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THE COMPARISON OF PERFORMANCE AND AVERAGE COSTS OF ROBOTIC AND HUMAN BASED WORK STATION FOR DISMANTLING PROCESSES

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ABSTRACT: *The main objective of this study was to compare human and robot performances for a simple dismantling operation by conducting a time study and cost evaluation. The dismantling task consisted of separation of a battery from a mobile phone (MP). Two work stations were analyzed and compared, one robotic and one human. The robotic work station was schematically designed and evaluated in simulation in order to achieve the dismantling times and costs. The human dismantling work station was tested in laboratory conditions. On the basis of calculating the average costs of dismantling of the battery for one mobile phone we can conclude that in the assumed conditions the robotic work station is a more efficient dismantling work station (1.20 eurocent per MP), and the human dismantling work station is less efficient.*
KEYWORDS: *average costs, dismantling processes, human performance, robot performance*

INTRODUCTION

One of the instruments for promoting productivity and flexibility in industrial dismantling seems to be by increasing mechanisation and automation [1]. More than 50 percent of the dismantling tasks concern disconnection of joints through the processes of releasing, dismounting, unscrewing etc. These jobs make up more than 50 per cent of the time. These processes are critical, as they represent a high number of alternatives and negative influencing factors. The performance of industrial dismantling therefore seems to be dependent on highly flexible automation [2]. The experience of some dismantling companies proves that an automation level can be achieved in an economically acceptable way [3,4].

For the analysis of dismantling processes we use in our study simulation and experiments [5,6]. The virtual reality and 3D modeling can be also very powerful tools for creating realistic simulation models of the processes [7,8].

METHODOLOGY

Our study compares the costs of a dismantling operation (separation of the battery from a mobile phone) at a robotic work station and at a human work station. One of the studies [9] dealing with the comparison of a assemble work station with a human operator and with a robot-based work station is based on an analysis of the time and costs of performing a simple assemble operation. Analogous to this study, our approach to the comparison of a robotic work station (alternative 1) and human work station (alternative 2) is also based on an analysis of the times needed to perform the operations (dismantling), and on an analysis or comparison of the total costs of separating the battery from a mobile phone. [10,11]

The first alternative (robotic work station) simulates the condition where the manipulation objects (MO) are freely placed on the line conveyor strand by means of a simple-design batcher (Fig. 1). The only monitored condition is MO batching at an exact time interval – line cycle. The direction and position on the conveyor strand is not monitored; this is ensured by a camera system working with a conventional robot. The robot receives instructions from the camera subsystem in the form of data flow, and calculates and adjusts the angle and the position of the mobile phone on the conveyor strand. After grabbing it the robot moves the phone towards the dismantling work station, where automated dismantling is carried out by means of special preparations and work units adjusted to work with the particular MO type. After separating the battery and the cover, the robot grabs the MO and places it on the conveyor strand at the required position and angle. Further dismantling into smaller parts therefore does not require MO positioning and directing, which reduces the costs and complexity of solutions for the next work stations. This manipulation and technological scenario is assessed from the point of view of time in the analytical part, on the basis of which the annual performance of the work station is determined, and the individual pieces of the work station equipment and other types of costs related to that work station are assessed [6].

The second alternative refers to a manual dismantling work station. This work station, as shown in Fig. 3, consists of an input bin (simpler than in the case of robotic work stations, with passive operation), a line conveyor strand and a dismantling table. The average time needed to separate the battery from one mobile phone is determined experimentally by means of a time study (chronometering). The study takes into account the experience factor by averaging the time of an inexperienced worker and of the minimum dismantling time attainable by a worker (measured as actual dismantling time). The study also takes into consideration the factor of mobile phones diversity and the resulting differences in the dismantling times. Since our time study (chronometering) did not consider presence of a conveyor strand, in order to ensure a better comparison with the robotic work station alternative we experimentally determined the time needed to grab the MO, move it from the conveyor and place it to the dismantling work station and back. The resulting average time is subsequently used to calculate the annual performance of one dismantling worker. In respect of this alternative, the work station equipment and the other types of costs related to these costs are assessed as well. [12,13]

These two alternatives are compared from the economic point of view in the final part of this study based on the average costs of separating the battery from a mobile phone, calculated as proportion of the total annual costs (including investment and operation costs) and work station performance indicated as the number of dismantled batteries from mobile phones per year. [14,15]

ANALYSIS OF THE PERFORMANCE AND COSTS OF A ROBOTIC WORK STATION (SIMULATED DISMANTLING). DISMANTLING WORK STATION DESIGN AND DESCRIPTION

Undirected separated objects of dismantling – discarded mobile phones enter the line whose main inter-operational transport unit is the conveyor. The first automated cell within the line is the so-called battery dismantling cell, being the most dangerous object of manipulation and dismantling [5,16,17].

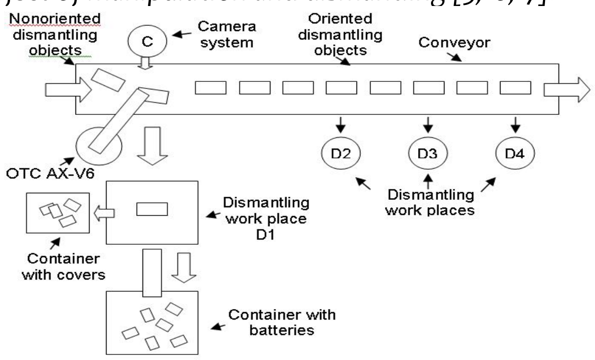

Fig. 1. Robotic work station for mobile phones dismantling

The robotic cell (Fig. 1) has the following manipulation and technological scenario:

1. Stopping the conveyor driven by a servomotor or stepper motor.
2. Image recording in real time and its evaluation by means of the Omron ZFV Monochrom camera system (Fig. 2).
3. Sending the data about the position and direction of the manipulation objects on the conveyor to the control system of OTC AX-V6 robot (Fig. 2).
4. Taking the right position using the scanning subsystem data.
5. Grabbing the object of manipulation with a special gripper.
6. Directing and moving the object of manipulation to the D1 dismantling work station.
7. Releasing the object of manipulation from the gripper.
8. Separation of the cover and battery at the dismantling work station.
9. Placing the battery into the container.
10. Grabbing the dismantled cover and placing it in the covers container.
11. Grabbing the rest of the object of manipulation and placing it on the conveyor at the right direction.
12. Starting up the conveyor.
13. One - cycle conveyor operation.

Table 1. Time simulation of the individual steps of the manipulation and technological scenario

Step	1	2	3	4	5	6	7
Time (s)	0.3	1.2	0.0	1.7	0.3	2.5	0.2
Step	8	9	10	11	12	13	ΣTime
Time (s)	1.9	0.1	0.1	2.5	0.3	1.0	12.1

Table 2. Investment costs of a robotic work station as per components and cooperating equipment

Dismantling line component	Input bin	5-year AX-V6 robot	Special gripper	Dismantling work station with containers	Conveyor
Estimated price/costs (€)	2300	27800	2000	35000	4500
Dismantling line component	Camera system	Estimated installation costs	Total costs	Estimated annual costs*	
Estimated price/costs (€)	1200	3000	75800	3032	

(Note.: *The estimated life-cycle of the equipment is 25 years)

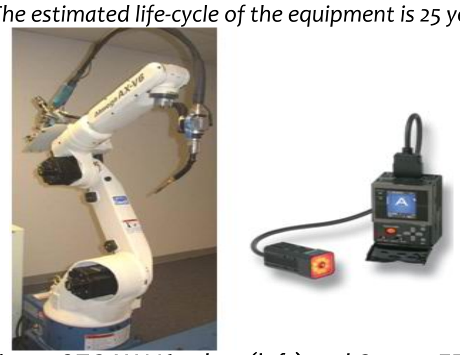

Fig. 2. OTC AX-V6 robot (left) and Omron ZFV Monochrom camera system (right)

The OTC AX-V6 robot is a high-speed, precise motion manipulator primarily intended for welding applications. It can also be used for mounting and dismantling types of applications, which requires replacement of the technological head with a grabbing head.

The working cycle of a dismantling work station was simulated with the robot. The output information is listed in Table 1. It is highly probable that this data does not differ from actual values of a working robot within a line's working cell.

ANNUAL WORK STATION PERFORMANCE

The time simulation of the individual steps required for separating the battery from a mobile phone (Table 1) shows that the total number of batteries separated from mobile phones would be 595042 per year (2000 hours * 3600 sec. / 12.1 sec).

AVERAGE ANNUAL COSTS OF THE WORK STATION

Two types of costs are considered in the calculation of the average annual costs: investment costs (Table 2) representing the price of the work station and the installation costs and operating costs, including electric energy consumption, maintenance and repairs.

The following procedure was followed in the calculation of the operating costs:

The electric energy consumption of the robot is approximately 2.6 kW. The price for 1kWh is 0.0859€ (KLASIK M tariff for small- and medium-sized enterprises from the local electricity supplier VSE), including VAT; the monthly payment is 0.83€. Hence, the monthly electrical energy consumption of the robot attains 36.56€, which is 439€ (12*36.56€) of the annual electric energy costs. The input bin with an energy input of 500W will consume 80 kWH per month, which represents annual electric energy costs of 83€. The conveyor is driven by 300W servomotor. The estimated costs of energy consumption for operating the conveyor in accordance with the set manipulation scenario are 14€. The annual electric energy costs are 536€.

The maintenance of the OTC AX-V6 robot counts with average annual costs of approx. 2500€. This amount includes inspection costs (inspection of the manipulation equipment once in two years, and inspection of the wiring system once in a year), diagnostics and planned maintenance. As far as the assisting equipment is concerned, such as dismantling work station and input bin, the estimated maintenance costs are the following:

- dismantling work station - 700€ per year,
- input bin - 400€ per year.

The total annual costs of maintenance are 3600€.

Hence, the total operating costs (the total of energy costs and costs of maintenance and repairs) attain 4136€ per year.

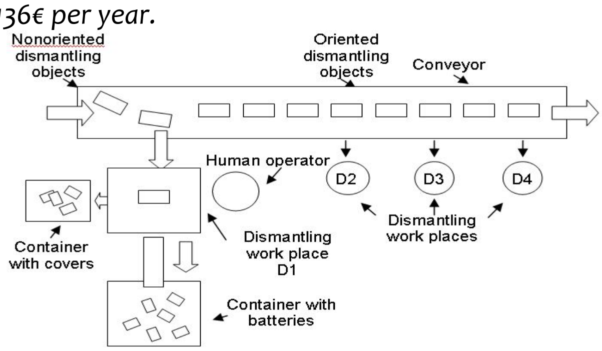

Fig. 3. Work station for manual dismantling of mobile phones

ANALYSIS OF THE PERFORMANCE AND COSTS OF MANUAL DISMANTLING WORK STATION (EXPERIMENTAL DISMANTLING) – Dismantling Work Station Design and Description

The manual dismantling work station (Fig. 3) is designed similarly as the robotic work station, and the differences are described in the methodological part.

ANNUAL WORK STATION PERFORMANCE

The calculation of the annual work station performance is based on the available working hours of a one-shift operation and average time of separating the battery from a mobile phone, determined experimentally.

The available (nominal) working hours of one worker in 2008 is 2000 hours [18].

The procedure for calculating the average time of separating the battery from a mobile phone, which is the main subject of our study, is the following:

First, we conducted a time study (we measured partial dismantling times) of the same mobile phone type with two operators (volunteers). The measurement methods in respect of the two operators differed. As for the first operator, the total duration of the individual dismantling operation including time for determining the method of dismantling was measured. As for the second operator, the actual time of the operation (physical job) was only measured, excluding the time for considering the dismantling method. Based on this data we could determine the limit times (minimum and maximum time) from the point of view of operator's experience. The maximum time represents the condition of an inexperienced worker, whereas the minimum time can be achieved by an experienced (trained) worker. On the basis of these values, the first average time was calculated. The results of this time study are provided in Table 3.

Next, we measured the actual dismantling time of nine mobile phones of different brands in order to eliminate the differences in dismantling times resulting from different phone designs. To measure the times, we chose such mobile phone types which had been used most frequently according to telecommunication operators' information, and their number would therefore be the highest in the actual dismantling process. The average time calculated from the total of times of the first two operations (taking off the external cover and battery) measured under study [9] for nine different phones is 00:03.84 seconds. All the dismantling operations were performed by the same operator and without the use of any tools.

The third step was to calculate the average time of battery separation from a mobile phone. The calculation of the average time of dismantling a mobile phone takes into account the data measured in the previous two steps in the following way: the mean average of the times measured in step 2 is used, reflecting the average time with different types of mobile phones. This average time equals 3.84 seconds. From Table 3 data, the index of operator's average experience was calculated, which represents the percentage increase of the time of a worker with average experience against the minimum possible time of dismantling (actual dismantling time). This index equals 4.2958716 (00:18.73/00:04.36). The resulting average time of separating the battery from a mobile phone (calculated as the average time calculated from the first two dismantling operations with different phone types multiplied by the index of operator's average experience) is 16.50 seconds, rounded up (3.84 seconds * 4.2958716) or 0.00458 hours.

For better comparability of the two alternatives, we also experimentally studied the time needed to grab, move and place the MP from the conveyor to the dismantling work station and back. The time per one operation (grabbing, moving and placing the MP from the conveyor to the dismantling work station and back) determined by measuring the time of ten such operations is 3 seconds. This time was added to the average time of battery separation from one mobile phone. The resulting average time equals 0.00542 hours.

Table 3. Time study of dismantling a Siemens 150 mobile phone [19,20]

Operation	Operator 1 –without any experience (maximum dismantling time)	Operator 2 – (minimum dismantling time)
Taking off the external cover	00:12.2	00:01.17
Taking off the battery	00:20.9	00:03.19
Total	00:33.1	00:04.36
Average time	00:18.73	

The average annual performance of a worker (number of batteries separated from mobile phones per year and worker), based on our calculation of the average time of separating the battery from one mobile phone (taking into account 3 seconds for moving the MP from the conveyor and back) is 369004 pieces (2000/0.00542).

AVERAGE ANNUAL COSTS OF A WORK STATION

Analogous to the previous alternative, the investment costs will first be determined for this work station counted over one year of the equipment's life-cycle. The prices/costs of the equipment of which this work station consists were set as follows: the estimated price of one simple input bin is 400€. The price of a simple dismantling table was determined on the basis of the information from REGAZ SK s.r.o. at 1000€ [21]. The bin and the table require no maintenance and their estimated life - cycle is 25 years, and can even be more. The estimated price of the conveyor, as in the previous cases, is 4500€ and its life - cycle is 25 years.

The total investment costs per dismantling work station equal 6100€, which is 244€ per year in the case of a 25 - year life - cycle (6100/25).

When determining the operating costs of the manual dismantling work station, the total annual labour costs are taken into account, as well as the conveyor's operating costs (or energy consumption costs) at the amount of 14.00€, since this alternative counts with the use of a conveyor.

The total annual labour costs/costs per dismantling worker are determined as follows: first, the total monthly costs per one dismantling worker are calculated as the sum of the average gross monthly salary of an employee working in the industrial production sector in Slovakia (SKK 22093 (Source: Slovak Statistical Office) and of insurance payments paid by employer (36 % of gross salary in 2008, rounded up) [8]. The total monthly costs per one dismantling worker are 997.36€. Hence, the total annual costs per one dismantling worker are 11968.32€ (997.36€ * 12 months).

CONCLUSIONS

The comparison of the individual work station from the point of view of average costs of separating the battery from a mobile phone under assumed conditions suggests that the costs of the manual work station (3.31 eurocents per MP) are approx. 2.7 - times higher compared to the robotic work station (1.20 eurocent per MP).

According to our assumptions, the performance of the manual dismantling work stations attains 62 % of the annual performance of the robotic work station.

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