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BENEFITS OF APPLICATION OF CAD/CAM SYSTEMS IN METAL PROCESSING COMPANIES

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Abstract: The main goal of the research presented in this paper is to show the benefits that companies from the metal processing industry gain from the implementation of CAD/CAM technology in all segments of the product life cycle, from design to production of final product. Analyzing the production processes in metal processing companies and the global market requirements, in order to stay competitive on the market, the implementation and using of the flexible automation and CAD/CAM technology in the companies in all steps of the product life cycle is necessary. The crucial benefits of using the CAD/CAM technology in the metal processing companies are increased productivity of the engineers-designers, increased production productivity, high and repeatable quality and high production flexibility.
Keywords: CAD/CAM technology, Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), metal processing industry, product life cycle, selecting of CAD/CAM systems

INTRODUCTION

The companies of the metal processing industry today are facing with very big challenges, as a result of the tremendous competition on global level. High quality, low price and short delivery times are the elements that the company should realize in order to stay competitive on the market. In one word, the companies have to orientate into the borders of so-called "Iron triangle", presented on Figure 1 [1].

Figure 1. "Iron triangle" [1]

On other side, the dynamic of product changes and improvements desired by the market, needs high flexibility of the company in all steps in the product life cycle, from design to production of final product.

High product quality and high productivity, the companies can achieve with application of automation in the production process. In order to enable desired changes, flexibility in the designing and production process, the implementation and using of the flexible automation and CAD/CAM technology in all steps of the product life cycle is necessary.

In practice, the CAD/CAM technology is used for creating technical drawings, making drafts, geometric modeling of parts and assemblies that actually present digital representation of the designed products, geometric model analysis, creating technical documentation, programming CNC (Computer Numerical Controlled) production equipment, production process, quality control, packaging, etc.

Implementation of CAD/CAM technology in metal processing companies includes choosing of the right combination of CAD/CAM system (software, hardware and production equipment), purchasing the system and staff education. Which type of CAD and CAM tools will be used, depends of the product type, prescribed production technology, desired quantities, desired quality level and quality repetition requirements and desired design and production flexibility. The benefits that the metal processing companies gain from the implementation of CAD/CAM technology in the design and production processes, as well as, the approaches in choosing the right CAD/CAM system, are presented in this paper. The presented results are based on practical experience from the metal processing companies.

POSITION OF THE CAD/CAM TECHNO-LOGY IN THE PRODUCT LIFE CYCLE

The Figure 2 [2], [7] presents the position of the CAD/CAM technology in the typical life cycle of one product from the metal processing industry. The typical product life cycle contains two main processes:

» The design process
» The manufacturing process

In general, the typical life cycle starts with idea for development of a new or redesigned existing product, mainly as result of market research (for new products) or market feedback (for existing product). All necessary information about the product (design and functionality requirements, quality level, desired production quantity, very often the price level, etc.) are collected and analyzed in order to define the final concept of the product that will pass through all steps in the designing and manufacturing process.

CAD (Computer Aided Design) is part of the designing process, which is based on creating geometric model of the product that presents a digital representation of the designed product. In this process, except the visualization of the product, the CAD tools are used for additional activities with the geometric model, like different types of strength analyzes, simulation of the product functionality and at the end, as output from the designing process, preparation of technical documentation and generating necessary files as DXF, STEP, IGES or other files, that could be used in the process of manufacturing, if is necessary.

CAM (Computer Aided Manufacturing) is a part of the manufacturing process. Input in this process are the technical documentation, the geometric model and the created files in the design process. The largest influence of the CAM technology in the production process is in preparation of the production (mainly in the process of CNC based equipment programming) and in the direct process of production, where CNC based production equipment is used.

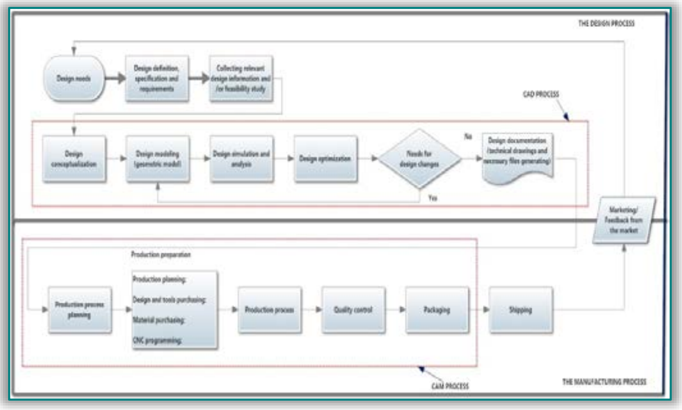

Figure 1. Typical product life cycle [2]

(COMPUTER-AIDED DESIGN) AND BENEFITS FROM IT`S IMPLEMENTATION

CAD (Computer Aided Design) can be defined as a product design by application of hardware (computer) and graphical software, that supports and improve the designing process in all its stages, from conceptualization to final documentation [9], [13]. The base of CAD is creating visual and digital interpretation of the product, represented by geometric model [4].

Today many different companies are present on the world market, that offer CAD applications, which includes different modules for designing and analyzing of the models, manipulation with the models and generating the necessary documentation [11]. From the wide range of applications on the market, the most used in the metal processing industry are CATIA and SolidWorks from Dassault System Company, AutoCad and Inventor from Autodesk, NX Unigraphis and SolidEdge from Siemens, etc.

All this applications include wide range of modules for different activities with the geometric model of the designed product, as modules for strength analysis, motion simulation, thermal and fluid flow simulation and analysis, etc. [9].

Nowadays, it is impossible company from the metal processing industry to be competitive on the market, without using CAD application in the design process. We can mention the general benefits that the companies gain with implementation of CAD system, compared with non using of CAD system. The major benefits are mentioned bellow [13]:

» Increased productivity of the engineers-designers;
» Increased quality of the product design;
» Unification of the design standards;
» Data base creation;
» Determination of the product quality and functionality early in the construction stage;
» Decreasing or completely elimination of the prototyping needs;
» Uniquely designation of the parts names;
» Elimination of the irregularities that can be issued by manual making of the drawings;
» Fast and simple way for model corrections;
» The engineers-designers become free from routine activities. That enables them to be more concentrated on creative activities;
» Design process starts directly with 3D (three dimensional) modeling;
» Easy file exchanges (communication) between different CAD applications using standard files – translators as IGES, STEP, ACIS, DXF, etc.;
» Geometric model can be used for different analysis and CNC programming directly.

For the purposes of this paper, in order to present the influence of using CAD application in the design process on the designer's productivity, two different approaches in designing with CAD application, are compared for the same product. Namely, the design process for one product group from the metal processing industry, fork extensions for fork lift (Figure 3), that contains 200 different dimensions (variants), cross sections and lengths from the same design, is analyzed. All dimensions that define the cross sections and the lengths of the variants, are closely connected with the dimensions of the parent fork on which the product is mounted, with exactly defined equations according ISO 13284-2003.

Figure 2. Fork extensions for fork lift – 3D model

For this purpose, the designing process is done by using SolidWorks software, as CAD application. The both analyzed approaches in the design process, are:

» Designing each variant separately;
» Designing, using parameter modeling with design tables.

In the first approach, all variants (cross sections and lengths) are designed separately with changing of each dimension that defines the product for each variant.

In the second approach, design table is created, in which all relations between the products dimensions and parent fork dimensions are defined, and each variant is designed only with changing of the parent fork dimensions. The only activity that designer should do is to fill the measures for the parent fork (Figure 4). The dimensions of the fork extension are calculated automatic using the defined equations, and all dimensions are applied on the 3D model.

For the both approaches, the times necessary for design process are measured and estimated per unit of variant. The results are presented in Table 1.

Analysing the results in the table, we can see that the first approach doesn't include any lead time for preparation of the designing of variants, which make it much more productive approach in designing of few variants. But designing of bigger number of variants, according the results in the Table 1, takes much less time using design tables, because the time estimated per unit of variant is few times less than the first approach.

Namely, the productivity of the designers using the second approach is 32/8.9=3.56 times bigger.

Saving time of 32-8.9=23.1 minutes per variant, for 200 variants is 77 hours in total, which equals to two work weeks of the designers.

Finally, we can summarize that different approaches in designing process, using different tools available in the CAD applications, can increase the designer's productivity several times.

Table 1. Measured times of the both approaches for designing product from (Figure 3), [10]

Design steps	Design each variant separately Time per variant (min)	Design using design table Total time (min)	Time (min) / variant for 200 variants
Creating 3D model	20		
Creating 2D drawing	10		
Creating DXF files	2		2
Creating 3D model and design table		360	1,8
Initial creating 2D drawing		20	0,1
Creating 3D model using design table for each variant			3
Creating 2D drawing using design table for each variant			2
Total time per variant (min)	32		8,9

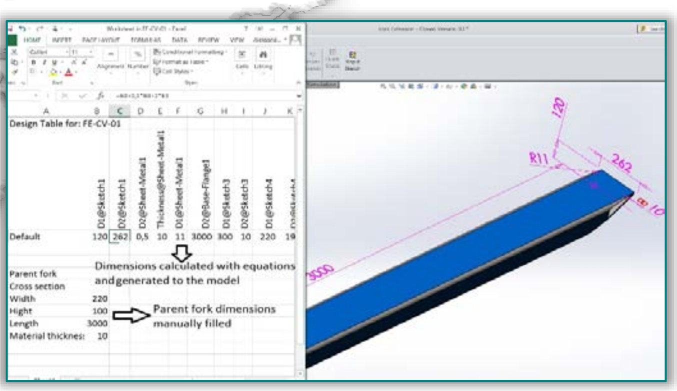

Figure 3. Modeling with design table

CAM (computer-aided manufacturing) and benefits from it`s implementation

CAM (Computer Aided Manufacturing) can be defined as application of computer technology in the process of production, using Computer Numerical Controlled machines (CNC machines) and software applications, nearly in all steps in the production process [9].

Implementation of CAM technology in the production process is one of the key factors for the companies from the metal processing industry to stay competitive on the market [4].

Today, almost all technological process that are part of the metal processing industry, are covered by CAM and CNC technology. Milling, cutting, bending, drilling, turning, painting, etc., as basic technological processes in metal processing industry are completely covered with flexible automation, with using CNC machines and adequate software applications (CAM tools) for programming of the machines.

Of course, the conventional approach in above mentioned technological processes using conventional production equipment is still present in metal processing industry. CAM supported and the conventional technological process have their own advantages and disadvantages. The general comparison, between CAM supported and conventional approach in metal processing technological processes are presented in Table 2.

The general benefits that the companies gain from the implementation of CAM technology in the production process, are:

- » High productivity;
- » High flexibility in the production process;
- » High quality and repeatability of the quality;
- » Less influence of the operators on the product quality;
- » Elimination of technological errors during the programming of the equipment;
- » Less scrap (For the cutting technology)

Table 2. CAM supported vs conventional technological processes

Criteria	CAM	Conventional
Flexibility	+	+
Productivity	+	-
Desired operator knowledge for the technological process	+	-
Influence of the operator on the product quality	+	-
Product quality	+	-
Quality repetition	+	-
Programming engineer engagement	-	+
Costs per hour	-	+
Maintenance costs	-	+
Production preparation time	-	+
Scrap (for cutting machines)	+	-

For purposes of this paper, in order to present the influence of the implementation of CAM technology on the productivity of production process in metal processing industry, two major technological process are analysed, milling and welding. For the both approaches, preparation and production times, for milling same part using CAM technology and conventional milling technology and welding of same product using robot welding station and manual welding, are measured. The results are estimated per unit of product and analysed.

A. Milling process

Milling process is analysed for metal part, shown on (Figure 5). Material of 407cm^3 is removed from the processed part with simple milling in lines, using the same milling tools on CNC milling centre and conventional milling machine and using optimal available milling parameters (number of revolutions, feeds and cutting depts.) on the both machines. CNC milling is done on CNC vertical milling centre with FANUC 0i-M controller. Programming is done using CamWorks software application.

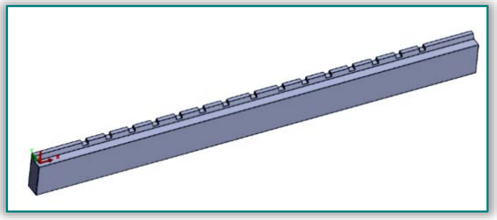

Figure 4. Milled metal part – 3D model

The conventional milling is done using conventional vertical milling machine.

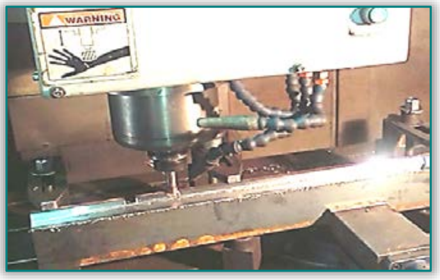

Figure 5. Milling process on CNC milling center

The time for production preparation and production time are measured and estimated per piece for the both approaches and they are presented in Table 3.

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Analysing the measured times, we can see that time for production preparation of the CNC milling centre is longer than preparation of the conventional milling machine, but the production time is smaller. For the current case, CNC milling as approach is 1.56 times or 56% more productive approach than the milling on conventional machine.

Increasing of the product quantity, decreases the preparation time per piece, and even for 10 pieces, the CNC technology is almost 3 times more productive approach. Additional increasing of the quantity (up to 100 or 1000 pieces), decrease the preparation time to minimal amount. The influence on the total production time, comparing with the direct production (milling) time, is minor and each quantity increasing, gives smaller and smaller rise of productivity. For example, for 10 pieces, the CNC technology is 2.9 times more productive than conventional milling, and for 1000 pieces, it is 3.27 times more productive, or for increasing the quantity 100 times, the productivity is increased only 12.7%.

Of course, these numbers represent only the current case. This analysis gives results that are different from case to case, but they present real and clear picture, how the implementation of CAM technology in metal processing industry influence on the productivity of the milling technology.

Table 3. Measured processes time for milling part form (Figure 5) using CNC milling centre and conventional milling machine [10]

Approach		For 1 piece Preparation time (min)	For 1 piece Production time (min)	For 1 piece Total (min)	For 10 pieces Preparation time (min)	For 10 pieces Total (min)
1	Milling on conventional milling machine	70	360	430	7	367
2	Milling on CNC milling center	165	110	275	16,5	126,5
3	Productivity of CNC milling VS conventional milling			1,56		2,90

Approach		For 100 pieces Preparation time (min)	For 100 pieces Total (min)	For 1000 pieces Preparation time (min)	For 1000 pieces Total (min)
1	Milling on conventional milling machine	0,7	361	0,07	360
2	Milling on CNC milling center	1,65	112	0,165	110
3	Productivity of CNC milling VS conventional milling		3,23		3,27

On Figure 7 is presented diagram of the measured times for the milling process that refers to Table 3.

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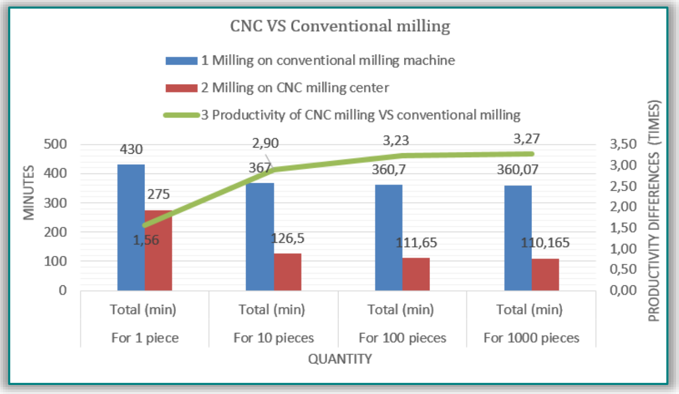

Figure 6. Diagram presentation of Table 3

Increasing of the product quantity, decreases the preparation time per piece, and even for 10 pieces, the CNC technology is almost 3 times more productive approach. Additional increasing of the quantity (up to 100 or 1000 pieces), decrease the preparation time to minimal amount. The influence on the total production time, comparing with the direct production (milling) time, is minor and each quantity increasing, gives smaller and smaller rise of productivity. For example, for 10 pieces, the CNC technology is 2.9 times more productive than conventional milling, and for 1000 pieces, it is 3.27 times more productive, or for increasing the quantity 100 times, the productivity is increased only 12.7%.

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B. Welding process

Welding process is analysed for metal assembly, shown on (Figure 8)

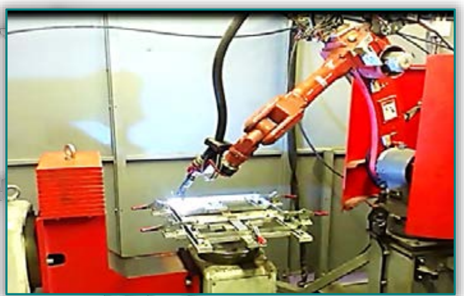

Figure 7. Welding on robot welding station

The welded part has 860mm weld length in total, and the same welding parameters (current, voltage and welding speed) are used for the manual welding and the welding using the robot welding station. For this purpose, PANASONIC robot welding station is used. For programming the robot welding station on-line method “Point to point” is used [7]. The time for welding preparation and welding process time is measured and estimated per piece for the both approaches. They are presented in Table 4.

On Figure 9 is presented diagram of the measured times for the welding process that refers to Table 4.

Analyzing the measured times from Table 4, we can see that the welding time on the welding station is less than the time necessary for manual welding, but the time necessary for programming of the robot welding station is significantly longer, that makes using of robot welding station for one piece, less productive and wrong choice. Even for 10 pieces, the total time for welding of robot welding station, estimated per piece, is longer than manual welding. According the diagram (Figure 9), the total time for robot welding approach will be on same level with the manual welding on quantity of around 50-60 pieces.

Table 4. Measured welding time for assembly from (Fig.8) using robot welding station and manual welding [10]

	Approach	For 1 piece			For 10 pieces	
		Preparation time (min)	Welding time (min)	Total (min)	Preparation time (min)	Total (min)
1	Manual welding	0	11,3	11,3	0	11,3
2	Robot welding	420	3,6	423,6	42	45,6
3	Productivity of robot welding vs manual welding (times)			0,03		0,25

	Approach	For 100 pieces		For 1000 pieces	
		Preparation time (min)	Total (min)	Preparation time (min)	Total (min)
1	Manual welding	0	11,3	0	11,3
2	Robot welding	4,2	7,8	0,42	4,02
3	Productivity of robot welding vs manual welding (times)		1,45		2,81

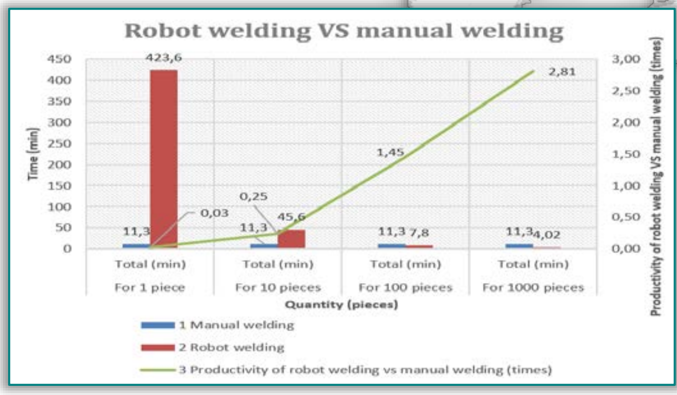

Figure 8. Diagram presentation of Table 4

Keeping in mind the fact that robot welding technology is much more expensive than manual welding, using of robot welding station could be right approach on quantity of more than 100 pieces, where the productivity of the robot welding station is 45% higher than the manual welding.

The additional quantity increasing of up to 1000 pieces, results with 2.8 times higher productivity of the robot welding station, compared with the manual welding.

According the results, we can summarize that if the preparation time for the robot welding process is longer (if the assembly on which is performed welding is more complex, the programming time is longer), the quantity that make this approach more productive is bigger.

Of course, these numbers represent only the current case, and this analysis gives different results from case to case. But nevertheless they present real and clear picture how the implementation of the flexible automation in metal processing industry influence on the productivity of the welding technology.

C. Influence of the CAM technology in material saving (Scrap decreasing)

In general, as a start of direct process of production in metal processing industries, the first action on the raw material is preparation of parts, using different technological processes for plates cutting (plasma cutting, laser cutting, gas or water jet cutting), tubes, bars and profile cutting (conventional or CNC controlled sawing), etc.

This step in the production process is directly connected with the material utilization and influence on the scrap quantity, especially for plates cutting. Using conventional cutting equipment, that is limited to cutting of straight line contours, enable big influence of the operator's skills on the material utilization. Namely, the plan for nesting of the desired parts on the raw material (the plate) is done by the operator, which in case of wide range of different part dimensions, is not always able to make the right nesting of the part, that leads to smaller material utilization (bigger quantity of scrap).

Implementation of CAM technology, mainly in the process of cutting complex contour shapes, supported with the market available nesting software applications, has improved the utilization of the row material, on the way that computer technology and software applications are used for complex calculations that make the nesting of the parts on the plates. The nesting applications have opportunities to generate NC code that is used for the CNC cutting machine as well. So the combination of the software application and CNC machine, forms the CAM system, which improves the productivity and quality of the cutting technology and the material utilization.

For purposes of this paper, in order to present the influence of the CAM technology on the raw material utilization, the case of conventional cutting using conventional shearing machine and the case of using CNC controlled plasma cutting machine for the same part specification, are analysed.

In the first case, the material nesting is done by the operator, and in the second case, it is used the nesting software ProNest (Figure10). For the second case, it is also analysed the material utilization, using different optimization levels in order to present the influence of the optimization level on the material utilization [10]. In all cases standard dimension of the raw material is used, mild steel plate 6mm thickness, 1500x6000mm plate dimensions, quality S355J2.

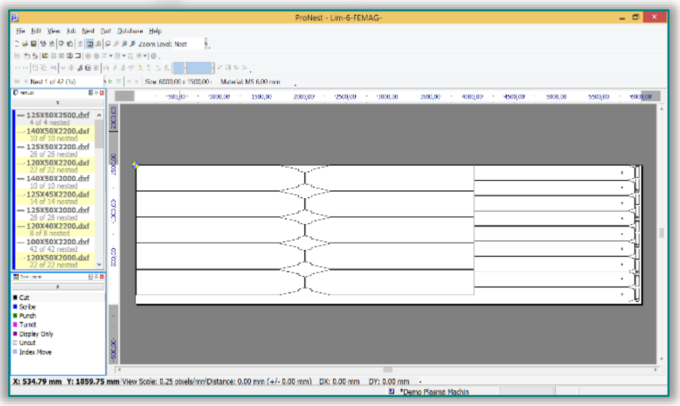

Figure 9. Nesting with ProNest application

The highest level of optimization requires larger computer capacities, which influences of the time necessary for nesting procedure, but results with higher material utilizations, Lower optimization level, requires lower computer capacities, takes less nesting time, but results with lower utilization. Which optimization level will be used, depends of the utilization criteria, the programmer`s experience and available computer capacities. On (Figure 11) is presented the material utilization using ProNest application, with higher optimization level and on (Figure12) is presented the material utilization using ProNest application, with lower optimization level. [10]

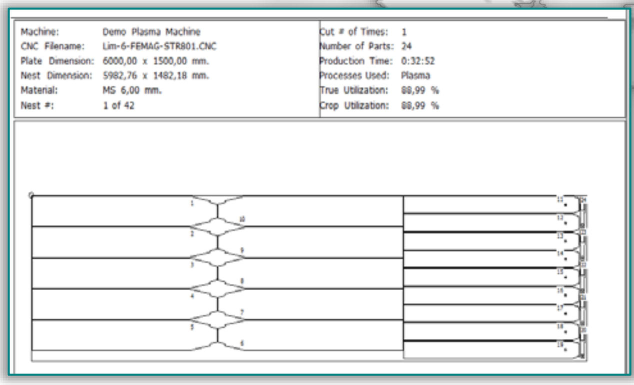

Figure 10. Material utilization with higher level optimization

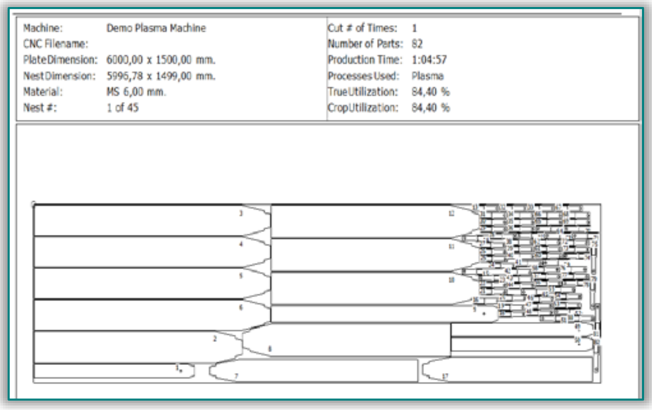

Figure 11. Material utilization with lower level optimization

The measured average utilization done by the operator for the same part specification is approximately 77%. The results are presented in Table 5.

Table 5. Material utilization for different nesting approaches

Nesting approach	Utilization
Utilization by operator	77%
Nesting with ProNest lower optimization level	84,4%
Nesting with ProNest higher optimization level	88,9%

According the results from Table 5, application of CAM tools can increase the utilization of the material from 7% to 10%, depends of the nested parts shapes and dimensions. Using different optimization levels, results with few percentage better material utilization.

We should mention, that manual cutting on conventional sawing machine, needs additional rework on the parts, which results with additional costs.

For illustration, one mid-size metal processing company that process annual quantity of 500 to 1000 tons raw material, with 10% material saves (50 to 100 tons saves), depends of the current material prices, the investment for CAM system in the process of cutting plates, can be returned in few years.

We can summarize that implementation of CAM technology in the process of material cutting, can save around 10% of the raw material, increases the productivity few times and enables cutting of complex contour shapes.

SELECTION OF CAD/CAM SYSTEM

Nowadays, on the market exist wide range of CAD/CAM systems and CNC production equipment that can be implemented almost in each technological process from the metal processing industry.

The companies from the metal processing industry sometimes have a doubt to choose CAD/CAM technology or to choose conventional approach in their processes, mainly in the production process because, as it is already mentioned, today the designing process is almost impossible without application of CAD system in the company.

D. Criteria for selecting CAD/CAM system

Which CAD/CAM system will be chosen by the company, depends on many factors, but in general, the company prescribes some criteria that the system has to fulfil in order to be adopted as best choice for the current needs of the company. There are many criteria, but in general can be classified in two bigger groups [3]:

» Exploitation criteria
» Economical-strategic criteria

The exploitation criteria, refers to the characteristic of the CAD/CAM system, which are directly connected with its usage in the practice. Some more important exploitation criteria are given below:

» Easy for use and learning;
» Compatibility with the existing company equipment;
» Effectiveness and efficiency;
» Available support, service and training;
» Upgrade possibilities;

» Available literature, manuals and handbooks.

As economical-strategic criteria we can mention the following:

» Company needs and strategies;
» Price;
» Total investment costs.

The priority level for each of above mentioned criteria, is defined by the company and it is part of its strategy. The most important during decision making is the right analysis of the company needs and adequate defining of the criteria priority. In practice, the process of analysis and making decision is time consuming, depends from case to case, and can lasts from few months to one year or more.

E. Productivity and cost effective analysis

Keeping in mind all advantages of the CAD/CAM systems and CNC technology, the decision, CAD/CAM or conventional approach in the production process, mainly depends on the volume of the production series. To determine which approach is better choice, it is necessary to analyse the both approaches from the aspect of productivity and cost effectiveness.

In general, CAM and CNC technology is much more productive, compared with the conventional technology, but the preparation for the production process takes much more time. Therefore, the production time and the preparation time estimated per piece have to be considered in order to make decision, which should be more productive. The total production time for the both approaches has to be compared, so the following equation can be used:

$$\frac{T_{pzc}}{n} + T_{prc} < \frac{T_{pzk}}{n} + T_{prk} \qquad (1)$$

where T_{pzc} is preparation time for the CAM based technological process, T_{prc} is production time of the CAM based technological process, T_{pzk} is preparation time for the conventional technological process, T_{prk} is production time of the conventional technological process and n is number of pieces form the production series. Hence, the minimal quantity of pieces in the production series that makes application of CAM systems and CNC technology more productive than the conventional approach, can be calculated as:

$$n_{min} > \frac{T_{pzc} - T_{pzk}}{T_{prk} - T_{prc}} \qquad (2)$$

But, in the decision making process, which approach is better choice, the CAD/CAM systems and CNC technology or the conventional production technology, one of the biggest disadvantages of the CAD/CAM technology, the costs for implementation and the running costs, have to be considered. Namely, the CAD/CAM systems and CNC based production equipment has higher costs per working hour, and depending on the analyzed production technology, can be even several times more expensive. Therefore, the productivity analysis is always connected with the costs analysis for the technological process. Each company has internal cost politic and calculated costs per working hour for each production equipment. The calculated costs per working hour for each production equipment include the following: costs for purchasing and implementation of the CAD/CAM system and CNC production equipment, costs for equipment amortization, labour costs, tooling costs, maintenance costs, staff education costs, etc.

Hence, considering the costs per working hour, the minimal quantity of pieces in the production series that makes application of CAM systems and CNC technology cheaper solution than the conventional approach, can be calculated as:

$$n_{min} > \frac{T_{pzc} * C_{tc} - T_{pzk} * C_{tk}}{T_{prk} * C_{tk} - T_{prc} * C_{tc}} \qquad (3)$$

where C_{tc} is the cost per working hour for the CAD/CAM system and CNC based production equipment, and C_{tk} is the cost per working hour for conventional production process.

The analysis of the productivity and the costs for both approaches in the production process, can help the company to decide – CAD/CAM system or conventional approach. Sometimes, the companies can chose CAD/CAM technology, even the costs are higher, if the productivity is decision criteria number one. At the end, the decision is part of the company strategy politic, which defines what are the priority criteria in decision making (productivity, costs, quality, etc.).

CONCLUSION

Implementation of the CAD/CAM technology in all steps of the product life cycle in the metal processing industry, from design to production, enable the companies to stay competitive and to response on the market requirements.

Analyzing the comparison between using CAD/CAM systems and conventional approach for the production technology processes, we can conclude that CAD/CAM systems have more advantages than the conventional approaches, especially in cases of higher volume of production series. Higher quality and quality repetition, higher flexibility, higher designers productivity, higher design quality, higher production productivity that can be bigger several times, saving material more than 10%, etc., are the key benefits that the companies gain from the implementation of the CAD/CAM technology and CNC based production equipment.

The analysis of the minimal volume of the production series, from aspect of productivity and economical aspects as basic criteria, helps the company to make decision which approach is more effective. Of course, the final decision needs more complex analysis, in which the companies prescribe the criteria list, and select the priority which the CAD/CAM systems have to fulfill.

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