrosion test, a three-hour test at 100°C, allowed limits 1a and 1b [6];*
- *Lower values of total acidity number –TAN, approximately 1 (0.9 – 1.1), as opposed to conventional gear reducer oils which feature 2 and 3 mgKOH/g Oil and higher. Tests are performed according to ASTM D-974 standard [7];*
- *Resistance to demulsification of food-grade gear reducer oils should also meet high standards. According to ASTM D 1401 10-minute test, mixture of 40ml oil and 40 ml water in a test tube must not result in a visible emulsion. The result is expressed as 40/40/0 (oil/water/emulsion) [8];*
- *Foaming of gear reducer oils should also be minimized to meet stringent requirements. During first stage of test, oil sample is tested at 24°C for 10 minutes, followed by the second 10 minute stage at 94°C, and the third 10 minute stage at 24°C. This experiment simulates real operating conditions of oil at various temperatures and loads, allowing the foaming to be monitored. The test result should equal zero. One of the most widely accepted specifications for such testing is ASTM D-892 [9];*
- *Corrosion protection test also shows that this type of oil must meet stringent exploitation requirements. According to ASTM D-665 A&B specification, the result of test should be - pass [10];*
- *Lubricating characteristics of food-grade gear reducer oils are tested according to various specifications, of which the most widely used are:*
  - *Four Ball test – a test with four balls where the oil sample is tested for a period of one hour at 75°C, under the 40 kg load and 1200 rpm. The result is a wear trace on the test ball which must not exceed 0.4 mm (ASTM D – 4172) [11];*
  - *Shell Four Ball EP test (ASTM D-2783) [12];*
  - *Timken OK wear test (ASTM D-2782) [13];,*
  - *FZG test (DIN 51517), which uses various loads to monitor the intensity of wear between a meshed pair of gears. Test result values depend on the meshed pair used - class 10 corresponds to light loads, while class 12 corresponds to heavy loads;*
  - *Oxidation stability test by a rotating bomb, according to ASTM D-2272, tested oil should be stable after a 250 minute test interval [14];.*

The discussed physical/chemical properties are common to all types of gear reducer oils, from conventional to the specific ones. However, they differ with respect to boundary values which are more stringent for food-grade lubricant oils.

LUBRICATION OF CIGARETTE FILTER MAKING MACHINE USING HF1 GRADE GEAR REDUCER OIL

The cigarette filter making machine is specific in terms of operating at very high speeds which range between 8.000 and 20.000 rpm. During operation, a compact circulation system for lubrication, with a 40 liter tank and lubrication pump capacity of 5.8 l/min, performs the task of lubricating all critical points.

Shown in Figure 1 is a photo image of the machine, while Figure 2 shows the head which rotates at high speed and attaches filters to cigarette paper (position 3, Figure 3).

Figure 1. Filter Maker machine [15]

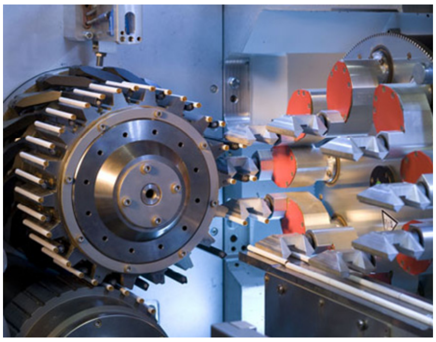

Figure 2. Rotating wheel which attaches filters to cigarette papers [15]

Figure 3 illustrates the lubrication circulation system and the cross-sections of all lubrication points.

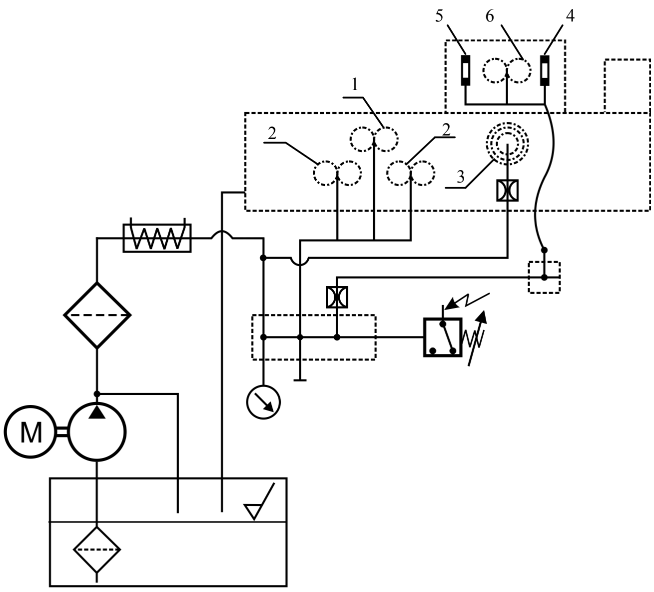

Figure 3: Circulation system for lubrication on the Filter Maker machine [15]

The Filter Maker machine has a total of six lubrication points which are vital to machine operation:

- Worm/worm wheel pair (Position 1) teeth contact is maintained over a point;
- Gear reducer with conical gears (Position 2) – teeth contact is maintained across a line;
- Main axle bearing the rotating head (Position 3);
- Roller bearing DIN 628 (Position 4) – the ball and cage maintain a point contact;
- Roller bearing DIN 625 (Position 5) – the ball and cage maintain a point contact;
- Gear reducer with conical gears (Position 6) – teeth contact is maintained across a line

Due to specific contacts, the worm/worm wheel pair is the most critical component (Position 1), together with the roller bearings (Positions 4 and 5) which maintain a point contact between work elements. In order to reduce wear, gear reducer oil used in the circulation system should, in addition to other properties, possess good EP (Extreme Pressure) and AW (AntiWear) characteristics, i.e., good lubrication properties which are maintained under high load pressures, and friction reduction under high rpms. The compact circulation system provides just the adequate lubrication with a quick circulation of lubricant fluid which takes 8 minutes to pass through the pump and the entire circulation system.

The advantage of gear reducer oil of this type is their solid base, which, beside high fluid throughput also allows a long-lasting oil operation during machine operation. The manufacturer recommends oil change at every 4000 hours of machine operation. However, within the discussed system, this oil retains its lubricating characteristics even after 8000 hours of machine operation. Considering its characteristics, this type of gear reducer oil allows very long exploitation providing regular maintenance (absence of water and solid particles, and stable operating temperature - as provided by the discussed system). Naturally, in order to keep its properties within the required limits throughout exploitation period, the oil must be sampled and tested for physical/chemical characteristics on a regular basis in certified laboratories.

CONCLUSION

Compared to conventional mineral oils, food-grade gear reducer oils possess two key elements:

- *Good base component – a high-quality ester base oil which guarantees long-lasting exploitation,*
- *Package of additives which enhance particular physical/chemical properties.*

It is exactly these elements that are key to providing good lubrication to gears and reducers which operate in extreme conditions. It has been shown in real exploitation conditions, that providing the adequate monitoring and maintenance, the oil can withstand long periods of operation without replacement, extending, in some branches of industry, over 20.000 hours of operation. Thus, together with turbine oils, this type of oil can be considered top-quality lubricant. In the future, food processing industry shall be dominated by ester based oil lubricants, gradually replacing the conventional oil types due to their superior characteristics. Moreover, the price of synthetic ester oils keeps dropping which means that in a matter of years these oils shall equal the price of mineral oils, providing yet another reason for their use, especially in the food processing industry.

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ILLUSTRATIVE COURSE OF COMPACTION PROCESS OF THE PELLET PRESS PLG 2010

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Abstract: *The article is aimed to clarify issues of calculation and illustrate the course of compaction process of pellet press PLG 2010. Construction of machine and its main parts are described in introduction to form image of the issue. Introduction also describes the basic principle of machine functioning. Next chapters are devoted to the principle of the finding out course of compaction ratio of the press. At the first 3D model of pressing space was created to find out of compression ratio. Next step was to divide the pressing space to smaller precisely defined parts, and measure its volume. The measured values were used to calculate exact values of compression ratio. And finally the calculated values were added to diagram, which describes illustrative course of compaction ratio the pellet press. Finally we must mention that the determined compaction ratio is not real but only idealized.*
Keywords: *pellet press PLG 2010, compaction process, 3D model, compaction ratio, illustrative course*

INTRODUCTION

Institute of manufacturing systems, environmental technology and quality management on STU in Bratislava are interested in biomass compaction research since 1995. The pellet press PLG 2010 is machine with progressive construction to compaction biomass, which was designed within the scientific research in our institute. There was produced three prototypes of this type of machine, each with new innovation or construction modification. The latest prototype was produced in 2010 and first test were made that time. We made the experiments to find out course of compaction ratio to get better idea about compaction processes during compacting on this machine.

PRINCIPLE OF COMPACTION

The spherical pellet press principle of compaction is based on dragging and compacting material between the two axially misaligned discs where the first is pressing tool and second is die. Pressing tool and die are rotary components and they are rotated relative to each of the wedge angle. Together with sphere and main machine body define pressing space. Pressing tool is driven by electromotor through a gearbox and to die torque is transferred by the friction or by contact form according to the type of pressing tools. Position of the sphere center is in the intersection of the tools axes. Sphere is rigidly connected and drifted by the press tool. Sphere, pressing tool and die define rotary part of pressing space. Static part of pressing space is defined by the body of the press. We can change pressing space geometry by changing set of tools and thus easy change conditions of compaction. Most of the pellet press parts are designed modular to reach easy and quick tools replacement.

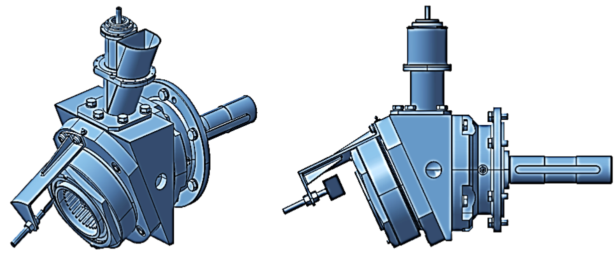

Figure 1. Pellet press PLG 2010

Insert of die and insert of pressing tool has important role in dragging, moving and compacting of pressed material. Material is *dragged to pressing space and then into pressing chamber of the die. The tools and sphere towards the press body creates movable pressing space with relative movable surfaces (figure 5). Angle of conical part is fix and it was determined with respect to reach good dragging, moving and compacting ability of the compacted material. During compaction with the drift system of torque transfer must be ensured sufficient friction between the tools. Friction depends on compacted material, its properties, shape of tools and the size of the minimal distance between them.*

CREATION OF PRESSING SPACE MODEL

We used CATIA V5 and original 3D model of machine to find out course of compaction ratio. The First step was to create pressing space of machine. Pressing space is defined by die, pressing tool, sphere and by body of machine as we can see on figure 2.

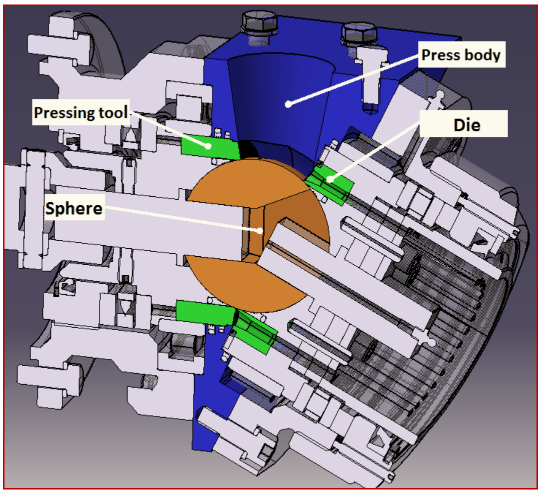

Figure 2. The pellet press section

Between the mentioned mating components arose pressing space, which is limited by two surfaces which projection is annulus. Its cut of conical surfaces with mild spatial conicity. Theoretical outside border surface is composed of two surfaces composed by intersection of two cut cylinders. Intersection is determined by outside edge of mentioned conical surfaces. At real is that theoretical surface adjusted, as the result of manually grinded edge created by intersection of cylinders. This adjustment wasn't taken into account during pressing space creation. Outside surface was simplified to spherical surface. Inner surface of the space is defined by cut of spherical surface of sphere. Plane of intersection of sphere are defined by superficial curves of mentioned inner conical surfaces. Angle between die and pressing tool is 25°. We simplify 3D model of die and pressing tool to create model of pressing space (Figure 3).Pressing chamber of die was filled up, because it isn't considered the working part of pressing space. It leads to simplification of subtraction of volumes in 3D software. Compaction in pressing chamber is disregard because of different processes inside. Model of pressing tool was simplified by adding material into the gaps of milling. It simulate real state where gaps are filled by pressed material.

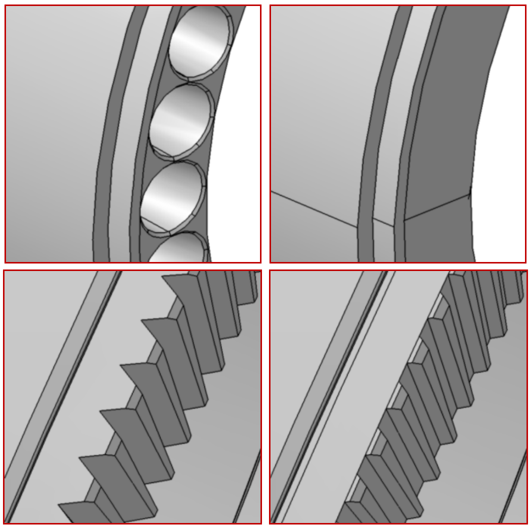

Figure 3. Pressing tool and die after editing

We added a layer of material on the outside surface of sphere, which will form base of the pressing space. That layer fill space between sphere, body and tools. Last step to create pressing space is to subtract individual part from sphere with added layer. Added layer on sphere intersects other parts, and that is the point of creating model of pressing space. On figure 4 we can see volume subtracting.

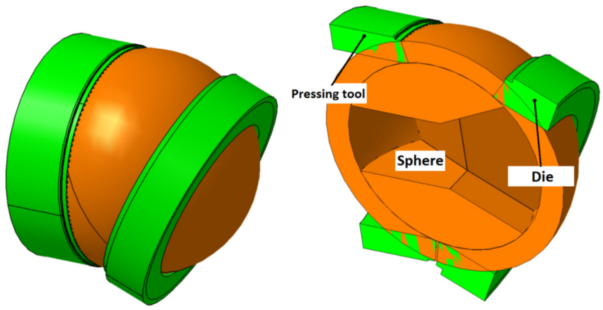

Figure 4. Volumes subtracting

After volumes subtracting was created following shape of pressing space:

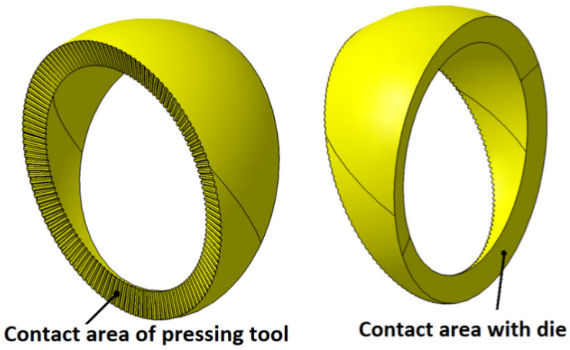

Figure 5. Pressing space

At the first model of pressing space must be divided to pieces with equal angle cut. We determine angle cut of one piece as 360° divided by number of output pressing chambers on the die. We were based on the assumption that the material will be equally pressed into each chamber of the die. Number of the chambers on the die is 30, thus angle cut is 12°.And finally volume of the first piece, is theoretically volume that will be extruded through one chamber of the die in the end.

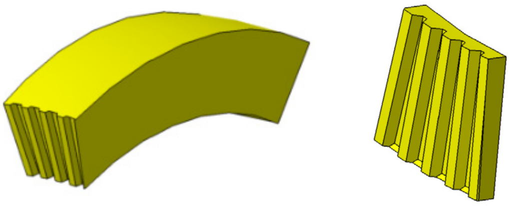

Figure 6. Input and output piece of pressing space

Whereas all moving parts have same direction of rotation, theoretically all compacted material will be extruded through chambers in only one half of whole created pressing space. Therefore we consider with the half of the pressing space model to calculate the course of compaction ratio. Angle of cut is same – 12°.

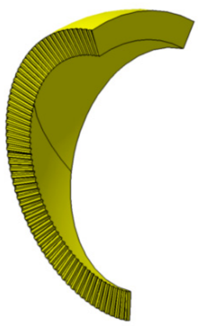

Figure 7. One half of pressing space

IDEALIZED COURSE

Compaction ratio is ratio of compacted material volume after compacting to material volume before compacting. In case of spherical press we can say that compaction ratio is ratio between inner volume of angle cut of pressing space and output volume of angle cut of pressing space. It means that we find out reduction (compaction) of one piece of pressing space. At the first we must found out volumes of pressing space pieces, that pressing space was divided. Total number of pieces is 15. Then for compaction ratio in specified place is valid relation:

$$zp_i = \frac{V_{D\max}}{V_{Di}} \qquad (1)$$

where: zp_i - compaction ratio in specified place [-]
V_{Dmax} - maximal volume of piece - inner volume [cm^3]
V_{Di} - volume of piece in specified place [cm^3]
We found compaction course after volumes measuring of specified pressing space pieces and substituting into formula. At figure 8 is shown course and measured volumes values of the specified pieces. Maximal volume of (input) piece is 4,749 cm^3. Minimal volume of (output) piece is 0,155 cm^3. Maximal value of compaction ratio is 30,64.

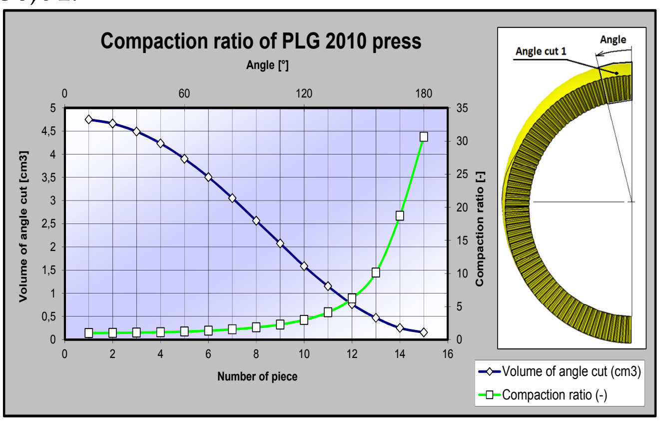

Figure 8. Idealized compaction ratio of PLG 2010 pellet press

CONCLUSIONS

Value of found out compaction ratio is only ideal. Theoretical – ideal pressing ratio should be only input for next thought and analysis of whole system. In real processes we cant consider conclusions as relevant to find out real compaction ratio, because processes inside pressing space are really difficult to describe exactly. There are much more other input variables that influence the process of compaction. How material is behaving during compaction process is influenced by mechanism of compacting, shape of pressing space, *technological parameters of compaction and material parameters (temperature, humidity, chemical composition, split) and that is the main subject of our workplace research. Conclusions of this research can be efficiently connected to conclusions of real experiments. On basis of further analysis and comparative tests we can predict theoretical density of pellets, only by defining inner conditions of compaction.*

Now this conclusions are suitable create base imagination about compaction processes inside the machine. Next research of compaction conditions leads to find out real compaction ratio and other parameters relevant with process of compaction on the PLG 2010 compaction machine.

ACKNOWLEDGMENT

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STEAM ENGINE – CFD SIMULATIONS WITH MOVING MESH

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Abstract: The first steam engine was designed almost 250 years ago. Nevertheless, even today there are its applications linked to energy utilization which are of interest. Especially in some technological processes were throttling of steam generates losses, which generate no useful energy. This paper briefly analyses problems arising from the CFD simulation of steam flow in a piston machine. Based on a prototype facility a simplified 2-dimensional model, with computational grid of the single-acting steam engine in pre-processor GAMBIT, was set up. In the first part of this paper the model generation is described and difficulties linked with moving and dynamic meshing are discussed. In the second part, the boundary conditions for the simulations are defined and results of simulations performed in the CFD code ANSYS-FLUENT are presented. The main outputs of the performed simulations are indicator diagrams that can subsequently be used for determination of the time-dependent forces acting to the piston.
Keywords: steam flow, CFD simulation, prototype, model generation, simulations

INTRODUCTION

In the last year PolyComp Ltd. Company was developing a piston steam engine with plan to transform even a small part of steam thermal energy which is lost through the throttling loss. Piston machines make it possible to transform some thermal energy to the energy of piston motion and next to generate electrical energy.

Imagine a case of using two levels of steam parameters (namely temperature and/or pressure) for different parts of one technological process. You have two general possibilities to solve it:

a) to separate the process into two parts leading to generating final levels of steam parameters;

b) to produce all the steam at higher level of these parameters and subsequently reduce demanded part of the steam to the lower level.

If the second case is better than the first one in his economic point of view, we need use non-reversible process – throttling loss. The first choice involves higher capital costs, the second one causes growing of the operating costs. However, in many cases these processes are already in operation, so that the possibility b) was chosen before and economies are founding afterwards. As we know, in throttling process all the steam superfluous energy is lost. Therefore we look into some machine designs with sufficient efficiency leading to the early economic return. For many cases with sufficient power, we can find solution in small steam turbines. But, if is there too small power to use, the investment to turbine machine is uneconomic. For small electric output (approximately up to 300 kW) it is better to use modified series manufactured piston engines (in Czech conditions e.q. Tedom engines). One of the main visible modifications is cams replacement of sleeve-valves. This innovators solution has some difficulties though, e.g. sleeve-valves sealing, heat stress during starting of the unit or strength limits of the crank mechanisms.

MODEL DESCRIPTION

Figure 1 shows a 2-D model consisting of input chamber with sleeve-valve, entry channel, steam cylinder with moving piston, output channel and output chamber with sleeve-valve. In reality the input and output chamber includes always 6 *parallel sleeve-valves which connect 6 parallel cylinders. Sleeve-valves have three pairs coupled to each other with 120° angle relative slewing. This linkage ensured more fluent steam distribution to the piston and speed-torque force to the crankshaft. The steam engine works as a two-stroker. When the inlet sleeve-valve is open, higher pressure steam expands to the cylinder and push to the downward moving piston. In this moving section useful work is done. When outlet sleeve-valve is open, the upward moved piston pushes steam away to the outlet chamber. This cycle works in nominal rotation speed 450 rpm [1].*

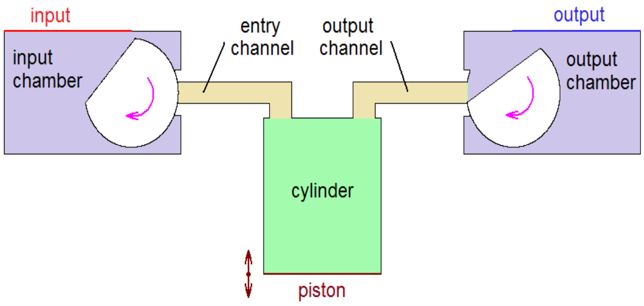

Figure 1. Boundary conditions setting and computational areas labeling of simplified 2D model geometry

MODEL CONDITIONS SETUP

To obtain sufficiently accurate steam flow description the ANSYS-FLUENT CFD code needs to solve a number of specific geometrical and computational parameters [3]:

- *Sliding and Dynamics Mesh Models – control area contains two different moving parts: piston and rotational sleeve valves.*
- *Two-face flow – intensive expansion of the superheated steam can lead to subcooling of steam under saturation temperature. We need to add in the solution suitable two-dimensional model which covers the condensation process.*
- *Transient – in merits of the case, this model causes high-unsteady behaviour of the flow. As a result it has very small time step.*

Sliding Mesh Model

Sleeve-valves generate rotating circle with cut-off segment (see Fig. 2). For this movement it can be suitable to use the Sliding Mesh Model which accounts the relative motion of stationary and rotating components. In the Sliding Mesh Model two main cell zones are used. Each cell zone is bounded by so-called Interface zone where it meets the opposing cell zone. The Interface zones of adjacent cell zones are associated with one another to form a Grid interface. The two cell zones will move relatively to each other along this Grid interface, which must be positioned so that it has fluid cells on both sides. On the right side of Figure 2 the detailed area around Grid interface (red line) is shown. For a better description of fluid behaviour there are more cells rows on both sides.

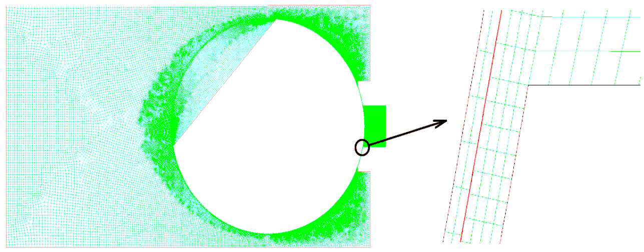

Figure 2. Computational mesh in the input chamber region with auxiliary view of slot area

Dynamic Mesh Model

The Dynamic Mesh Model uses the ANSYS-FLUENT solver to move boundaries and/or objects, and to adjust the mesh accordingly. Suitable cases include the piston moving inside an engine cylinder. We can use dynamic layering to add or remove layers of cells adjacent to a moving boundary, based on the height of the layer adjacent to the moving surface. The Dynamic Mesh Model allows specifying an ideal layer height on each moving boundary. The layer of cells adjacent to the moving boundary (layer j in Figure 3) is split or merged with the layer of cells next to it (layer i) based on the height h of the cells in layer j. ANSYS-FLUENT code also enables to set the in-cylinder options (crank shaft speed, starting crank angle, crank radius, etc.) which are used to convert between flow time and crank angle.

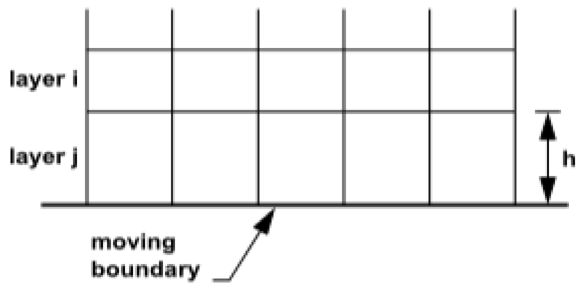

Figure 3. Dynamic Layering

Transient

Sliding and Dynamic Mesh Models are the most accurate methods for simulating flows in multiple moving reference frames, but also they are the most computationally demanding.

For CFD simulations it is necessary to find a convergent solution. In order to find it, we need to set useful especially physical convergence criteria. For this case the temperature and pressure course criteria was set. Criteria conditions are satisfied when the controlled variable had coincident course with minor deviations in two consecutive (crankshaft) revolutions. In reality, pressure relative deviations do not exceed limit of 2% and average relative deviation under 0.3%. The temperature relative deviations were a little higher because of steep pressure rising during the time, when sleeve-valves were just opening. Nevertheless, the maximum temperature relative deviation does not exceeds 5%. One example of a successful convergence of temperature course is on Figure 4 [5].

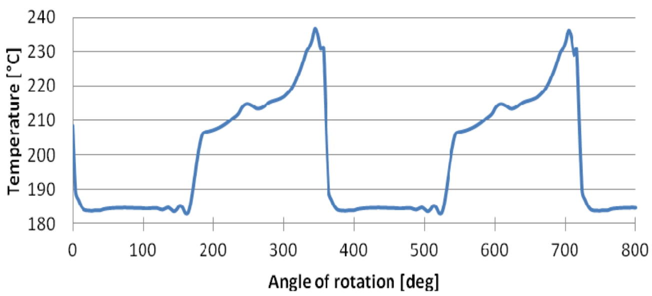

Figure 4. Example of cylinder average temperature course (load time 5°)

To reach convergent solution we need 5 or 6 revolutions with 0.1° slewing time step (i.e. $3.704x10^{-5}$ s for 450 rpm). With 20 iterations per one time step it leads approximately to 400,000 iterations. Using the 16 processors of Intel Nehalem server we totally need just between 80 and 100 hours of computational (real) time.

Condensation

For solved technological processes, the pressure and temperature conditions of admission steam are near to the saturation state. During a rapid expansion of steam, a condensation process will take place shortly after the state path crosses the vapour-saturation line. The expansion process causes the super-heated dry steam to first subcool and then nucleates to form a two-phase mixture of saturated vapour and fine liquid droplets. For these cases ANSYS-FLUENT code implements Wet Steam Model, which uses the Eulerian-Eulerian approach. The flow mixture is modelled using the compressible Navier-Stokes equations, in addition to two transport equations for the liquid-phase mass-fraction (□), and the number of liquid-droplets per unit volume (□). The phase change model, which involves the formation of liquid-droplets in a homogeneous nonequilibrium condensation process, is based on the classical nonisothermal nucleation theory. Physical restrictions of the Wet Steam Model are the following: the velocity slip between the droplets and gaseous-phase is negligible; the interactions between droplets are neglected; the mass fraction of the condense phase is small (□ < 0.2) and droplet sizes are typically very small (between approximately 0.1 and 100 mm) [3].

Above-mentioned restrictions are in good accords with solved case conditions (□ exceed over 0.2 values only locally) therefore the Wet Steam Model can be used.

SIMULATIONS SETUP

Basic operating parameters setup of the simulations includes: inlet operating pressure (0.1 MPa); inlet gauge pressure (2.0 MPa); inlet temperature (213 °C); outlet gauge pressure (1.0 MPa); sleeve-valves and crank shaft rotation speed (450 rpm); crank radius (75 mm) and connecting rod length (250 mm). For transients problem setup time step was $3.704x10^{-5}$ s which corresponds to the angular rotation of sleeve-valves and crank shaft by 0.1°. According to the model variants we set up lead times (5°, 7° respectively). The lead time presents the angle of rotation by which the open input/output sleeve-valves preceded the piston top/bottom dead centre.

Basic simulation parameters are: numeric schema – Density-Based Solver; viscous model – turbulent Standard k-□ model with Standard wall function; discretization schemas - Upwind second order [5].

RESULTS

Simulations results for the PolyComp Company include:

- *Sliding and Dynamics Mesh Models – control area contains two different moving parts: piston*
- *Quantity of steam leaving from input chamber in a closed state - steam outflow through slots was analysed.*
- *Indicator diagrams – applies for cycle efficiency determination in different settings (load times*

or pressure levels) and for determining of the forces acting on the piston.

- *Temperature fields on the walls – enables to better temperature stress definition in construction materials (stress analysis).*
- *Mass flow quantity of the aqueous phase – steam moisture quantity checking towards limit values of the used model (□ < 0.2).*
- *Videos of the tracked variables –visualization providing better process understanding.*

The most important results are indicator diagrams, whose values for subsequent strength calculations have been used. Examples of indicator diagrams for two different load times (5° and 7°), inlet pressure p_{in} = 2MPa and outlet pressure p_{out} = 1MPa are shown in Figure 5. Diagrams show the average values for the static pressure in the cylinder, depending on the angle of rotation. Zero angle was set up to the top dead centre.

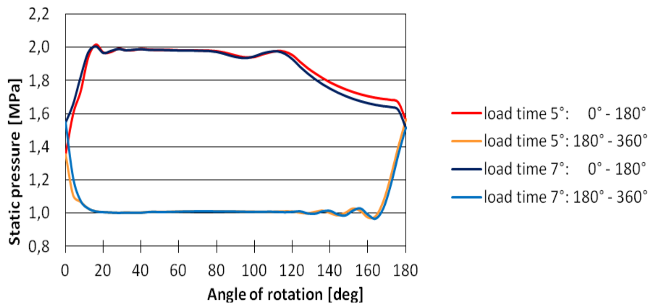

Figure 5. Indicator diagrams for p_{in} = 2 MPa and p_{out} = 1 MPa; load times 5° and 7°

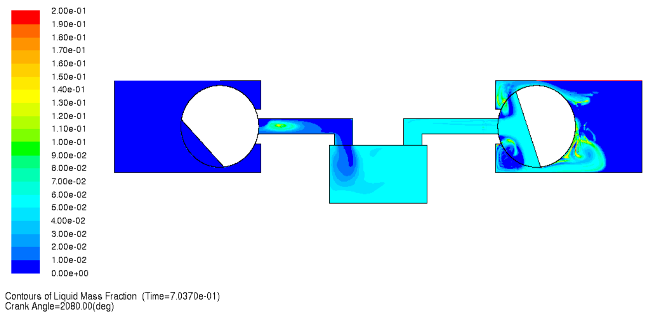

Figure 6. Weight ratio process of aqueous phase in the model for selected rotation angle

When we compare the two shown diagrams, we can notice minor effect of the load times setting onto performed work, or on the forces acting on the piston as it is by the piston internal combustion engine. A more important point of view to the load times setting is creation and diffusion of supercooled steam, which influences the formation of condensation. The process of aqueous phase diffusion for the selected rotation angle is shown in Figure 6. In general, it can be concluded that a higher aqueous phase fraction is formed but in the output chamber.

CONCLUSIONS

2D steam flow simulation on the CFD model of the piston engine was carried out. Sliding and Dynamics Mesh Models and also Wet Steam Model including condensation process were used. As a main result chosen indicator diagrams were described. 2D symmetry cannot substitute a full 3D simulation of the entire machine. The results are used especially as an alternative method of monitored parameters course determination (temperatures, pressures and condensation). The chosen solution method also indicated present possibilities of the CFD simulations in this area.

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A SURVEY ON SECURE AUTHENTICATION OF CLOUD DATA MINING API

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Abstract: *Cloud computing is a revolutionary concept that has brought a paradigm shift in the IT world. Thishas made it possible to manage and run businesses without even setting up an IT infrastructure. It offers multifold benefits to the users moving to a cloud, while posing unknown security and privacy issues. User authentication is one such growing concern and is greatly needed in order to ensure privacy and security in a cloud computing environment. This paper discusses the security at different levels viz. network, application and virtualization, in a cloud computing environment. A security framework based on one-time pass key mechanism has been proposed. The uniqueness of the proposed security protocol lies in the fact, that it provides security to both the service providers as well the users in a highly conflicting cloud environment.*
Keywords: *Hash functions, Cloud API Security, Data Mining, DoS attacks, DDoS attacks*

INTRODUCTION

Internet has given rise to one of the most revolutionary concepts of recent times, known as Cloud Computing.

The Cloud, as it is often referred to, involves using computing resources – hardware and software – that are delivered as a service over the Internet. Organizations are no longer required to build their own IT infrastructure. Instead, they are presented with an alternative to host their data on a third party system such that they would be able to access the same by means of Internet. Cloud computing is gaining popularity due to the features that include scalability, multi-tenancy and reduced hardware and maintenance cost. Cloud technologies are enabling the users with multifold facilities but at the same time, they bring additional security and privacy issues. The rate at which cloud technologies are being adopted, it has become imperative to analyze the service offerings from different cloud service providers (CSPs) and then decide their suitability based on the organization's needs and requirements.

Data mining technology and services refer to yet another interesting domain that has caught the attention of researchers in the recent times. It is the process of analyzing data from different perspectives and summarizing it into useful information. It finds a great deal of use in business and economics.

The emerging usage of cloud computing trends provides its users with the unique benefit of unprecedented access to valuable data. This will enable the users to gain valuable insights towards achieving their business goals intelligently.

Simple Cloud API project focuses on improving the portability of PHP based applications across different cloud platforms facilitates services offered by different cloud service providers to be accessed through a common API [31].

Now-a-days, most of the CLOUD API systems use passkey based authentication methods. Passkeys are very popular and useful as they are convenient for users and easy to implement. Passkey-based authentication, although very convenient, have some drawbacks due to the nature of the system.

It has been a tendency to choose relatively simpler ways to implement passkey authentication system. This in-turn makes it less secure and vulnerable and hence susceptible to exhaustive use or attacks. There are several examples of this type of attacks on various systems worldwide. Some of the relatively secure authentication techniques include ZIGSAW based secure data transfer [8] and encryption keys based on RSA technique.

Another approach to design a security platform involves making use of one-way hash functions. They act as the building blocks of a security system that attempts to eliminate online dictionary attacks by implementing a "challenge-response system"[5]. This challenge-response system is designed in a way that does not pose any difficulty to a real user, but is time and computationally intensive for an adversary trying to launch a large number of login requests per unit time as in the case of an online dictionary attack. This system is stateless and therefore attacks are less vulnerable to DoS (Denial of Service) [12] [14]. Also, it is quite tough to implement Intrusion Detection System (IDS) [9][10][11] based protection approach. So, passkey based approach becomes significant in these type of systems.

But this approach is unable to assure a fully secure way for CLOUD API access. Security is a major concern in public clouds than in an internal environment. User has no control and information of any other code sitting on the same machine. Unaware of this, user may allow public access to the API leading to a security breach. Thus we see that security remains an ongoing concern in cloud deployments [6][42].

OVERVIEW

Data mining techniques and applications are needed in a cloud computing paradigm. Cloud based technologies are finding a great deal of use in the fields related to business and scientific computing. Data mining and warehousing techniques targeted to applications such as: fraud detection, prediction of potential threats, identification of criminal suspects etc. are being used in cloud computing scenarios.

Cloud Computing

Cloud computing can be defined as one of the most popular trends in the history of online computing that has taken the world by a surprise. It offers a flexible IT architecture, enabling its users to be able to use services which would have been considered impossible incase of standard IT based solutions.

A cloud based architecture can be defined as a set of resources – hardware and software, which combine together to deliver the aspects of computing as a service. Services in such a scenario are charged on a usage based pricing model and the users are no longer required to care about the intricacies which are needed to be taken care in a traditional on-premise computing model.

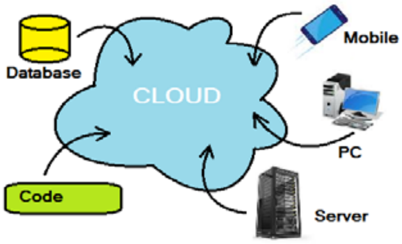

Figure 1. Cloud Model

Cloud based service models can be categorized into three types: Infrastructure as a Service (IaaS)[18], Platform as a Service (PaaS)[19][20][21], and Software as a Service (SaaS)[17] [27]. Managing a cloud computing service level via the surrounding management layers are as follows:

- *Infrastructure as a Service (IaaS). The IaaS [22]-[26] layer offers storage and computing resources that are used by the developers and IT organizations to deliver high valued business solutions. The core of IaaS is based on virtualization. In an IaaS model, resources can easily be scaled up, depending upon the demand from the user, services being charged in a pay-per use model.*
- *Software as a Service (SaaS). In the SaaS [28][29] layer, the service provider hosts the software such that the user has no need to install it, manage it, or buy hardware for it. Users are onlyrequired to connect and make use of the services provided. SaaS examples include high valued customer relationship management as a service.*
- *Platform as a Service (PaaS). The idea behind PaaS is to provide a platform that would enable the developers to build applications and perform end to end testing. These applications may then be deployed on a web-based model such that they can be refined if a need arises.*

A few state of the art techniques that distinguish cloud computing from other computing paradigms like grid computing, global computing etc. include elasticity, scalability, self-service provisioning or automatic de-provisioning, application programming interfaces (APIs) [13], and billing and metering of service usage in a "pay-as-you-go" model. These flexibilities are attracting individuals as well as the businesses to move to better suited cloud platforms rather than managing the whole IT infrastructure by themselves.

The three types of users that are predominantly seen in a cloud computing environment are:

- The end user who needn't know anything about the underlying technology and the architecture.
- Business management who needs to take responsibility for the governance of data and services lying in a cloud. Cloud service providers must provide a predictable and guaranteed authenticated service level and security to all their users and constituents.
- The cloud service providers, who are also responsible for IT assets and maintenance.

Cloud computing can be deployed in four different ways: public cloud, private cloud, hybrid cloud – combination of both public and private and community cloud.

Cloud computing can significantlychange the way how companies are using technologies to serve customers, partners, and suppliers. Organizations have already started leveraging the benefits offered in a cloud environment in the form of cloud- based solutions which include Qualcomm's wireless solutions on the cloud, Oracle's ERP solutions on the cloud, Schneider Electric's energy solutions on the cloud etc.

Data Mining

Data Mining [30] techniques are most often used to analyze data in the fields of finance, supply chain management (SCM), customer relationship management (CRM), marketing and distribution [7]. For instance, it helps in optimizing customer related data, determining the buying potentials of customers and predicting sales figures by the usage of statistical-mathematical methods implemented over large sets of historical data. Thereby companies can make a blueprint of a new and improved marketing strategy, by spending less amount as well as time to achieve better and effective statistical results.

In essence, data mining techniques enable the companies to predict the market condition, customer response and estimate the sales figures for the upcoming period. With data mining, a retailer could use the historical data of customer purchases to set targeted promotions. By mining demographic data from review comments or feedback form, the retailer could launch new promotions and appeal to specific customer segments.

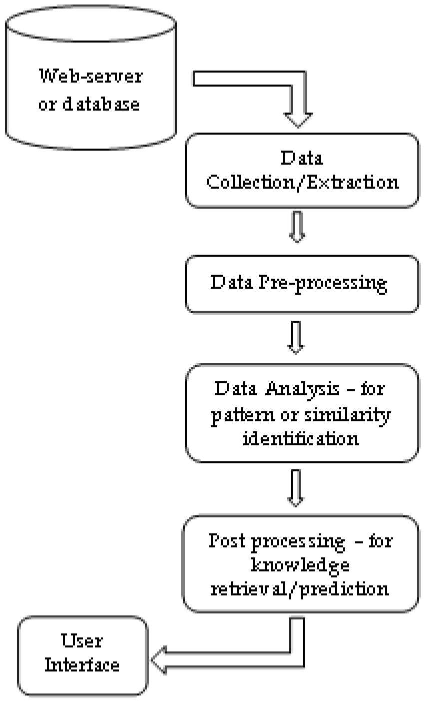

Figure 2. End to End Data Mining Network

A generalized framework describing the various stages in a data mining algorithm is explained below:

1. Extraction and Pre-processing of raw data: This includes data collection and then implementing techniques to perform dimensionality reduction and redundancy removal.
2. Pattern Discovery and Analysis: Once the data is pre-processed, it undergoes algorithmic analysis to discover if there exists any pattern or similarity among the different classes of processed data. These patterns are then extrapolated to predict the behavior in future, as per the need.
3. Information retrieval and Data prediction: Once a pattern is located, it is then used to retrieve the information or predict the behavior in

future. For e.g. estimating the sales in future, stock levels to be maintained in the inventory, predicting the class of data etc.

Data mining tasks can be classified under the following sections:

- *Clusters formation: Data items are populated to organize the grouped segment according to logical relationships or consumers' strategic preferences. For example, data can be populated to identify sales segments or consumers' purchase affinity trends.*
- *Classes: Populated and segregated data is used to indicate the class, data belongs to.*
- *Associations: Data can be populated to identify associations of segments.*
- *Sequential patterns: Data is populated to predict behavioral patterns and trends of segregated data.*
- *Regression: Extrapolating the model (based on the known response) to estimate the values for an unknown segment.*

A few of the techniques to implement these algorithms are: support vector machines, genetic algorithms,artificial neural networks, nearest neighbor algorithms etc.

Cloud Data Mining

An increasing trend towards the adoption of cloud services has mandated the need of data mining algorithms in a cloud environment. Data mining in the cloud is the process of extracting useful information from huge chunks of data basically referred to as 'Big Data'. It has given rise to a non-relational database model, better suited to companies operating on a cloud based model. NoSQL is one such cloud-friendly approach that does not follow the standard concepts of a relational database and provides greater scalability and flexibility. Some of the concepts which have been designed in order to ensure smooth data processing in a cloud computing environment include: Apache Hadoop, Apache Hive, Pig, MapReduce etc. A detailed analysis of these techniques has been carried out in [32].

A cloud-based data mining platform which demonstrates the solution of data mining as a service (DMaaS) has been presented in [33]. In this paper, the authors have gone on to propose a comprehensive framework suitable to work with Big Data in a cloud environment. The end user will be able to access the service by means of a light weight browser. Moreover they can also design the analytics flow in a drag and drop manner and interact with the results obtained [33]. Thus we see that data mining services will be offered in the same pay-per-use model as the other application/software based services are provided in the cloud.

Cloud API

Cloud computing is a style of computing in which dynamically scalable and deployable resources are provided as a service over the network. Users need not have knowledge of system, expertise in underlying architecture, or control over the underlying infrastructure. A cloud API is basically used to integrate applications in order to enhance the cloud experience and provide inter-cloud compatibility. They are broadly classified into two categories: in-process APIs and remote APIs. In-process APIs are the ones used on a regular basis and are most commonly used in a typical infrastructure based IT environment. However, remote APIs are the ones which are used to develop cross-border, bridging applications and include web-services (SOAP or REST), remote calls (Sun RPC, Java RMI), application dependent protocols (FTP, SNMP). These types of APIs are based on HTTP and SHTTP protocols and GET, PUT, POST, DELETE requests are used. These types of APIs communicate based on the data structures like: JSON, XML etc. Most of the cloud service providers are found to exploit the second type of API model. A detailed analysis of API requirements and architecture has been carried out in [35].

Companies are now-a-days opting for multiple cloud service providers and the existence of multiple cloud platforms makes cross-platform APIs a necessity. This particular need to enable the companies to have a connected platform, has generated a new cloud API market. Some of the companies operating in this domain are: Google Compute Engine, Citrix, VMware, Simple Cloud, Amazon web services API etc.

Cloud API Security Concern

If on one hand cloud computing is enabling the organizations to function without bothering about *the need to maintain an IT infrastructure, update the software's, host a team of database administrators, it is posing many questions that need to be answered, concerning the security and privacy in a cloud computing environment. The organizations have already started adopting the cloud offerings and the days are not far when a huge chunk of organizational data will reside on cloud-based servers. This will require stringent security measures to be placed across the cloud platforms which will safeguard the data from internal as well as external security threats. Some of the measures that could be taken in this regard are:*

1. *Ensuring proper security measures to safeguard hypervisor to any sort of security threat.*
2. *Careful assessment of the security practices as implemented by the cloud service providers need to be done before adopting any of them*
3. *Proper SLAs between the customer and the CSP, defining the organizations' security requirements that need to be addressed.*
4. *APIs in use need to be looked after and screened carefully. In the current scenario, most of the organizations prefer an integration of security techniques with their service models. They should be aware of the security implications associated with the usage of these cloud services. Reliance on weak APIs may jeopardize the security of important organizational data.*

"Insecure APIs" constitute one of the major security concerns in cloud computing. APIs are defined as a set of interfaces which are used to interact with the cloud services in a cloud based model. These APIs are most often used by the cloud service providers (CSPs) to offer additional services. A two stage API access control mechanism using the Role Based Access Control Model has been proposed in [34]. This model is based on providing access to the users based on the roles assigned to them. Each user is assigned a role and it serves as a connecting layer between the user and the permissions assigned to him/her. This however doesn't guarantee protection against the threats arising from within the organization such as: mishandling of resources from an authorized user (granted a role with high level of responsibilities assigned to it). Hence it is required to carry out the inspection of roles and responsibilities assigned, at regular intervals.

The need for security and privacy in today's highly conflicting computing world has provided cloud service providers with an opportunity to provide security solutions. Numerous cloud service providers are making use of cloud-based models to deliver these services. However, this makes it necessary for the organizations to evaluate the service offerings of different cloud service providers before adopting them. They need to understand the basic principles of operation in a cloud environment and use this knowledge to identify the security features needed to ensure security against possible external and internal security threats.

SECURITY IN THE CLOUD

Security in a cloud environment can be broadly classified into three categories: Network level security, Application level security and Virtualization security. It has been observed at multiple instances that the active cloud virtual machine instances are accessible through public cloud and allow hackers to leverage this opportunity to carry out DoS attacks. Cloud instances running on public cloud are most prone to these types of attacks and hence require a network level access control solution that would enable the delivery of cloud services in a highly protected environment. A detailed analysis of network level attacks has been carried out in [39]. The authors have gone on to propose a network based access control solution that provides additional security against such types of attacks. A few of the security threats that could be classified as network level attacks include: DoS attacks, DDoS attacks, Sniffer attacks, BGP prefix hijacking, DNS attacks, Man in the Middle attacks etc. A detailed analysis of these types of attacks has been carried out in [6].

Application level security refers to securing applications from any type of security attack in a cloud computing environment. Application security is important in the sense that it can be exploited to extract sensitive information or nefariously used to make inappropriate changes to important data. An evaluation model that can be used to assess the risks in moving a service to the cloud has been presented in [41]. The authors have *focused on integrating end to end services in a secure manner in a cloud computing model.*

Virtualization security refers to securing a VM or a hypervisor in a highly virtualized and distributed cloud environment. In a virtualized environment, hypervisor is defined as a virtual machine monitor that allows many VMs to be deployed on a single OS or multiple operating systems to run on a system at the same time. In brief, hypervisor can be referred to as a controller that monitors/controls the activities of all virtual/guest machines operating in a virtualized environment. There are risks associated with using the same physical infrastructure and even a small number of malicious users may cause threats to the others operating in the same environment. Since the VMs are mobile, they may switch between the hypervisors depending upon the availability of resources. These VMs are most often subjected to risks when they are moving. A few of the security threats, that could compromise the functioning of other VMs and of the hypervisor in a virtualized environment include: VM hopping [36], VM escape [36], mobility etc. Virtual machine images can also be exploited by attackers to launch a security attack. A virtual machine image contains information of the installed and configured applications and is used to restore the desired or initial state of the system. These images may be exploited to leak sensitive information. And hence it is necessary to keep them up-to-date with latest security patches [40].

Virtual network vulnerabilities such as: sniffing and spoofing virtual networks have been discussed in detail in [37]. Since the VMs share the same set of resources in a virtual network, it is highly possible to carry out the above mentioned activities. The authors [37] have leveraged the characteristics of different operating modes of a Xen hypervisor to propose a novel virtual network model that would make the communication (between the VMs) more secure and reliable.

Data security applicable to various states of data such as: data-in-transit and data-at-rest need to be considered. Security incase of data-at-rest refers to providing secure storage by making use of encryption techniques. The major limitation of this approach is that the data cannot be processed without decrypting it or without revealing the keys used for encryption [38]. A detailed analysis of techniques that could enable data processing without disclosing the keys has been carried out in [38].

PROPOSED SECURITY MECHANISM

The secure extraction of useful data mining information via Data Mining and Clustering API depends on a major factor: proper Authenticity and Security. Various mining or clustering API are used for numerous purposes. Some mining or clustering APIs are less secure to unauthorized accessof information that violates the dataand report privacy.

To make this mechanism secure,two types of security measures are proposed here. First one is the use of "The One Time Password System"[2] as pass key for authentication of API user and second is the implementation of Cloud Service User Authentication Agent (CS_A) [3] at the Server Side to authenticate the API user and client host details i.e. "Domain Trust" [1].

The system mechanism process of "One Time Pass Key":

The one time passkey is remembered by the Server Side API. CS_A (Server Side Authentication Agent) contains the following information:

- *The User ID*
- *A counter p, where p > 0 and which gets decremented every time CS_A authenticates an User ID*
- *The hash function Hp (k), i.e. H(H(…(H(k))…))*

Each time the sever side API wants to start access process; it has to choose passkey k and p in order to authenticate with the server side authentication agent CS_A. It then starts p times iterations of the one way hash function over this pass key k, i.e. Hp(k). Server side API user then securely transmits p and Hp(k) along with user-id to CS_A to initialize the system.

For authentication, server side API user sends user-id details with credentials to CS_A which in turn sends p. Then Server side API user computes Hp-1(k) and sends the result to CS_A along with the next "one time pass key (OTPK)"[4]. CS_A starts computing the hash calculation on the received OTPK and compares it with the stored

Hp(k). If they match, CS_A overwrites Hp(k) with the received Hp-1(k) and decrements p.

After the login credentials of server side API are authenticated, the attackers cannot determine Hp-1(K) from Hp(K). Since, the hash function cannot be determined, the system is against both eavesdropping and server database compromise. When p reaches 1, after getting decremented for server authentication of user ID, the Server side API user should select a new password and should reinitialize the system. There is no known secure way of automatic re-initialization and it should be done using Server Side API User Handler function.

Here, H is a one-way hash function such as MD5 [16] or RSA [15] and k is the pass key. None of the stored informationis considered to be sensitive to security. Therefore the "one time pass word"[2] system is suitable for authentication in this scenarios wherein the Client side API user procedure is considered not to be trusted or is vulnerable to compromise.

The first stepis the authenticationof domain using "Domain Trust" mechanism. It checks the client IP from where the request is made for Cloud API is trusted or not. Ifit is found to be"trusted", then CS_A procedure checks if the user id exists or not. If user id exists in the database then it checks its credential. If all the credentials are found correct then only the API is authenticated by CS_A and also executed for mining the data.

CONCLUSION

The proposed approach integratesCLOUD API User IP authentication along with One Time Key based User Authentication by discarding malicious users from the domain reducing unauthorized access of API. It also increases the security overhead using User's ID based on "One Time Pass Key" using Hashingprinciple and this framework fails to prevent malicious activity using any malicious code or parameter transfer procedure. In future fraudulent activity identifying approach can be added to this proposed approach which in turn makes the system to generatean alert about unauthorized fraudulent activity. Also this would help to prevent unauthorized accesses to cloud data as well as process. The procedure may also be extended to eradicate unauthorized data access and prevention in a heterogeneous cloud computing platform.

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