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THE POSSIBILITIES OF IMPROVING THE HUMAN-MACHINE CO-OPERATION IN SEMI-AUTOMATIC PRODUCTION PROCESS

MOŻLIWOŚĆ DOSKONALENIA WSPÓŁPRACY CZŁOWIEKA I MASZYNY W PÓŁAUTOMATYCZNYM PROCESIE PRODUKCJI

Abstract

Nowadays, modern production processes are undergoing intensive technological development, according to Industry 4.0 and Industry 5.0 assumptions. Despite the separate differentiation and numbering of these terms, the assumptions of the two approaches do not contradict each other. Industry 5.0 is a type of an extension of the drive for the highest possible degree of integration of automated systems (along with the pillars assumed in Industry 4.0) by finding a place where humans prove to be irreplaceable and their needs are identified as the most essential, central aspect. This leads to the implementation of semi-automated processes in which the cooperation between human and machine is the key. The paper presents an analysis and the results of the studies performed in company that produces vehicle control systems in automotive. The research includes quarter-a-year of studies and observation of production process. The studies aimed identifying waste in production process and proposing improvement methods, with particular reference to automated operations. Implementation of proposed improvements was mainly based on re-programming automated systems, but also on adding new process of cleaning brakes, that allowed to reduce the number of scrapped parts. Moreover, the implicated solutions allowed to achieve reduction of production process cycle time, financial savings and risk of the defects.

Keywords: semi-automatic production process, human-machine co-operation, Industry 4.0, Industry 5.0, production process improvement

Streszczenie

W dzisiejszych czasach nowoczesne procesy produkcji przechodzą intensywny rozwój technologiczny, powiązany z wdrażaniem założeń Industry 4.0 i Industry 5.0. Pomimo odrębnego rozróżniania i numerowania tych terminów, założenia obu tych podejść nie są ze sobą sprzeczne. Industry 5.0 jest niejako poszerzeniem dążenia do możliwie wysokiego stopnia zintegrowania zautomatyzowanych systemów (wraz z filarami zakładanymi w Industry 4.0) o odnalezienie miejsca, w którym człowiek okazuje się być niezastąpiony, a jego potrzeby identyfikowane są jako najistotniejszy, centralny aspekt. Prowadzi to do powstawania procesów pół-automatycznych, w których znaleźć można miejsce na współpracę pomiędzy człowiekiem i maszyną. W artykule przedstawiono analizę i wyniki badań przeprowadzonych w firmie produkującej systemy sterowania pojazdami w branży motoryzacyjnej. Badania obejmują kwartał-rok badań i obserwacji procesu produkcyjnego. Badania miały na celu identyfikację marnotrawstwa w procesie produkcyjnym oraz zaproponowanie metod usprawnień, ze szczególnym uwzględnieniem operacji zautomatyzowanych. Wdrożenie zaproponowanych usprawnień polegało głównie na przeprogramowaniu systemów automatycznych, ale także na dodaniu nowego procesu czyszczenia hamulców, który pozwolił na zmniejszenie liczby złomowanych części.

Słowa kluczowe: pół-automatyczny process produkcji, współpraca człowiek-maszyna, Industry 4.0, Industry 5.0, doskonalenie procesu produkcji

1. Introduction

Improving manufacturing processes has been an area of research being performed by the scientists for decades. There are many methods and tools to help organize processes so that they are efficient. Most often, these methods are based on the reduction or elimination of waste, mainly oriented toward reducing the time of activities that do not add value to the product, such as transportation, redundant operations or excess inventory.

The industry and the technologies used in it are among the most rapidly growing areas of the modern world. For years, companies have been striving to deliver their products and services in the most efficient way possible. All companies that improve continuously look forward to reducing waste, defects and costs while keeping the high quality and possibly

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low price of the products or services [1, 2]. The development of industry is characterised by the occurrence of breakthroughs and inventions, which result in the technologies used being replaced by new, better, more efficient and often cheaper solutions. Industrial revolutions represent milestones achieved by industry and technology for hundreds of years. From the introduction of steam engines and machine control in the first industrial revolution, to the emergence of production lines based on electrical solutions in the second revolution, to automation in the third industrial revolution. Since then, the solutions introduced in successive revolutions have, as it were, been further developments of technology and automatization rather than replacements.

Until recently, mainly four stages of industrial development could be found in the literature, although references to a further, fifth stage are increasingly common (fig. 1).

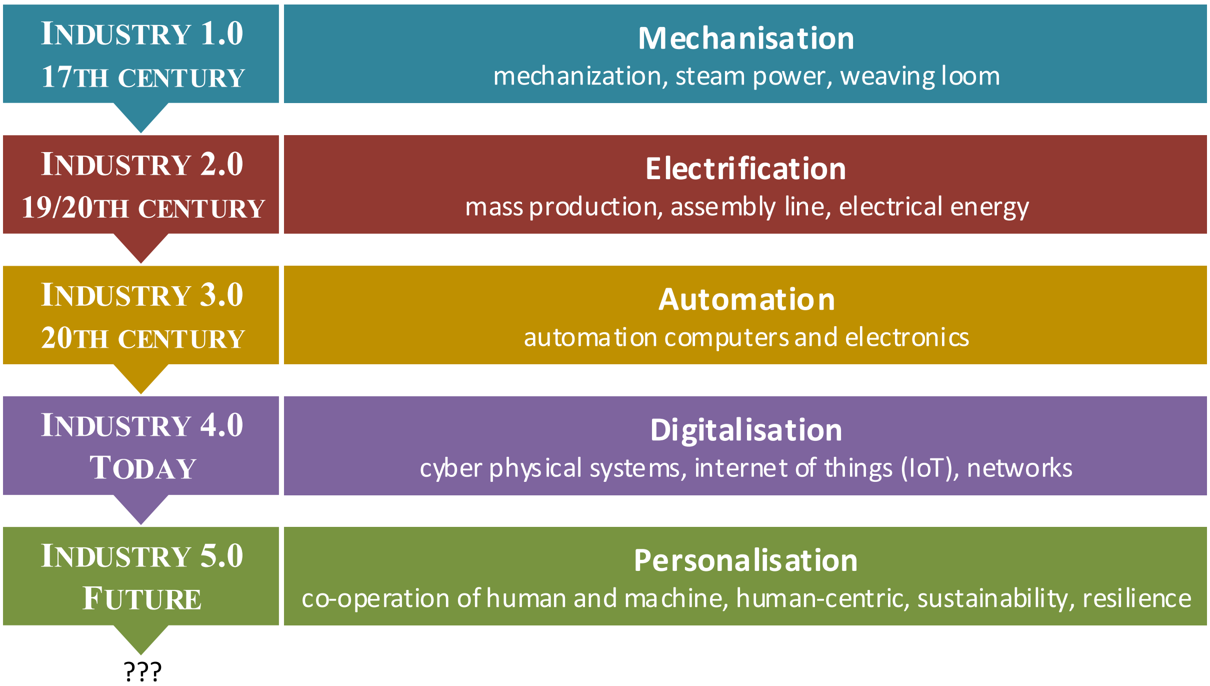

Fig. 1. Industry development phases

The reality and industry development shows that it is impossible to completely replace human work in every area, thus many companies are opting for a semi-automated way of manufacturing products. This is a method of manufacturing that combines both manual work by an operator and automatic methods. This has given rise to the fourth revolution, called Industry 4.0, and the fifth revolution, gaining in popularity, called Industry 5.0. Both of them are adding new and relevant assumptions, that should be implemented in innovative companies. Following the implementation of Industry 3.0, which primarily included process automation, researchers and practitioners began to look for solutions to integrate these processes and systems, which led to the fourth industry revolution, Industry 4.0, which was introduced in 2011 [3, 4, 5]. The assumptions of Industry 4.0 base on the nine pillars, which are are being more and more often implemented in the companies by performing various improvements, which include using autonomous robots, simulations, system integration, internet of things (IoT), cybersecurity, cloud computing, additive manufacturing, augmented reality and big data in production processes [6, 7, 8, 9, 10]. However, the sustainability is getting more significant among researchers over last decades [11, 12]. The researchers are working on finding solutions that allow to perform the same processes but with the more ecological solutions, i.e. by the reduction of pollutant emissions [13].

The aim of this article was to verify the possibility of improving existing semi-automatic processes based on human and machine co-operation, basing on an example of the automotive industry.

2. Semi-automatic processes as a solution of human and machine co-operation

Nowadays, in the reality of Industry 4.0, production process improvement usually involves automatization of the process. Automation is one of the most important issues in industrial development, representing one of the four main pillars of Industry 4.0, the concept of Smart Factory, or enterprises in which "*manufacturing will be completely equipped with sensors, actors and autonomous systems*" [14]. The greatest degree of automation of manufacturing processes is found in companies in the IT, electronic engineering and mechanical industries [15]. However, there are few works in the literature discussing the improvement of already automated processes. However, the waste and losses occur in all manufacturing processes, including automated ones. This situation also occurred in the company that case was described in the article, which is an international manufacturer of safety systems in the automotive industry. The research was conducted on the basis of observation and analysis of processes over a quarter of year.

The area of research described in the article concerned the manufacturing process of brakes, used in trucks. The analysed production process is semi-automatic. In this case, the degree of automation of individual operations has been divided according to the components involved. The product is a calliper, which is the main, largest and heaviest component of the finished product, and a number of small parts, such as bolts and seals. The process primarily consists of assembling the brakes and performing tests on various parameters to ensure the quality of the finished products. Some of the assembly operations are performed by a human and some by a machine, as shown in the matrix of actual production process automation stage (fig. 2).

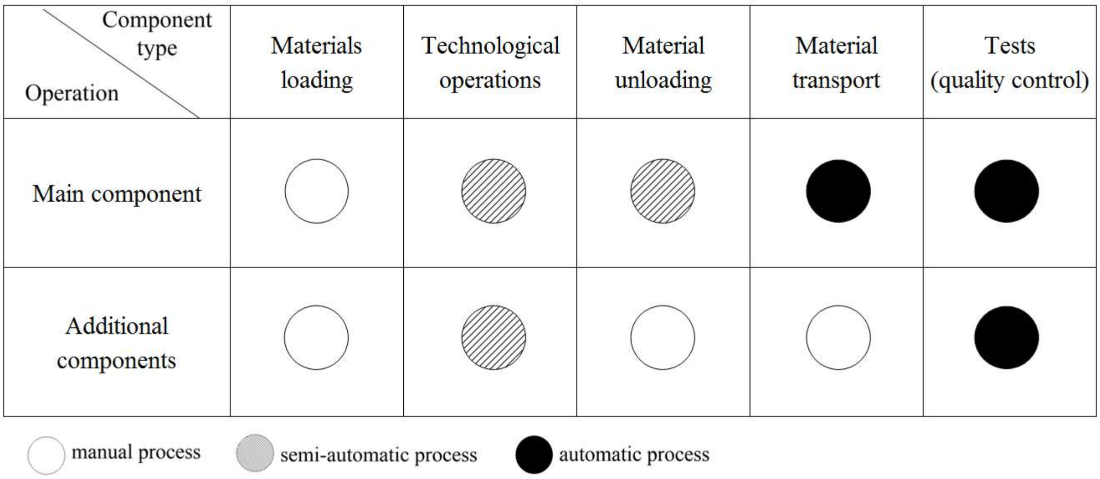

Fig. 2. The matrix of actual automation stage of production process

Automatization of the operations performed does not mean that there are no opportunities for improvement. In the research the methods to improve both automatic and semi-automatic operations were proposed.

3. Semi-automatic process: waste identification and improvement propositions

An analysis of the possibility of improving individual stations, as well as the entire production line, was carried out. The base of the research was an observation of the process performed with particular emphasis on downtime that required to stop the production process. This is an extremely important issue due to the fact that each stoppage interrupting the production process generates significant losses, both financial and in the form of delays in fulfilling customer orders. In order to identify the causes of downtime, an Ishikawa diagram was developed (fig. 3).

According to the research, the main causes of downtime in the company's production process were found to be parts shortages, machine breakdowns and maintenance, and staff training and meetings. The Ishikawa diagram highlights the area of machine breakdowns, as they also cause downtime by generating production shortages that require disassembly. Machine breakdowns in the company in this case are mainly failures of optical sensors and automatic tests. This issue was measured by observing production for 12 weeks (table 1).

In the company, production is mainly in a two-shift mode, with a shift lasting 8 hours and operators taking a 20-minute break. Thus, downtime due to machine breakdowns represents an average of 17.8% of the total time available for production per week. In total, for 12 weeks, downtime related to machine breakdowns alone amounted to almost 164 hours. These figures indicate the need to improve processes to reduce machine breakdowns and therefore reduce the time the plant is not producing products.

A total of one production line was analysed for improvement opportunities during the observation. Three workstations, which are equipped with automatic testing systems and optical sensors, were selected for further analysis. Subsequently, the entire production line was also analysed for opportunities for improvement.

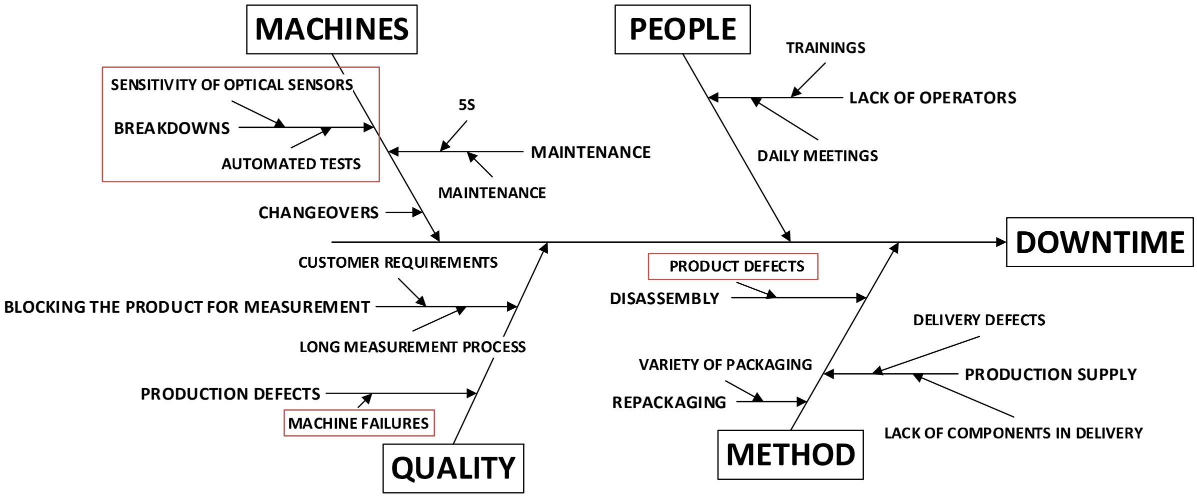

Fig. 3 Ishikawa diagram: production downtime reasons

Table 1. Production downtime caused by machines failures

Week no.	**Downtime [min]**
W1	605
W2	1320
W3	1260
W4	1640
W5	820
W6	520
W7	375
W8	740
W9	605
W10	865
W11	285
W12	790
Total downtime in 12 weeks [min]:	9825
Average downtime in one week [min]:	818,75

3.1. Greasing, assembly and clamping processes improvements

The first station where changes were made is the greasing station. This is a station where the machine first performed an automatic test of one of the parameters and then performed the greasing process. These activities were performed independently of each other, one after the other, and each took an average of six seconds. This resulted in the need to wait for an employee to complete the automatic operation of the machine. It was proposed that the machine be reprogrammed so that the two operations were performed in parallel. In this way, the process is still automated, but the operation has been shortened by 6 seconds.

The next station analysed was an assembly station, where the organisation of the operation required the separate confirmation of two steps, one after the other. This confirmation triggered the start of the automatic assembly operation of the components. It is important to note that the double confirmation of the automatic assembly operation was not due to safety requirements. Therefore, the opportunity arose to integrate the system in such a way that it required a single confirmation for both steps. According to the analysis, this saved a further five seconds from the production time of the product.

The third station analysed for improvement was the pressing station. In this process, the machine pressed the workpiece with a high force, using an automated clamp descending towards the workpiece. It turned out that it was possible to significantly reduce the height of the original clamping position, as illustrated by the diagram in Figure 4. With such a simple improvement, the production time of the product was reduced by as much as nine seconds.

The clamping position was lowered which allowed to perform this operation quicker. The application of the improvements within the three stations described, greasing, assembly and clamping, saved a total of 21 seconds of production time per unit of product. This is a significant change, as the production cycle time for this assembly line was, before the improvements, 69 seconds. These improvements therefore reduce the production time of the product by approximately 30%.

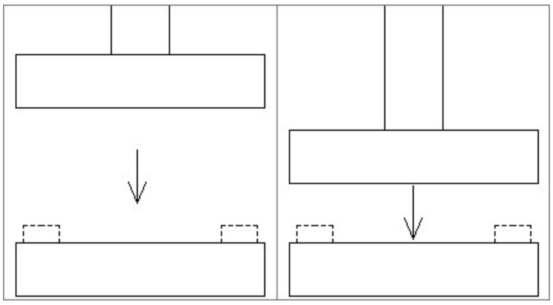

Fig. 4. The change of clamping height scheme

3.2. Sensors and visualisation as a production process improvement

In addition to the proposed ways to improve individual workstations, the production line as a whole was also analysed. The line, consisting of a total of fifteen workstations, requires regular checks on the operation of the machines performing automatic assembly operations. This check applies to seven workstations and is carried out by the operator checking the visual inspection panel located next to the workstation. This results in the operator having to turn away from the work in progress. Because of this, it is easy to miss errors in machine operation. It has been proposed to install an automatic lights, integrated into the visual control panel, within the worker's line of sight. It is difficult to calculate the actual impact of this solution on actual performance, but based on information obtained from the company's engineers, it has been estimated that each error eliminated immediately, rather than after time, represents a saving of around 450 Euro.

The company is also equipped with a number of fully automated optical sensors, which are subject to frequent failures. There are usually multiple optical sensors within a single station, so that detecting the onset of a fault in one of them is problematic. These sensors report defects in the products, but their failure does not stop production. It was investigated that each failure of an optical sensor required about 30 minutes for the operator before it was detected. According to the data, during a half-hour of production with a faulty optical sensor, a maximum of 26 defective semi-finished pieces could be produced. Once the failure is detected, the potentially defective pieces must, according to quality requirements, be disassembled. As a solution, it was proposed to introduce automatic visualisation of the sensors with which the station is equipped, so that it took the operator a maximum of one minute to detect a defect. This is too short a time to produce a piece, so no defective product can be produced as a result of a sensor failure. It has been estimated that this could save as much as 1300 Euro per failure.

3.3. The reduction of the number of wasted components

The main component that was mentioned earlier, the calliper, is the most important part of the brake. This is mainly due to its dimensions, as it is a much larger and heavier part, but also more expensive than the others. The part is a body with a total of six threaded holes in the appropriate places (fig. 5). All six threads needs to be cleaned in the process.

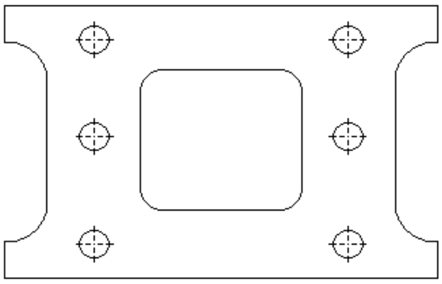

Fig. 5. Calliper general scheme (main component)

The calliper is moved in the production line in an automated manner using conveyor belts. In the production process, it is possible to make corrections to errors that arise only when these are identified by the machines in the production process. This mainly concerns non-compliance with quality requirements within the brake parameter tests. However, some products are only identified as defective products at the last station, so finished non-conforming products are created. In this case, the non-conforming product is scrapped. However, before this can happen, the product must be disassembled, for waste separation. Small components, such as screws or bolts, do not represent a major loss, due to their low unit price. The situation is different for the calliper, which is a much more expensive component. After disassembly, grease remains in the holes of the clamp, which is the only reason why the entire clamp cannot be reused. According to data obtained from the company, it was estimated that this is a source of loss for the company of about 6.5 pieces per week. As a solution to this problem, it was proposed to implement a cleaning process for dismantled callipers. Using suitable brushes mounted in a rotary device, the holes can be cleaned of grease without damaging the threads. Appropriate quality measurements of the parts cleaned in this way were also carried out, which confirmed the applicability of this improvement. By recovering parts in this way, the company has reduced the number of scrap clamps by around 80%. The remaining 20% consists of terminals that do not meet requirements for other reasons. The implementation of this improvement has saved the company around 200 Euro per week.

The improvements proposed in this article have been further analysed, in terms of the priority of their implementation. The proposed methods of improvement have been summarised (table 2).

4. Conclusion

The improvement proposed in the research discussed in this article proves that it is possible to improve already automated processes based on human-machine co-operation. This means that the process of automating the activities performed does not necessarily represent the end of the optimisation effort. Both the development of technology and the ability to take an objective look at the process make it possible to perform further changes that ensure continuous improvement of the production efficiency. In this case, the proposed improvements enabled to reduce the time of one piece production by 20 seconds, which is a huge difference in the automotive industry reality, where every second counts. Moreover, the reduction of failures and detects also enabled to achieve measureable financial savings in the process. The summary of achieved profits is shown in table 2.

Table 2. Propositions of improvements – summary

No	Waste	Solution	Profit
1	Automatic test and greasing performed independently of each other, one after the other	Reprogramming of the machine: test and greasing performed in parallel	Reduction in the production process by 6 seconds per unit
2	Need to confirm two steps consecutively	Reprogramming of the machine: confirmation of steps at a time	Reduction in the production process by 5 seconds per unit
3	Long travel of the automatic press from the starting point to the blank	Lowering the starting point of the automatic press to shorten the travel of the press to the blank	Reduction in the production process by 9 seconds per unit
4	Necessity to look away in order to control the operation of automated machines, easy to overlook errors	Installation of automatic lights to spot errors in machine operation immediately	Estimated savings of around 450 Euro for each error eliminated
5	Frequent failures of the automatic optical sensors, requiring up to 30 minutes for identification	Installation of automated visualisation of sensors, integrated with the machine, shortening the time for the identification of failures to 1 minute	Elimination of the risk of producing defective products (up to 26 pcs.) as a result of failure of an automatic sensor (up to 1300 Euro savings for one failure)
6	The need to scrap callipers in which grease was left in the holes after disassembly	The implementation of a threads cleaning process from the grease and reusing the callipers after disassembly	Reduction in the number of scrapped callipers by about 80% (ca. 200 Euro savings per week)

Proposed solutions and improvements of the process mainly included an analysis of opportunities to reduce production time and the costs incurred. In the course of further research, it would be worth extending the analysis to include environmental and ergonomic factors, which are the basic principles of Industry 5.0.

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