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IMPLEMENTATION OF THE INSTALLATION MONITORING PLAN IN AN ENERGY COMPANY

WDROŻENIE PLATFORMY MONTAŻOWEJ W FIRMIE ENERGETYCZNEJ

Abstract

The work presents five stages of implementation of the assembly platform in an energy company. It focuses on indicating the adaptation of the assembly platform for the final product, which are low, medium and high voltage switchboards in the energy company. The first two chapters present the definition and application of the assembly platform. The next chapter deals with the research carried out on the introduction of the assembly platform to the energy company. The work ends with a summary and conclusions.

Keywords: assembly platform, assembly areas, efficiency, low-, medium-, and high-voltage switchboards

Streszczenie

W pracy zostało przedstawione pięć etapów wdrożenia platformy montażowej w firmy energetycznej. Praca koncentruje się na wskazaniu dostosowania platformy montażowej dla produktu końcowego, jakim są rozdzielnie niskich, średnich i wysokich napięć w firmie energetycznej. Pierwsze dwa rozdziały przedstawiają definicję i zastosowanie platformy montażowej. Kolejny rozdział przedstawia wykonane badania nad wprowadzeniem platformy montażowej w firmie energetycznej. Pracę kończą podsumowanie i wnioski.

Słowa kluczowe: platforma montażowa, obszary montażowe, wydajność, rozdzielnice niskiego, średniego i wysokiego napięcia

1. Introduction

In the 21 century manufacturers are considerably challenged by low production costs. They focus on delivering products as soon as possible in order to satisfy varied consumer demands. Adapting products to these demands, which combines aspects of economies of both scale and scope, seems to incrementally depend on an industrial production mode. Researchers and companies concentrate on the end product which is a strategy element in mass product adaptation project. The end product may increase competitive power, promote sustained development and improve innovative skills [5, 17].

The concept of product platform has become a key term in the entire innovative process of end product development. Such an approach may have a tremendous effect on the entire process of end product development, including relations between a supplier and a customer [12].

Developing a model of the end product family manufactured on the basis of the same product platform is considered to be an effective solution. More and more companies are using such an approach in the manufacture process of their end products, which indicates substantial economic benefits in the face of the ever-changing global production market. Those benefits mainly arose from a higher quality of end products, a faster response to market demands and lower manufacturing costs. Using product platforms and studying their architecture or structure are attracting more and more attention from both research community and industry [8, 9, 22].

2. Definition of product platform

The concept of product platform has become the key term in innovation process. Such an approach can have a tremendous effect on the entire product manufacture including relations between a supplier and a customer [12].

By definition, product platform, which the author develops, is a relatively large set of product components whose elements are connected with each other as

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a stable component and are common for various end product models. Some of the components serve the same function; however, it does not apply to all the components. By using such a product platform, a company may create a substantial group of various end products. Generally speaking, potential benefits resulting from using a product platform can be summarised as follows:

- lower production costs,
- reducing construction time and end product assembly time,
- reducing the complexity of the whole construction and end product assembly system,
- facilitating a constant end product improvement [12].

Using a product platform influences the organizational structure of companies in which such a platform is implemented [12].

McGrath defines a product platform as "a set of similar elements, especially technological ones, used in a particular set of products" [10].

Robertson and Ulrich emphasise that "by division of components and production processes on a product platform, companies may manufacture varied end products successfully, increasing flexibility of manufacturing processes and taking market shares from the manufacturers that make one product at a time" [16]. What is more, a product platform facilitates end product adaptation, which makes it possible to develop different products in an easy and rapid manner in order to satisfy needs of different market niches [15, 19]. The influence of product family and product platform structure on the variety of products obtained from a given platform and their mass adjustment is still the topic of extensive studies [3, 6, 7, 20, 21].

The essence of product platform development lies in acquiring as many end products as possible by using standardized components and different manufacturing processes. Therefore, adjusting a product platform involves discovering common elements of a specific product family (such as shared functions, parameters, characteristics, components, subsystems or sufficient amount of information related to manufacturing of a specific product family) and subsequent adjusting and standardization of the aforementioned common elements or parameters [11, 22].

The use of a product platform consists in:

1. Analysing the usefulness of a product platform in manufacturing a given set of end products.

a) Developing a product family and a suitable structure of the product platform in the way which allows obtaining the final platform that stands out among others in terms of design or construction.

b) Discovering restrictions which impact the parts manufactured by the most frequently used product platforms, which includes:
   - identifying both common modules/subsystems in a given product platform and the correlations between their interfaces,
   - identifying both common components of a given end product developed on the product platform and the correlations between them.

Product platform standardization is made primarily by using the elements of a given platform as well as its components and subsystems.

This process involves the standardization of:

a) components of a product platform, including its structure and parameters,
b) subsystems and interfaces,
c) the process of production and product system managements, etc. [22].

Using product platforms has become the priority in competition between companies, and therefore many businesses accept the concept of such a product platform. However, they interpret it differently and vary in the way they make us of it. Japanese companies have introduced a strategic programme of using a product platform in the process of manufacturing end products, which, thanks to further efforts, resulted in simplifying the end product model. Different functions of a platform need to be examined if one wants to understand why the strategic programme has been adopted [12].

Table 1 shows strengths and weaknesses of product platforms.

The significance of a product platform can be examined both from strategic as well as from organizational or technical point of view. Implementing a product platform strategy has an effect on the course of product manufacturing process, and particularly on the costs, reduces the end product design time as well as the time of its introduction onto the world markets. The programme of strategic use of product platforms improves the management of companies in which such they are implemented. The product platform strategy is closely connected with the way in which a platform is developed in relation to other elements of the product. The process of product platform development is also subject to technical correlations because it involves the use of various troubleshooting aspects related to further stages of end product manufacturing such as its construction or its modularisation. The significance of product platform does indeed have a close relationship with both end product modules and its construction or appearance [12].

Table 1. Strengths and weaknesses of product platforms, the author's own compilation based on [1, 2, 12, 18]

Product platforms	
Strengths	**Weaknesses**
Strategic phase - various products reach the market faster, - entering niche markets, - implementing new technologies, - lower technological risk, **Design phase** - lower development costs, - reusing components and systems designed earlier, - reusing well-tried technologies, **Product managment phase** - possibility of using the same tools in the production of various products, - economical manufacturing, - possibility of bulk purchasing of the same subsystems used for manufacturing various products, - reduction in warehouse stock, - lower quality-related expenses, - flexibility in the number of product variants, **Phase of testing and putting into operation** - reduction in the time devoted to testing and putting product into operation for the first time, - shared testing equipment of various products, - reduction in the number of certification tests, **Phase of operating and maintaining the product** - reduction in fixed costs of maintaining products due to their shared functions, - lowering costs of staff training, - lowering variable costs due to more efficient logistics activities.	**Strategic phase** - restrictions on future investment in extending the platform, - risk of the market being monopolized by a company developing the product manufacturing strategy, **Design phase** - the necessity to do research into the technical and economic feasibility of developing a product, - extra costs connected with the necessity to design additional product-differentiating components of the product platform, - overhead costs connected with commonality management of the product platform elements, **Production management phase** - increased complexity of product configuration management on the assembly line, - increase in the costs of subsystems production, **Phase of testing and putting into operation** - increase in the costs of developing the methods of verifying and validating the product and the product platform, **Phase of operating and maintaining the product** - risk of failure in manufacturing common elements for a variety of end products, - increased complexity of operating multi-purpose elements, - increase in the costs of operating subsystems, - increase in the costs of product platform management.

End product construction involves setting functional elements of the product into physical blocks. The goal of end product construction is to define basic structural blocks of the end product in terms of both their performance and their cooperation with the remaining elements of a piece of equipment. Therefore, a module can be described as a large group of physically interrelated parts forming a component, which often has a standardized design interface. Modules can be the same in different projects, but they can be specific only for one end product model as well. In such case, using modularisation has many benefits, including:

- possibility of manufacturing various end products which has little effect on manufacturing end product components,
- reducing the number of manufactured end product components,
- better effectiveness resulting from automation [12].

The significance of a product platform can be examined in terms of organization. A product platform is essentially a method of creating a functional set in the process of end product development. However, integrating such a set can be limited to technical decision-making or can involve some responsibility for commercial aspects of the end product. Looking at the significance of a product platform from organizational perspective, requires different criteria of aggregation (the process of combining elements into a larger whole) which are significant for the platform operating team.

Technical criteria usually have priority in selecting the 'universal' product platform. Nevertheless, factors such as a market segment and a method of market saturation should be considered as well.

There are many similarities between various types of product platforms, as a result of which organizational and technical aspects of product platforms can overlap with each other [12].

3. Research product platforms

Research on the implementation of the assembly platform has been carried out in an energy company. He provides comprehensive construction and assembly services for investments related to the energy, petrochemical, mining and public utilities industries in the turnkey system [4].

The significance of product platform is more and more visible in various industry sectors and many companies have to make a number of decisions on this matter. Work is heading towards elaboration of the five basic stages of the product platform development.

Stage One – creating the product platform as a physical structure of the product. This raises two essential questions. Firstly, how should a product platform be defined from a technical perspective when complexity of the product is considered? Secondly, in what way does the product platform relate to other concepts connected with end product planning process such as product construction or modularisation? To illustrate this stage Table 2 enumerating the components of low and medium voltage switchboards is complied and Figure 1 showing a diagram of the product platform for low and medium voltage switchboards is presented.

Table 2. The components forming low and medium voltage switchboards

Equipment (Safeguards)							
Component / **Supplier**	**Current and voltage transformers**	**Breakers**	**Contactors**	**Circuit breakers**	**Disconnectors**	**Earth switches**	**Safeguards**
Elektrobudowa	-	-	-	-	-	MV	-
ABB	LV & MV	LV & MV	LV & MV	LV & MV	LV & MV	-	LV & MV
Siemens	-	LV & MV	LV & MV	-	LV	-	LV & MV
Schneider Electric	-	LV & MV	LV & MV	-	-	MV	LV & MV
ZWAE	-	LV & MV	LV & MV	MV	MV	-	-
Drive							
Manual	LV & MV						
Motor	LV & MV						
Conductor rails							
Rectangular (30 x 3)	LV						
Rounded (10 x 80)	LV & MV						
Rounded - Special (24 x 33, 30 x 15)	LV & MV						
Channel Section and T Section (45 x 45)	LV						
Cables & cable cross-sections							
power 75 – 240 mm^2, control 1,5 – 4 mm^2, in auxiliary circuits 1 – 4 mm^2	LV						
power 75 – 400 mm^2, control 1,5 – 4 mm^2, in auxiliary circuits 1 – 4 mm^2	MV						

Source: the author's own study (LV – low voltage, MV – medium voltage).

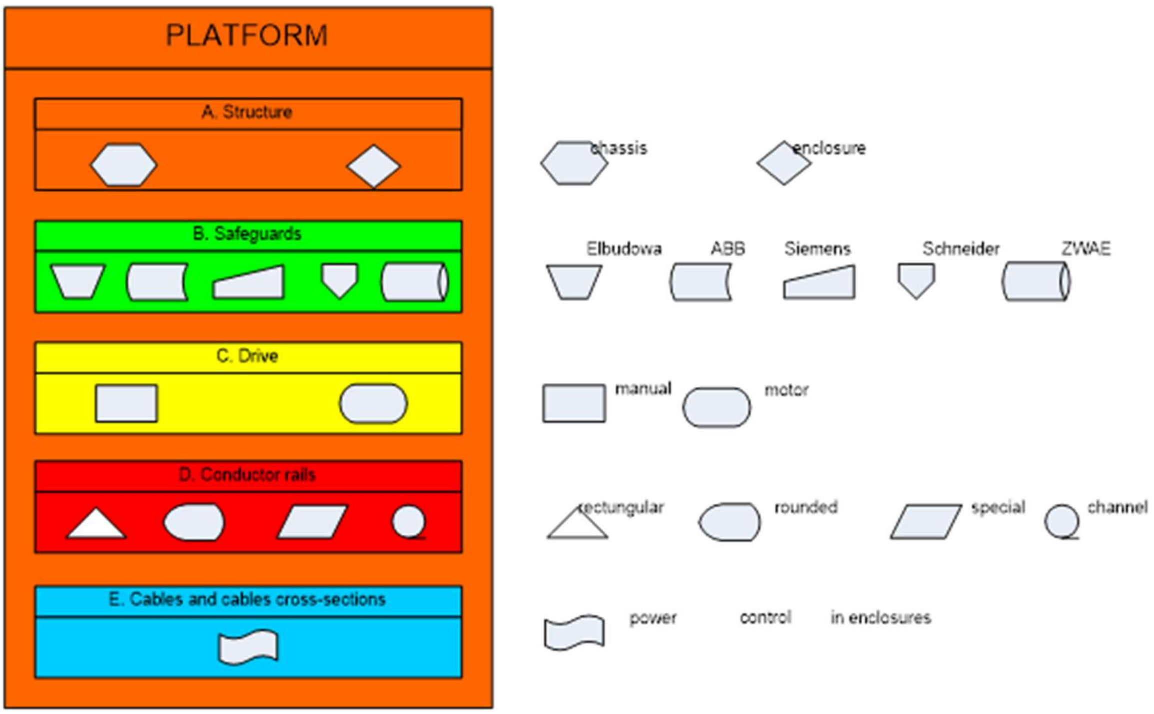

Fig. 1. Diagram of a product platform for low and medium voltage switchboards (the author's own study based on [13, 14])

Below there are combination matrices (i.e. all the possible customer choice combinations for a given product; lines of a matrix represent switchboard components while columns of a matrix represent variants of switchboards possible to manufacture) of variants for manufacturing low and medium voltage switchboards. 16 variant choices are available for manufacturing both low and medium voltage switchboards (Fig. 2 & Fig 3).

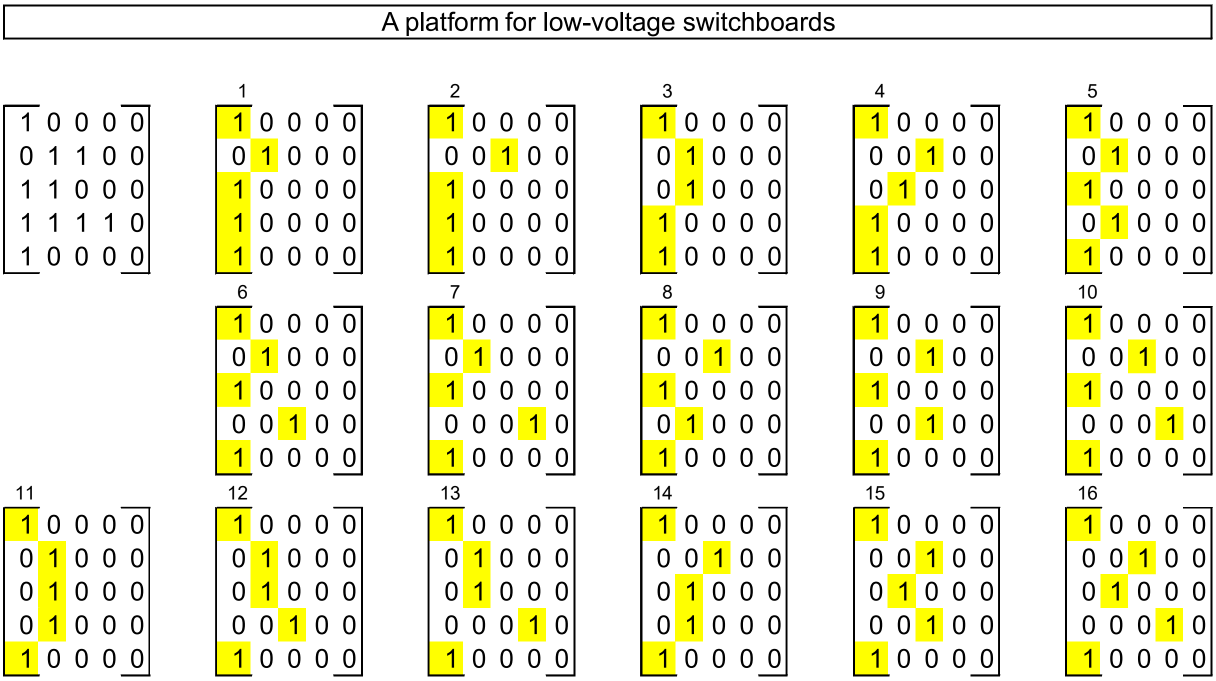

Fig. 2. Matrix of combinations for manufacturing low voltage switchboards [the author's own study]

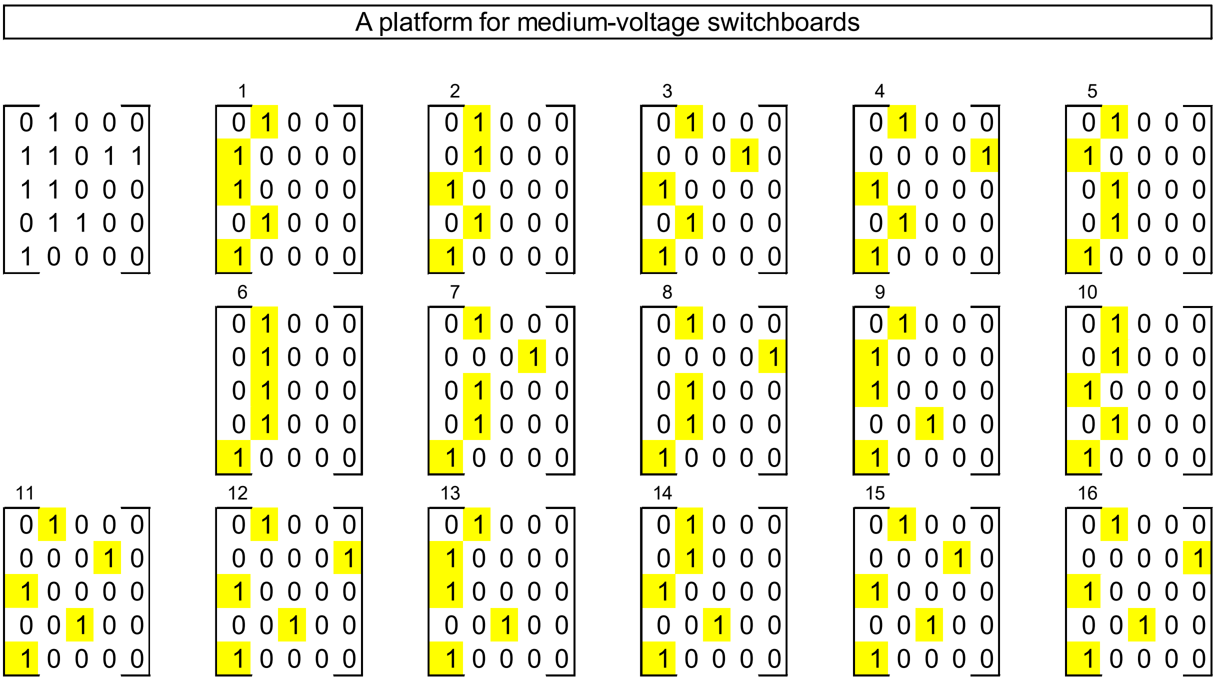

Fig. 3. Matrix of combinations for manufacturing low voltage switchboards [the author's own study]

An example of the matrix is shown below:

Columns represent feasible variants of switchboards (e.g. frame or enclosure)

Lines of the matrix represent switchboard components (e.g. design, safeguards, drive, conductor rails, cables and cable cross-sections)

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Authors used binary system in combination matrices in which 1 represents an occurrence of a specific component while 0 represents no occurrence. The matrix consists of five columns, which is determined by five types of safeguards. As regards the number of lines, it is connected with the number of switchboard components.

Stage Two – grouping operations in order to define the technological similarity or commonality of the manufactured products. This raises two essential questions. Firstly, how should operations involved in installation of a particular switchboard be grouped (Table 3)? Secondly, how is the product platform connected with other operations related to the process of manufacturing the end product such as the construction of a given product?

Table 3. Operations performed in making low, medium and high voltage switchboards

No.	Summary	LV	MV	HV
1	Manufacturing essential structural elements	1	1	1
2	Adhesive bonding of bushing insulators on stainless steel sheets	0	0	1
3	Combining the detailed parts of the tank and priming with switchgear	0	0	1
4	Filling the tank	0	0	1
5	Switchboard buses assembly	1	1	1
6	FOBOX box assembly	1	0	0
7	Upper earth switch box or voltage measurement box assembly	0	1	0
8	Slide-out modules assembly	1	1	0
9	Earth switch modules assembly	1	1	0
10	Assembling modules for drying the motor or measuring the transformers	0	1	0
11	Lower measurement modules assembly	0	1	0
12	Hub assembly	0	1	0
13	Bus bar assembly	0	1	0
14	Control gear assembly	1	0	0
15	Screwing the FOBOX enclosure together	1	0	0
16	Assembling the post for modules	1	0	0
17	Switchboard access platform assembly	0	1	0
18	Back or side attachment for switchboards	0	1	0
19	Testing the proper functioning and technical state of the switchboard before shipment	1	1	1
20	Final assembly of external front and back shields	1	1	1
21	Packaging and shipping	1	1	1
	Total	**11**	**14**	**8**

Source: the author's own study (LV – low voltage, MV – medium voltage, HV – high voltage).

It was assumed that the basic grouping criterion should be the technological commonality of the manufactured parts, thus on a scale from 0 to 1 it was assigned weight of $w_T = 1$. For the mass of the product (switchboard), a weight of $w_M = 0,75$ was assigned, and for the external dimension (width), significant because of the amount of the occupied space, a weight of $w_{DZ} = 0,2$ was assigned.

The next stage of the procedure is the normalisation of the value of a feature. It was assumed that the numerical value representing a particular feature should be placed between 0 and 1. In such a case, the normalised value of a feature:

- for a technological process of product 1 is equal to a ratio of 11 operations performed on the LV switchboard to a maximum number of operations, that is 11/21 = 0,52; this value multiplied by weight $w_T = 1$ results in a final value of 0,52,
- for a technological process of product 2 is equal to a ratio of 14 operations performed on the MV switchboard to a maximum number of operations, that is 14/21 = 0,67; this value multiplied by weight $w_T = 1$ results in a final value of 0,67,
- for a technological process of product 3 is equal to a ratio of 14 operations performed on the HV switchboard to a maximum number of opera-

tions, that is 8/21 = 0,38; this value multiplied by weight $w_T = 1$ results in a final value of 0,38.

The comparison performed on the basis of these calculations indicates that basing solely on the criterion of technological commonality, the deviation between features of product 1 and 3 amounts to 0,14, that of product 1 and 2 amounts to 0,15, and that of product 2 and 3 amounts to 0,29.

Under these circumstances, if one intends to perform a division of operations into two groups, group A can consist of operations of product 1 and 2, whereas one should attempt to incorporate operations of group 3 into another group (obviously, one can also decide to incorporate it into group A, but this commonality is a slightly lower than for operations for products 1 and 2). An additional criterion was introduced into the grouping example. The criterion was a switchboard mass: LV = 760 kg, MV = 600 kg and HV = 11100 kg. Assuming that there is a ratio of 760/11100 = 0,07 for LV, then the feature multiplied by weight of 0,5 has a value of 0,03. The values of the feature of external dimension (width) were calculated in a similar manner. Thus, every operation has defined feature values (Table 4).

Table 4. Feature values for low, medium and high voltage switchboards

No.	Feature	L	M	H
1	Technological process	0,52	0,67	0,38
2	Switchboard mass	0,03	0,03	0,50
3	External dimension (width)	0,21	0,19	0,25

Source: the author's own study (LV – low voltage, HV – medium voltage, HV – high voltage).

Applying a distance classifier (KO – abbreviation derived from the initials of the Polish name) in which every part is represented by a matrix of feature value, the value of KO was calculated for each pair of products.

- for product 1 and 2:

$$KO_{1-2} = \sqrt{\left[\begin{pmatrix}0,52\\0,03\\0,21\end{pmatrix} - \begin{pmatrix}0,67\\0,03\\0,19\end{pmatrix}\right]^T \cdot \left[\begin{pmatrix}0,52\\0,03\\0,21\end{pmatrix} - \begin{pmatrix}0,67\\0,03\\0,19\end{pmatrix}\right]} =$$

$$\sqrt{\left[\begin{pmatrix}-0,15\\0,00\\0,02\end{pmatrix}^T \cdot \begin{pmatrix}-0,15\\0,00\\0,02\end{pmatrix}\right]} = \sqrt{0,025+0+0,0004} = \sqrt{0,0229} = 0,15 \quad (1)$$

- for product 2 and 3: $KO_{2-3} = 0,55$,
- for product 1 and 3: $KO_{1-3} = 0,49$.

The lowest value of a distance classifier for products 1 and 2 indicates the highest level of commonality from the perspective of the analysed features.

Stage Three – performing the cost analysis of manufacturing products by means of a product platform. This raises two essential questions. Firstly, what factors should be taken into account for determining the cost of a product manufactured by means of a product platform? Secondly, what will be the value of a coefficient for the cost analysis?

First, the analysis of the time required for the switchboard assembly was performed in to the energy company. The time study was divided into three stages: preparation, the measurement of the time consumed by the operation and the calculation of the results (of the time study). Steps taken during the time study were as follows:

1. familiarizing with the employees performing the researched operation, as well as with the organization and operation of the workstation and the device on which it will be performed (table 5),

Table 5. Analysis of an assembly workstation, the author's own study

Company employees responsible for research	Research time	Researched workstation
technologist	6^{00} - 14^{00}	Work team of engineers and electricians who were responsible for assembling the product

2. Familiarizing with the correctness of the working methods, the usefulness and sequence of actions performed, groups of operations and actions,
3. Preparing observation worksheet of the time study,
4. Determining the number of essential measurements dependent on how much time is consumed by particular operations or its elements as well as the production volume,
5. Performing the measurements of time consumed by the product assembly by means of continuous observation or random observation using instruments selected for this task (duration times of each operations for every product were measured by stopwatches manufactured

by German company Hanhart MODUL featuring the accuracy to one second).

6. Entering the values of the time consumed by product assembly into the observation worksheet prepared beforehand (which form a series of timings).
7. Analysing the series of timings by rejecting values grossly deviating from the average values calculated by means of the so-called 'integrity coefficient',

$$K_s = \frac{x_{max}}{x_{min}} \quad (2)$$

where:
x_{max} – the longest measurement duration,
x_{max} – the shortest measurement duration [30],

8. calculation of the average measurements (arithmetic averages) of time required for performing specified tasks (only percentage values are shown due to trade secret policy of the company) (Fig. 4).

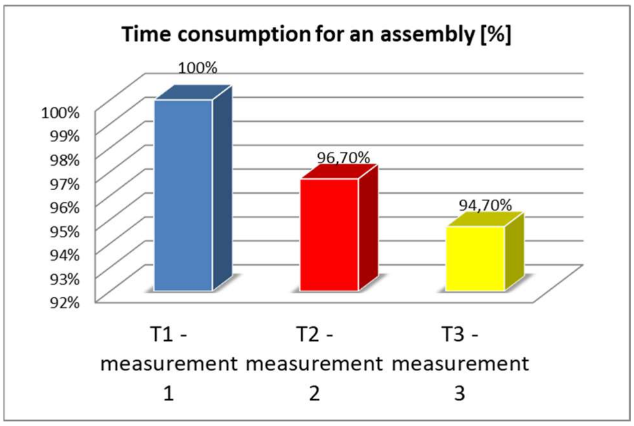

Fig. 4. Presentation of time consumption of switchgear assembly in an energy company (the author's own study, T1 – measurement 1, T2 – measurement 2, T3 – measurement 3)

The conducted research shows that the time required for switchboard assembly is inversely proportional to the number of repeated operations performed by a particular employee. As for cost-effectiveness and profitability of manufacturing, it was proved that both indicators are directly proportional to the number of repeated operations. In short, the more particular operation is repeated, the less time is required for assembly with a simultaneous rise in cost-effectiveness and profitability of the manufacturing.

This analysis indicates a possibility of implementing the rule known as 'practice makes perfect' in the technological process and implementing the learning curve (Fig. 5) since performing repeating operations, which is training, causes a reduction of the time required for performing a particular action. In Figure 5, R value specifies the expertise rate which is 'learning' rate; it means improving efficiency in relation to each succeeding execution cycle of a particular operation. Obviously, the listed methods of production capability adjustment are presented as examples. With creativity of managers in this regard, the range of these possibilities is constantly expanding [13, 14].

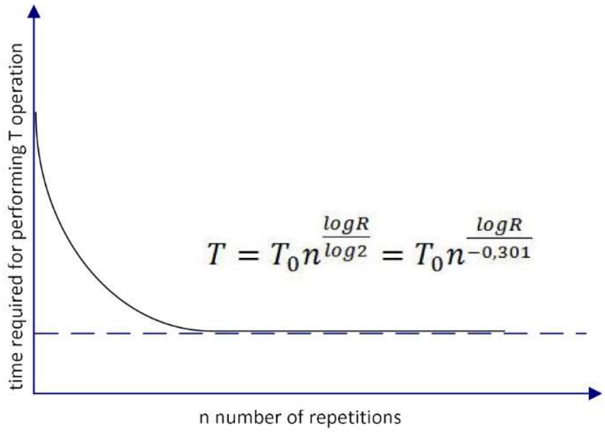

Fig. 5. A typical learning curve: T_0 – time required for manufacturing the first unit, R – expertise rate [13, 14]

On the basis of research performed in the company it was determined that the basic indicators for a cost analysis for the manufactured products will be:

- **runtime ratio**

$$W_t = \frac{T_m}{T_o} \cdot 100\% \quad (3)$$

where:
T_m – direct working time for switchboard assembly,
T_o – standard working time for switchboard assembly,

- **cost-effectiveness ratio**

$$W_o = \frac{P}{K} \cdot 100\% \quad (4)$$

where:
P – production value,
K – production costs,

- **profitability ratio**

$$W_r = \frac{D_{cz}}{K} \cdot 100\% \quad (5)$$

where:
D_{cz} – company income „net profit",
K – production costs,

- **material consumption ratio**

$$W_m = \frac{N_m}{P} \cdot 100\% \qquad (6)$$

where:
N_m – materials required,
P – production value.

Using the data from the company about the runtime, cost-effectiveness, profitability and material consumption ratios, a comparison of manufacturing with and without the product platform was made. Thanks to an analysis performed on the basis of the "learning curve" it was estimated that in case of the application of the product platform, production effectiveness will increase by **4,3%,** and that there will be a decrease in timing and material use factors and increase in cost-effectiveness and profitability factors at the same time, compared to the standard manufacturing.

Stage Four – defining the structure of the elements used in the product platform. First, it should determine what elements will be required for developing the given product platform. The process of designing every new element can be divided into three steps: preparation, design of the model in the CAD/CAM software selected by worker or by company and calculation of the performance results. The project procedure may be as follows:

1. familiarizing with the employees performing the researched operation, as well as with the organization and operation of the workstation on which it will be performed (Table 6),

Table 6. Analysis of an assembly workstation, the author's own study

Company employees responsible for product platform research	Product platform research time	Researched workstation
e.g..: technologist	e.g.: 6^{00} - 14^{00}	e.g..: Work team of engineers and electricians

2. familiarizing with the structure of assembly tools present in the assembly hall which can facilitate the design of new elements of the product platform structure,
3. analysing the evolution of the tools selected by the employees,
4. defining, in cooperation with the technologist, the requirements the new elements of the product platform will have to comply with,
5. designing the model of the element for the product platform in CAD/CAM software which is selected either by worker or by the company,
6. doing the strength test calculations essential to design the element for the product platform in CAD/CAM software selected either by worker or by the company,
7. working out the whole manufacturing process on operation and instruction sheets.

Fifth Stage – developing the product platform. This stage involves implementing the action strategy for the given product platform in the company. In this stage, the presentation of all elements of the given product platform on the CAD/CAM software selected either by a worker or by the company, as well as putting it into operation in the selected manufacturing plant. Additionally, the authors will perform timing measurements via several methods of working time regulation. On the basis of these measurements, it will be possible to specify time saved after the implementation of the whole product platform in the chosen workplace.

4. Conclusions

The principles of making product platforms is the topic of further research conducted by engineers in every manufacturing company of national and international scope.

The main purpose of the article was to develop the assumptions for the creation of an assembly platform in an energy company.

In order to effectively use product platforms in the manufacturing process, one should start using them at the stage of product development. Presented by the author in this paper, the five stages of developing a product platform allow creating the plans of production lines, which decrease the cost of end product design and result in products which satisfy customer demands better.

The platform developed in the energy company can be extended with the use of more and more elements such as pre-assemblies workstation. In the next stage of the assembly platform implementation, a cost estimate and a launching schedule will be developed. Due to the usage of additional elements in the platform, the costs incurred by the company will be reduced. The analysis of the assembly platform shows that the efficiency of production in an energy company will increase by 4.3%.

In order to find out that product platforms can rightly be used by engineers, they can be analysed with regard to more complicated technological assembly processes.

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MODELING AND SIMULATION OF THE FURNITURE MANUFACTURING AND ASSEMBLY PROCESS IN THE ARENA SIMULATION SOFTWARE

MODELOWANIE I SYMULACJA PROCESU WYTWARZANIA I MONTAŻU MEBLI W PROGRAMIE SYMULACYJNYM ARENA

Abstract

The article describes issues related to creating discrete simulation models for the implementation of the furniture manufacturing and assembly process in a furniture company. The methodology of the manufacturing system analysis was presented, which is aimed to support the appropriate approach to the construction of simulation models. The scope of the work includes the technological identification of the furniture manufacturing and assembly process in real production conditions, on the basis of which the appropriate simulation model was built. The course of the process was analyzed in the Arena software on the basis of a computer simulation based on reports. As a result of the simulation of the manufacturing process with the use of information from report of usage, an area for improvement was located. The re-analysis of the material flow made it possible to propose a change in the input parameters for the simulation model in the indicated area. The results of the second simulation show significant changes in the effective use of workstations and increase in the efficiency of the production line. In practice, it can be the basis for introducing simulated changes in the production system.

Keywords: manufacturing system, modeling, simulation, production, assembly, process improvement

Streszczenie

W artykule opisano zagadnienia związane z tworzeniem dyskretnych modeli symulacyjnych dla realizacji procesu wytwarzania i montażu mebli w przedsiębiorstwie branży meblarskiej. Przedstawiono metodykę analizy systemu wytwarzania, która ma za zadanie wspierać właściwe podejście dla budowy modeli symulacyjnych. Zakresem praca obejmuje identyfikację technologiczną procesu wytwarzania i montażu mebli w rzeczywistych warunkach produkcyjnych, w oparciu o którą zbudowano właściwy model symulacyjny na przykładzie procesu wytwarzania w rzeczywistych warunkach produkcyjnych. Analizę przebiegu procesu na podstawie symulacji komputerowej w oparciu o raporty przeprowadzono w oprogramowaniu Arena. W wyniku przeprowadzonej symulacji procesu wytwarzania z wykorzystaniem informacji z raportu obciążeń stanowiskowych zlokalizowano obszar do doskonalenia. Powtórna analiza przepływu materiałowego pozwoliła zaproponować zmianę parametrów wejściowych dla modelu symulacyjnego we wskazanym obszarze. Wyniki drugiej symulacji wskazują istotne zmiany w zakresie efektywnego wykorzystania stanowisk pracy oraz zwiększenia wydajności linii produkcyjnej. W praktyce może to stanowić podstawę do wprowadzenia symulowanych zmian w omawianym systemie produkcyjnym.

Słowa kluczowe: system produkcyjny, modelowanie, symulacja, produkcja, montaż, usprawnianie procesu

1. Introduction

When searching for products, customers tend to focus on finding both cheap and high-quality items. However, the criteria that determine the value of low price and high-quality are changing over time and becoming increasingly stringent [15]. Therefore, in order to remain competitive, manufacturers need to ensure flexibility, the ability to dynamically respond to changes and operate effectively [14]. From the current point of view, technological progress can be divided into forth main eras in history, which are characterized by revolutionary solutions in a given period of time – from Industry 1.0 to Industry 4.0 [15]. However, more and more publications also describe the fifth revolution – Industry 5.0 [8, 20]. As part of the current

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fourth industrial revolution, an overall increase in efficiency is expected, thanks to the effective analysis of data generated in intelligent environments and the integration of digital production systems. Digital transformation supported the development of modern information technologies, such as: cyber-physical systems, Internet of Things, Internet of Services, Big Data, smart factory [4, 7]. The concept of Industry 5.0 is to complement the fourth revolution and puts more emphasis on sustainable development and people [8]. Industry 5.0 uses, among others, the synergy effect by combining innovation and human creativity with the efficiency and reliability of machines [20].

Implementation and integration of modern digital technologies constitute the way to transform traditional production systems into future production systems, which are often characterized by high complexity [15].

Complex production systems are characterized by a large number of different variants of settings or layouts, which makes it difficult to choose the right solution using classical analytical methods. Computer modeling and simulation can be a tool that effectively supports the understanding of the process and proper decision-making at various levels of management of the manufacturing and assembly processes [17, 18]. Simulation methods allow for a relatively quick, efficient and easy way of searching for acceptable solutions, without having many limitations and not only solving specific problems [19]. Due to the development of modeling and simulation, the trend of digital twins is also gaining momentum. Traditional simulation and modeling methods have limited capabilities to assess the performance of a given production system, while the technology of digital twins through the integration of Internet of Things systems is a breakthrough in this regard. The Internet of Things is based on real data from the system obtained in real time [16].

The aim of the article is the analysis and improvement of the furniture production and assembly process carried out in the Make-to-Order z system using computer simulation methods.

2. Modeling and simulation in industrial practice

The variety of phenomena that occur in industry and the unpredictability of some incidents contribute to the growing interest in the topic of modeling and simulation. According to Gościński, modeling is "the act of selecting an acceptable substitute called a model for the original, i.e. it is an approximate reproduction of the most important properties of the original" [5]. Simulation consists in creating a model that reflects a given phenomenon and observing its behavior by manipulating independent factors. Running a computer simulation is intended to present possible phenomena occurring in the modeled process, but it can be carried out in order to obtain various effects. In the case of computer simulation, three main categories should be distinguished - simulations for forecasting, identification and rationalization purposes. In case of prognostic simulation, quantitative and/or qualitative characteristics of the tested system's functioning under given conditions are determined; in case of identification purposes, quantitative and/or qualitative rules for the functioning of a given system are prepared, while for rationalization purposes, quantitative and/or qualitative characteristics of a system are determined that meet certain rationality criteria [9].

Due to the significant increase in the computing power of devices in recent years, many different computer applications have been developed to create simulations. A large group of simulation programs are the programs that enable for creating simulations of discrete processes [19].

When it comes to production processes simulation, the most popular tools include: Flexsim, Dosimis, Enterprise Dynamis, Visual Simulation, Arena, eM-Plant, Lean MAST, Plant Simulation, ShowFlow 2, SIMUL8 [3, 13]. The choice of the proper software is important for the simulation effect – depending on the needs and the purpose of the simulation. A significant aspect is also to be guided by functionality in terms of how the model is built. Another important criterion when choosing the software is the selection of tools for reporting and analyzing simulation results [21]. This criterion is related to the fact that broad knowledge is required of a user modeling the simulation, despite a usually intuitive interface, transparent functional blocks and graphical facilities in the form of 3D animations used in simulation programs [19].

The literature on the subject [1, 6, 11, 12] indicates that computer simulation is increasingly often used in practice in the field of improving production systems and processes. A properly built simulation model enables many experimental and analytical activities to be carried out for a real production system, e.g. in terms of material flow or production system efficiency. These analyzes may concern, among others: examining the impact of the introduced changes and the possible effects they may have on the system. As a result of these tests, a set of data is obtained on the basis of which the company's management can make further decisions regarding to the management of the production system.

3. Technological identification of furniture assembly

During the elaboration of the production system under study, it is necessary to collect basic information and input data. In the initial phase a model is developed at the appropriate level of detail while simplifying the entire projection at the same time [2]. Further part of the article presents the process of building a model for a manufacturing and assembling system of finished products, which is custom-made furniture, e.g. lockers. For this purpose, the Arena simulation program will be used. The tests were carried out in real production conditions as part of the author's research.

3.1. Identification of the manufacturing and assembly process

The technological identification of the production process of lockers made of chipboard was carried out in production conditions of a selected furniture manufacturer. As a result of this identification, the characteristics of the phenomena occurring in the selected production process were obtained. In the technological identification of the finished product, technological cards, available machine documentation, as well as historical data of production processes were used. Process time standards for individual activities were adopted on the basis of registers of operations from machines and devices.

3.2. A model of furniture assembly production system

The production process described further in the article concerns the production of a standard locker in accordance with customer order, which consists of warehouse and transport processes, robotic material handling, semi-automatic cutting with a panel saw, edge banding, milling, drilling, assembly and packaging. The process flow is presented in the block diagram (Fig. 1).

Table 1 characterizes individual processes involved in the production of a furniture cabinet. The elaboration of this type of production process characteristics is the basis for starting work on constructing a simulation model.

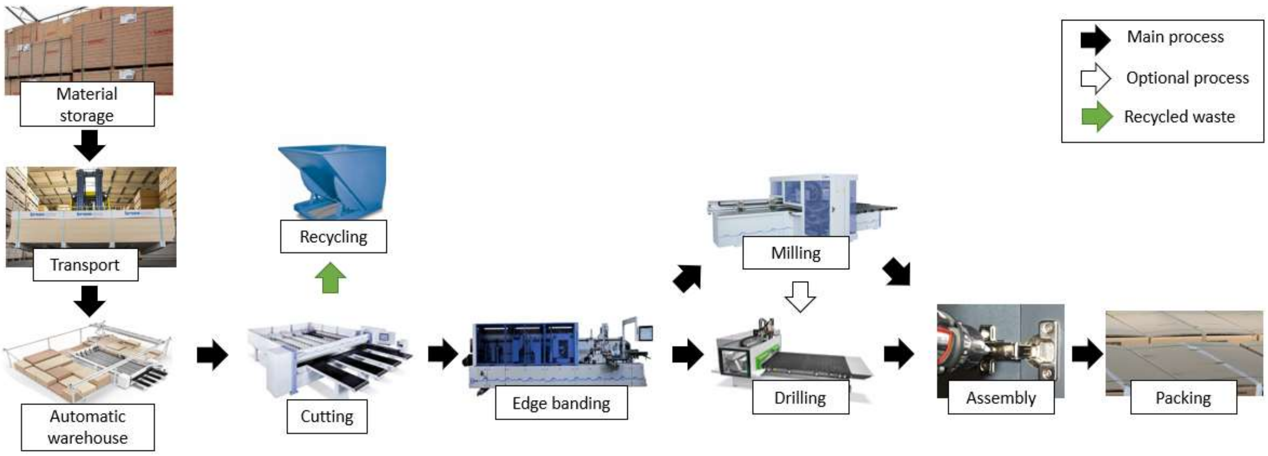

Figure 1. Process flow of furniture manufacturing and assembly

Table 1. Furniture manipulation, production and assembly processes

No.	Process name	Resource	Description
1	Storing material	Block warehouse	A separate area of the production hall is intended for block storage of chipboard sheets
2	Transport	Forklift	Transport of chipboard sets for loading the TLF buffer
3	Material handling	TLF – automatic warehouse	Frameportal center for handling and lifting chipboards
4	Cutting	Panel saw	Numerically controlled panel saw with automatic loading from an automatic warehouse
5	Storage	Storage area	Picking the cut chipboard sheet elements on pallets according to the order
6	Recycling	Container	Picking the unused cut chipboard sheet elements into special containers
7	Edge banding	Edge bander	One-sided banding of straight edges, with automatic feeding and turning of elements
8	Milling	CNC machining center	Milling holes and shapes in chipboards
9	Drilling	CNC machining center	Drilling technological holes in chipboards
10	Assembly	Assembly line	Assembly of finished furniture elements
11	Packing	Packing line	Packing of finished furniture (lockers)

3.3. Assumptions for the simulation model

The assumptions for a simulation model concern a furniture industry enterprise. The simulation model was created in Arena program and elaborated using the available functional blocks, including a fully automated warehouse for storing and leading out chipboards, as well as a simulation model of chipboards cutting process (according to the production order, the **so-called cutting**), edge banding, milling shapes and holes for hinges, drilling holes for mounting pins, complete assembly, as well as packing and securing the finished product. The assumptions of the model include the process of comprehensive storage before cutting the chipboards to a given size. The *Mag_plyty* block (Fig. 2) is responsible for generating items (units) together with the *Pole_mag_plyty* module that defines the preparation time for the processes of further manipulation. This model is part of the transport processes within the input warehouse. Blocks (*Pole_mag_plyty*, *Transport_Mat_1*, *Woz_wid_1*, *Pole_TLF*, *TLF_Start*) are responsible for transport activities supplying the automatic warehouse with chipboards. The simulation model is shown in Figure 2. All numerical data needed to define the simulation model was obtained from the appropriate enterprise management systems [13].

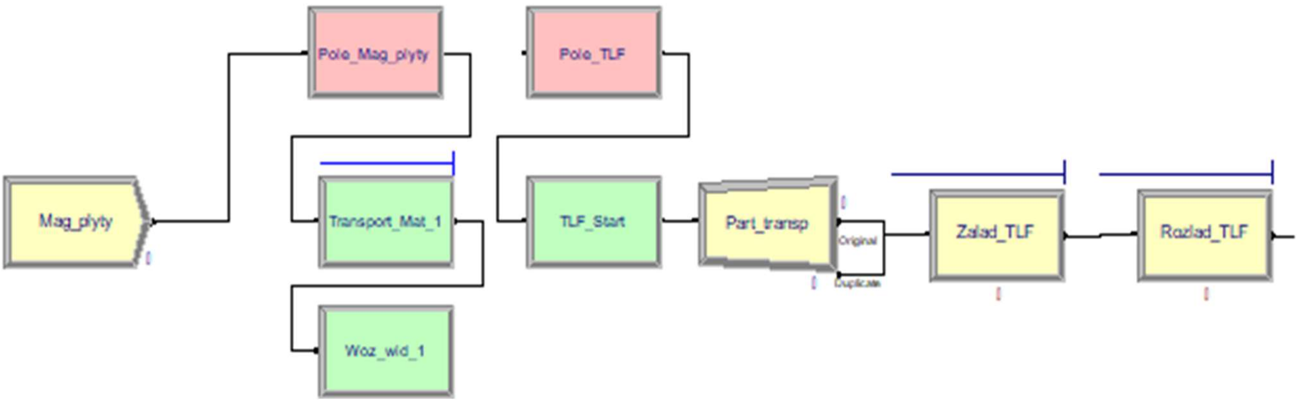

Figure 2. A general simulation model of the warehouse space of the analyzed manufacturing system

In the simulation model, the *Mag_plyty* block is responsible for supplying the manufacturing process with material – chipboard (*plyta_wior*). The duration of running the simulation was set at 8 hours (1 shift) (Fig. 3). Figures 4 and 5 show in detail the parameters of the selected functional blocks in the Arena environment at the analyzed stage.

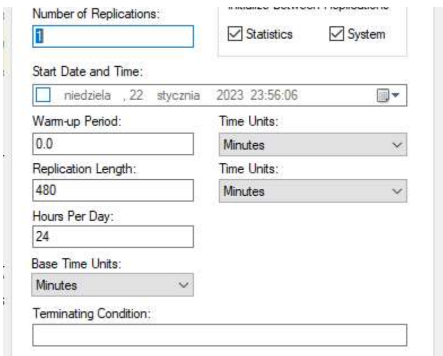

Figure 3. Main parameters of the simulation run

In order to better illustrate the operation of cutting chipboards in accordance with the production order, there will be input buffers within the machining station, including a block storage warehouse for chipboards (*Mag_plyty*), an automatic warehouse storage field (*Pole_TLF*), and a frameportal center (*Zalad_TLF* i *Rozlad_TLF*) (Fig. 2).

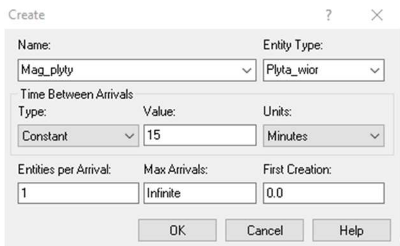

Figure 4. Parameters of the block supplying the model with the input material – chipboard

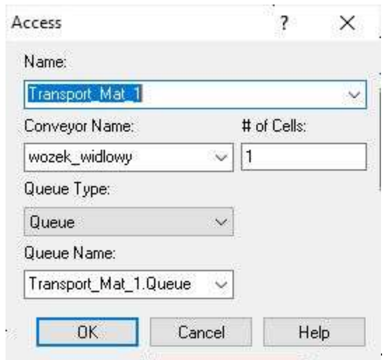

Figure 5. Parameters of the block transporting the input material to the automatic warehouse (TLF)

The use of buffers allows for a better use of manipulation and machining stations consisting of 2 automatic panel saws (defined in model as *Ciecie_300* and *Ciecie_400*), 2 edge banding machines (*Okleinowanie*_1 and *Okleinowanie_2*), CNC machining centers for milling and drilling (in the model *Frezowanie* and *Wiercenie* blokcs), and final preparation lines of the finished product by its assembling and packing (*Montaż* and *Pakowanie* blocks).

In the proposed simulation model, all resources of the manufacturing system form the resource set **Z**. For the considered system of the chipboard cutting process in accordance with the production order, there are the following elements of the set **Z**={*Mag_plyty*, *Woz_wid_1*, *Zalad_TLF*, *Rozlad_TLF*, *Ciecie_300*, *Ciecie_400*, *Mag_Braki*, *Okleinowanie_1*, *Okleinowanie_2, Frezowanie, Wiercenie, Montaż, Pakowanie*, *Mag_WG*}.

The workpieces in the presented system form a set of items **P={P1}.** For each such element from set **P**, an item flow table **T** was created (Table 1). The dimensions of this table (14x14) result from the number of elements of the **Z** set.

The values in the table at the intersection of the relevant resources inform about the maximum number of items in the target resource.

In the described example, in the first row *Mag_płyty* of table **T**, the value "15" was entered at the intersection with the column *woz_wid_1*. It means that the transport batch of item **P1** from the *Mag_płyty* warehouse with a forklift truck *woz_wid_1* consists of 15 pieces of chipboards. Similar relations [19] were established for the remaining resources of the production system (Table 2). Depending on the available and prepared space, the maximum buffer capacity was determined expressed in the number of boards, including boards after cutting.

Table 2. Chipboards and their elements flow table (capacity) for item **P1**

P1 (From) / To	*Mag_plyty, [pcs.]*	*Woz_wid_1, [pcs.]*	*Zalad_TLF, [pcs.]*	*Rozlad_TLF, [pcs.]*	*Ciecie_300, [pcs.]*	*Ciecie_400, [pcs.]*	*Mag_Braki, [pcs.]*	*Okleinowanie_1, [pcs.]*	*Okleinowanie_2, [pcs.]*	*Frezowanie, [pcs.]*	*Wiercenie, [pcs.]*	*Montaż, [pcs.]*	*Pakowanie, [pcs.]*	*Mag_WG, [pcs.]*
Mag_plyty, [pcs.]		15	-	-	-	-	-	-	-	-	-	-	-	-
Woz_wid_1, [pcs.]	-		15	-	-	-	-	-	-	-	-	-	-	-
Zalad_TLF, [pcs.]	-	-		**1500**	-	-	-	-	-	-	-	-	-	-
Rozlad_TLF, [pcs.]	-	-	-		4	5	-	-	-	-	-	-	-	-
Ciecie_300, [pcs.]	-	-	-	-		-	4	36	-	-	-	-	-	-
Ciecie_400, [pcs.]	-	-	-	-	-		5	-	45	-	-	-	-	-
Mag_Braki, [pcs.]	-	-	-	-	-	-		-	-	-	-	-	-	-
Okleinowanie_1, [pcs.]	-	-	-	-	-	-	-		-	8	28	-	-	-
Okleinowanie_2, [pcs.]	-	-	-	-	-	-	-	-		12	33	-	-	-
Frezowanie, [pcs.]	-	-	-	-	-	-	-	-	-		4	16	-	-
Wiercenie, [pcs.]	-	-	-	-	-	-	-	-	-	-		65	-	-
Montaż, [pcs.]	-	-	-	-	-	-	-	-	-	-	-		1	-
Pakowanie, [pcs.]	-	-	-	-	-	-	-	-	-	-	-	-		1
Mag_WG, [pcs.]	-	-	-	-	-	-	-	-	-	-	-	-	-	

Creating this type of table **T** (Tab. 2) of the flow of objects in set **P** for the defined and appropriately grouped elements of the **Z** set is necessary before building a model of the production system. Due to the complexity, specificity and variety of objects constituting the manufacturing systems, the number of functional blocks used in the model may vary.

Based on the material flow table (Tab. 2), Figure 6 shows a full model of the manufacturing process of locker type furniture (**P1**) produced to an individual customer order, on the basis of which the simulation was run according to the settings.

Time parameters [8] for selected production processes of the simulation model discussed in the article are presented in Table 3. The experiment assumed using triangular and normal distributions as the most useful ones for describing the occurring phenomena. The calculations were carried out in the Statistica 9.0 environment [13].

Table 3. Contents of the block of basic time parameters of simulation processes

Process - Basic Process												
	Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Minimum	Value	Maximum	Std Dev	Report Statistics
1	Zalad_TLF	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	0.5	0.8	1.5	.2	☑
2	Rozlad_TLF	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	0.5	0.8	1.5	.2	☑
3	Ciecie_300	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	2	5	8	.2	☑
4	Ciecie_400	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	2	5	8	.2	☑
5	Okleinowanie_1	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	2.5	3	3.5	.2	☑
6	Okleinowanie_2	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	2.5	3	3.5	.2	☑
7	Frezowanie	Standard	Seize Delay Release	Medium(2)	1 rows	Normal	Minutes	Value Added	.5	2	5	.2	☑
8	Wiercenie	Standard	Seize Delay Release	Medium(2)	1 rows	Normal	Minutes	Value Added	.5	2	5	.2	☑
9	Montaz	Standard	Seize Delay Release	Medium(2)	1 rows	Normal	Minutes	Value Added	6	8	10	1	☑
10	Pakowanie	Standard	Seize Delay Release	Medium(2)	1 rows	Normal	Minutes	Value Added	.5	4	1.5	1	☑

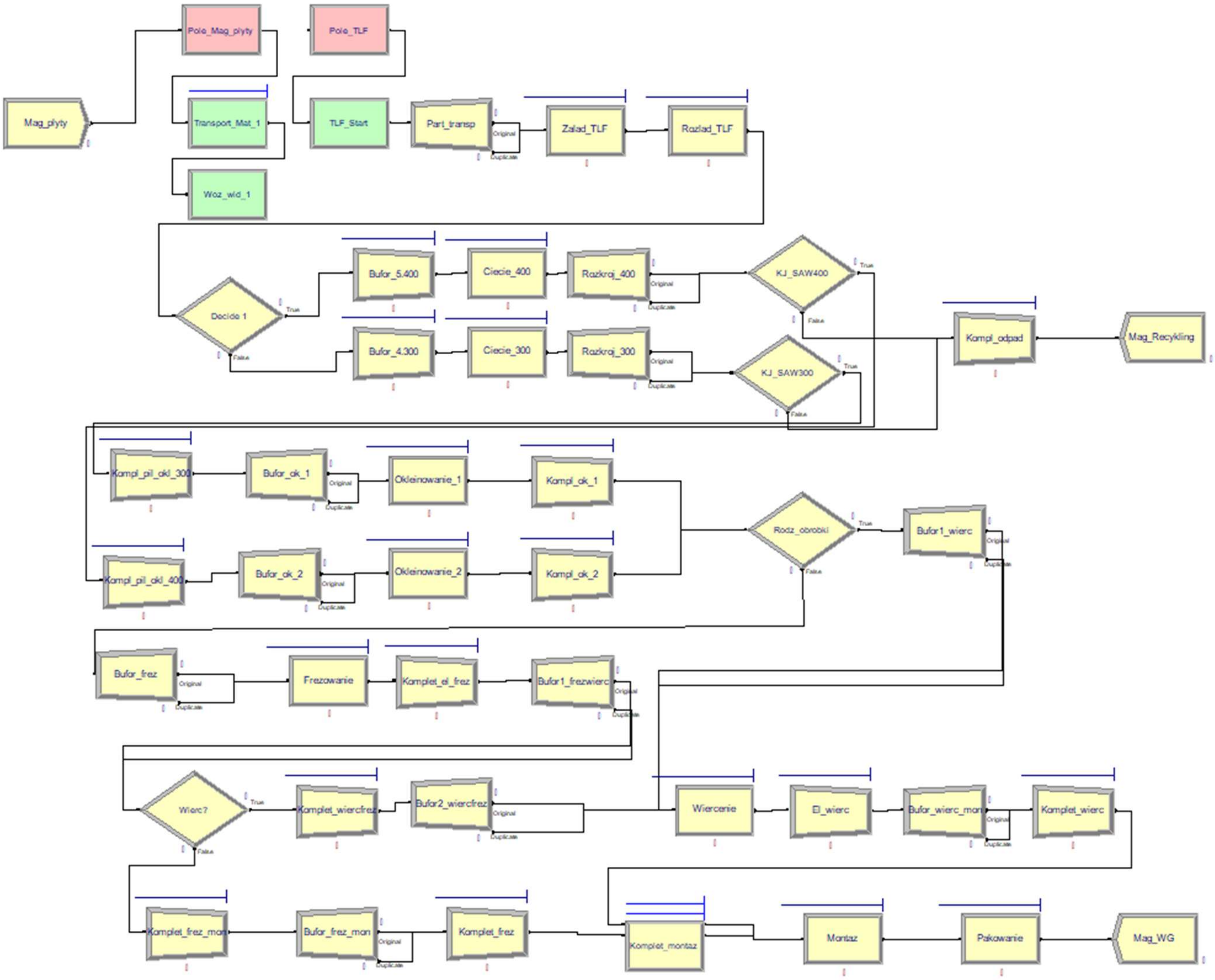

Figure 6. A Simulation model of the locker manufacturing and assembly system in an analyzed company in the Arena software

The classical methods of describing the duration of technological operations involved mainly using statistical methods. Due to the very extensive mathematical apparatus, probabilistic models are rarely used. However, in the subject literature dedicated to industrial practice and the description of phenomena occurring in production, probabilistic models based on the following types of distributions can be found [10]: exponential, Weibull, normal, Gumbel, Ferecht, Reyleight, Gamma, log-normal, triangular, uniform.

The presented distributions are largely applicable to production processes simulation. However, this requires extensive knowledge of the production process itself, as well as the methodology of developing simulation models. Most of these distributions require applying advanced numerical techniques and experimentation on large samples, which significantly increases the cost of using these methods in industrial practice. Therefore, during the technological identification of a given process, it should be assumed at the outset that the applied probabilistic model is able to provide information on the characteristics of occurring changes during the production process [10].

Normal distribution is used to reflect time processes with a certain symmetry. Triangular distribution is most often used to describe phenomena that are only positive values, such as process execution time. It is characterized by a simple estimation of the input parameters of the model and is limited to three time estimates: two extreme ones (the shortest and the longest) and the most probable one [10]. Uniform distribution is adopted wherever the randomness of events in a certain interval of time values is assumed. It can be used to describe processes that are not stabilized in terms of production [22]. As a result of conducting research in real production conditions, probabilistic models were generated in the Statistica 9.0 software, which made it possible to adjust the distribution describing the assumed phenomenon. The maximum likelihood method was used, for this purpose the Anderson-Darling test [23] was used. As a result of the analysis, it was assumed that in most cases the fluctuation of individual operations' duration can be described by a triangular or close to normal distribution, less often by a uniform distribution. If a given process is described using a probabilistic model based on a triangular distribution, the technological process itself tends to have technological breaks, during which chipboards are loaded (internal buffer) and unloaded (powering the saw) at the same time, and the process itself is not interrupted by an emergency stop.

After executing simulations based on the above model, Arena generated a number of reports.

4. Evaluation of the results obtained in the simulation

On the basis of the built model of the production system and the input parameters included in it, it is possible to analyze the flow by referring it to the actual results achieved by the company.

4.1. Analysis of the simulation report

The production volume based on the simulation (480 min, 1 work shift) is 9 finished pieces of furniture (lockers). Due to the specificity of cutting boards from ready-made pieces of chipboard, the waste generated in the process is approximately the equivalent of 4 chipboards, which will then be recycled. One of the possibilities of analyzing the production process flow based on the functionality of the software is the assessment of the use of workstations and the accumulation of materials at the workstations. For single-shift production, the simulation will have some limitations related to a wider production picture. In order to more fully illustrate the simulation models, it was decided to complete the reports with the second and third shifts. From the simulation model for 3 shifts, data was obtained in which the furniture production volume is 113 pieces, with 17 waste chipboards. The results of reports from 3 work shifts are presented in Figure 7.

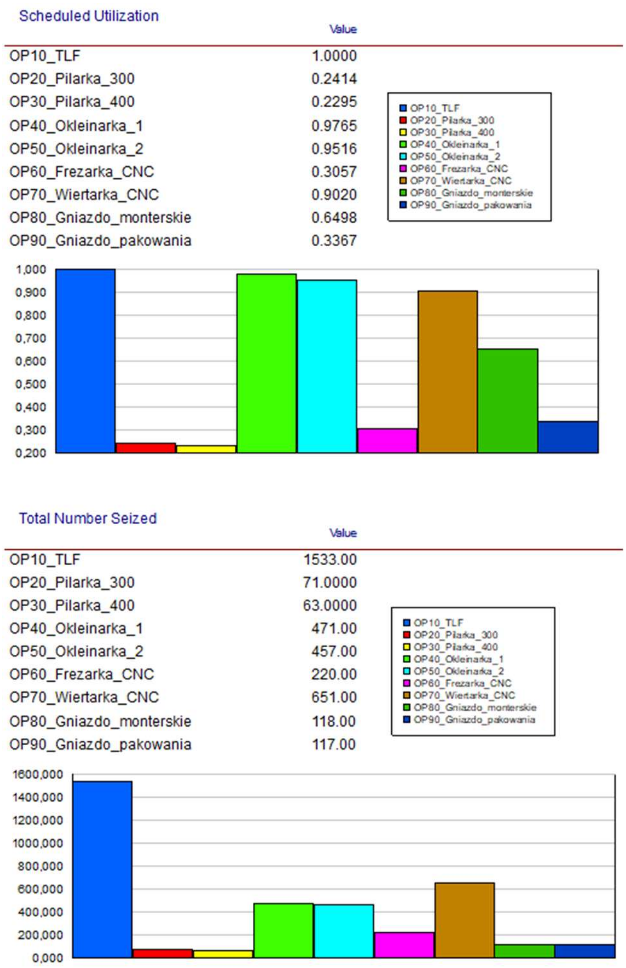

Figure 7. Usage on workstations for the 3-shift model – percentage (top) and accumulation of material on selected workstations (bottom)

Analyzing the data from Figure 7, it can be concluded that the workstations are not evenly loaded. The TLF station (automatic warehouse) and edge banding machines are loaded almost at 100%, and e.g. both saws at respectively 24% and 23% of the available working time. In some real conditions, such a situation actually takes place in this enterprise. This situation results from the specificity of realizing orders, the nature of the handling robot's operation and the high efficiency with which the saws can work. As shown in Table 1, the saws in one cycle can simultaneously cut 4 and 5 chipboards respectively (this is evidenced by the flow analysis), which was also included in the simulation. The picking of chipboards before the cutting process results in undesirable waiting times at the cutting stations.

4.2. Corrected simulation model based on previous assumptions

In the analyzed case of the production of the P1 item, there are a number of possibilities for introducing changes to the production (simulation) process in order to stabilize workstation loads (reducing the impact of bottlenecks), thereby increasing production efficiency. Having a simulation model in a comprehensive and quick way (based on experts knowledge, process improvements, statistical calculations or the trial and error method) it can be checked whether and how the change of selected parameters will affect final results.

As part of the discussed simulation model, the possibility of changing the amount of the picked material (chipboard) before the cutting stations was proposed. The modification concerns the reduction of the number of boards (respectively from 4 to 3 pieces for the *Ciecie_300* station and from 5 to 4 pieces for the *Ciecie_400* station) to one batch subject to the cutting process at both analyzed cutting stations. The area of changes made to the model is marked in Figure 8.

After implementing the changes, another simulation of the analyzed process was carried out for the time of 1440 minutes (3 work shifts).

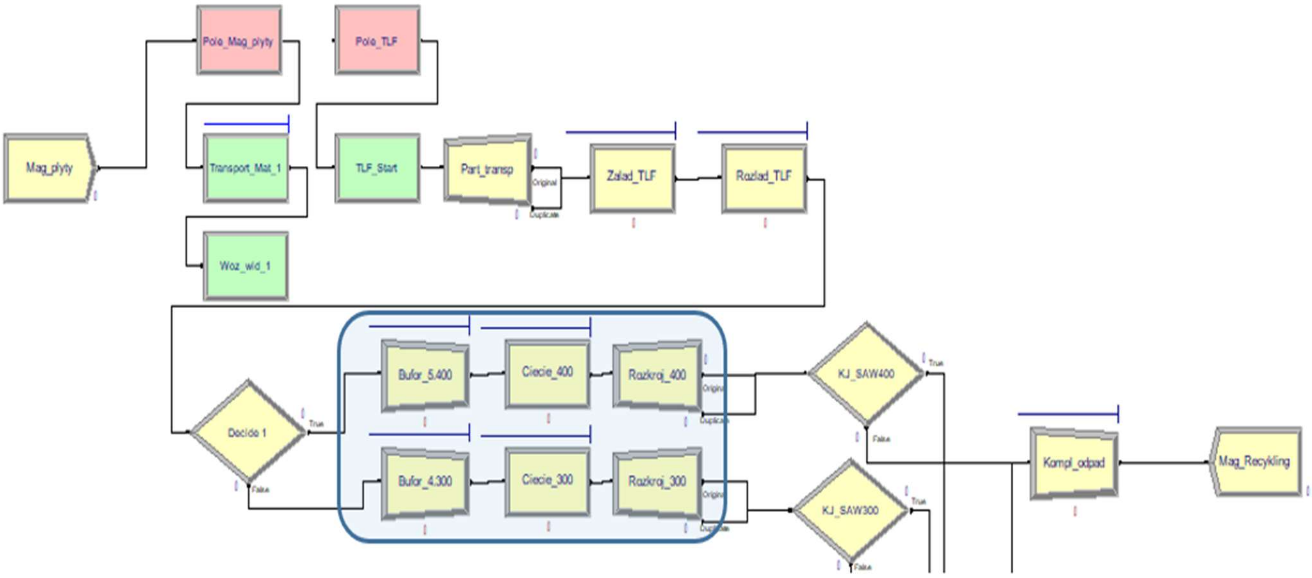

Figure 8. The area of proposed changes in the simulation model (fragment)

4.3. Analysis of the corrected model report

Based on the corrected model, the analysis of selected Arena software reports was repeated (Fig. 8). The production volume based on the simulation (1440 min) is 133 finished furniture pieces and the amount of waste is approximately equivalent to 15 chipboards for recycling.

Similarly, the occupancy of and material accumulation at certain stations were analyzed. The simulation reports show that the reduction in the number of assembled chipboards before the cutting process increases the use of both saws, which was the desired effect of the corrected model. In addition, the simulation model shows that the proposed change has a positive effect on increasing productivity by 16 additional finished products, mainly due to the reduction of waiting time for material. The illustrative results have been collected and presented in Table 4.

Table 4. Comparison of selected results of 2 simulations carried out

Simulation	Resource	Picking buffer [pcs.]	Finished product [pcs.]	Recycled waste [pcs.]	Resource usage [%]	Seized material [pcs.]
1 (first)	*Ciecie_300*	4	117	13	24	71
	Ciecie_400	5			23	63
2 (corrected)	*Ciecie_300*	3	133	15	33	98
	Ciecie_400	4			26	76

It is worth noting that as part of the production operation before the modification of the simulation model, the assembly usage was at the level of 65%. The changes introduced to the simulation model resulted in an increase in production volume due to more efficient delivery of components to the assembly station. This increase amounted to 9 pp. Figure 10 presents a summary of the results of furniture production, respectively for the simulation of 1, 2 and 3 shifts.

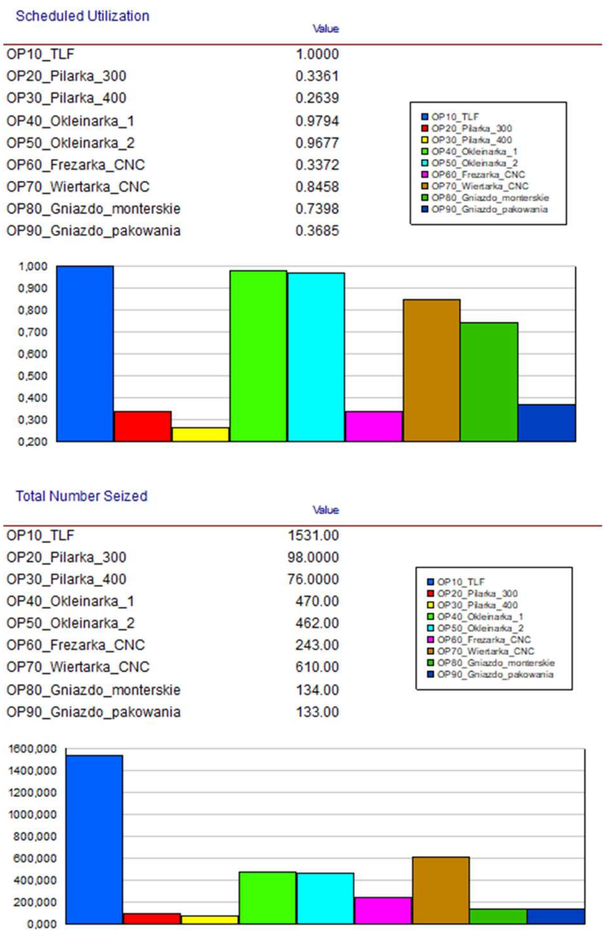

Figure 9. Usage on workstations for corrected model – percentage (top) and accumulation of material on selected workstations (bottom)

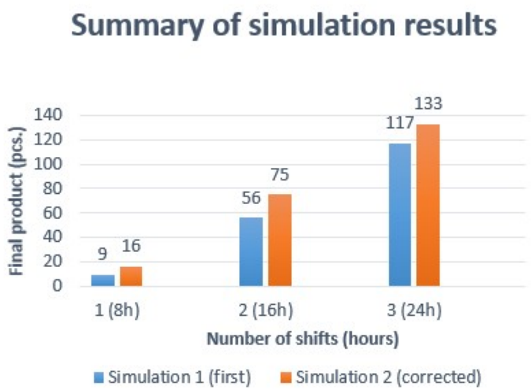

Figure 10. Comparison of furniture manufacturing and assembly simulation results

It should also be noted that the proposed change does not significantly affect the size of the accumulation, although it is a bottleneck in the scope of the TLF stand in both simulations. Consideration of this phenomenon is the subject of further research by the author conducted as part of his doctoral dissertation and the analyzed production system.

5. Summary

Analyzing the manufacturing system with the use of computer simulation methods provides a lot of valuable information on its functioning and enables us to achieve measurable material benefits. However, this requires the user to properly identify the processes taking place in the given production environment and to have proper knowledge of the correct approach to building simulation models and conducting experiments on them.

On the example of a furniture company, basic parameters shaping the process of chipboard cutting, edge banding, drilling and milling holes, as well as final assembly and packaging of the finished furniture were defined, which enabled for the construction of a proper simulation model. As a result of simulating the manufacturing process with the use of information from the bench load report, an area for improvement was located. The re-analysis of the material flow made it possible to propose a change in the input parameters for the simulation model in the indicated area. Based on the prepared simulation model, the process of furniture production and assembly were re-simulated, additionally taking into account the proposal to change the size of the buffers.

The results of the second simulation show significant changes in the effective use of workstations and increase in the efficiency of the production line. This gives the possibility to conclude that based on this type of simulation models, many different variants of the material flow can be created and compared in order to improve the manufacturing process.

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EXPERIMENTAL STUDY OF THE IMPACT OF CHAMFER AND FILLET IN THE FRONTAL EDGE OF ADHERENDS ON THE FATIGUE PROPERTIES OF ADHESIVE JOINTS SUBJECTED TO PEEL

BADANIA EKSPERYMENTALNE WPŁYWU FAZY I PROMIENIA NA CZOŁOWEJ KRAWĘDZI ELEMENTU KLEJONEGO NA WŁAŚCIWOŚCI ZMĘCZENIOWE POŁĄCZEŃ KLEJOWYCH PODDANYCH ODDZIERANIU

Abstract

The paper presents the influence of simple structural modifications of the adherend on the fatigue properties of adhesive joints subjected to peel. The considered modifications consisted in making a chamfer and fillet on the front edge of the adherend. The purpose of such modifications was to locally increase the thickness of the adhesive layer in the area of stress concentration. Fatigue strength tests were carried out using an electrodynamic shaker at the resonant frequency of the flexible adherend.

On the basis of fatigue strength tests carried out at the limited number of cycles equal to 2×10^6, it was shown that a local increase in the thickness of the adhesive layer in the front part of the joint allows a significant increase in the joint's fatigue lifetime and fatigue strength. The greatest effect was shown for the variant with the fillet R2. In this case, an increase in fatigue strength of 33.1% compared to the base variant was demonstrated. For the fatigue stress level of 20.25 MPa, an increase in fatigue lifetime of 337.7% was also demonstrated. Based on the conducted research, it was shown that the reason for the improvement of the fatigue properties of the joints due to the local increase in the thickness of the adhesive layer is the phenomenon of energy absorption in the frontal area of the joint. Absorption of energy that inhibits the process of fatigue results from, among others, local flexibility of the joint, as well as nucleation of cracks in the locally increased volume of the adhesive.

Keywords: adhesion, adhesive joints, fatigue strength, high cycle fatigue, S–N curves

Streszczenie

W pracy przedstawiono wyniki badań określających wpływ modyfikacji konstrukcyjnych elementu klejonego na właściwości zmęczeniowe połączeń klejowych poddanych oddzieraniu. Rozważane modyfikacje polegały na wykonaniu fazy oraz promienia na czołowej krawędzi elementu klejonego. Celem takich modyfikacji było miejscowe zwiększenie grubości warstwy kleju w obszarze koncentracji naprężeń. Badania wytrzymałości zmęczeniowej przeprowadzono za pomocą wzbudnika elektrodynamicznego przy częstotliwości rezonansowej klejonej płytki. Na podstawie badań wytrzymałości zmęczeniowej przeprowadzonych przy granicznej liczbie cykli równej 2×10^6 wykazano, że lokalny wzrost grubości warstwy kleju w czołowej części złącza pozwala na znaczny wzrost trwałości zmęczeniowej oraz wytrzymałości zmęczeniowej. Najkorzystniejszy efekt wykazano dla wariantu z promieniem R2. W tym przypadku wykazano wzrost wytrzymałości zmęczeniowej o 33,1% w stosunku do wariantu bazowego. Dla poziomu naprężenia zmęczeniowego 20,25 MPa wykazano również wzrost trwałości zmęczeniowej o 337,7%. Na podstawie przeprowadzonych badań wykazano, że przyczyną poprawy właściwości zmęczeniowych połączeń na skutek lokalnego zwiększenia grubości warstwy kleju jest zjawisko pochłaniania energii w obszarze czołowym złącza. Absorpcja energii hamująca proces zmęczenia wynika m.in. z miejscowego uelastycznienia złącza, jak również zarodkowania pęknięć w lokalnie zwiększonej objętości kleju.

Słowa kluczowe: adhezja, połączenia klejowe, wytrzymałość zmęczeniowa, wysokocyklowe zmęczenie, krzywe S–N

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1. Introduction

Nowadays, adhesive joints are widely used especially in those areas of industry where it is desirable to reduce the weight of a product. One of the most important advantages of the structural adhesive joining technique is the ability to join different materials and the uniform distribution of stress in the area of a joint. These are the main reasons why adhesive joining is used in the technology of composite materials commonly used in the aircraft industry. They demonstrate high temperature resistance and high adhesiveness performance [1-3]. Apart from a number of unquestionable advantages, there are also significant drawbacks of adhesive joined structures, such as relatively low durability and fatigue strength, when compared to other joining techniques [4-7]. The best polymer materials for adhesive bonding, with high cohesive performance, are epoxy resin adhesives [8].

The strength properties of adhesive-bonded joints depend on many factors. The most important ones are the type of the applied adhesive composition [9], the methodology of preparing surfaces of adherends before joining, the adhesive hardening conditions of the bonding process, and the thickness of the adhesive layer [10-11].

Many references state that the optimal thickness of an adhesive layer is about 0.05-0.15 mm [12]. However, in the case of a loaded joint, there is a phenomenon of stress concentration occurring near the frontal edge of a joint.

The authors of [13] performed the FEM analysis of a single lap joint with the geometrical modification of adherends. They considered different sizes of the chamfer on the frontal part of an adherend and proved by FEM that it is possible to significantly reduce stress concentration.

Other references [14] reported that the geometrical modifications of an adherend could improve the shear strength of a single lap of an adhesive joint by 20%.

In the article [15], the authors described the FEM analysis of a single lap of adhesive joints subjected to the shear with the fillet on adherends. It also proves that there is a possibility to improve the strength of adhesive joints by the fragmentary enlargement of an adhesive layer.

Because of the increase in the application of structural bonded technology, it is desirable to develop every method to improve adhesive joining, which is the purpose of the presented research.

The presented results are the continuation of the research related to the static strength tests [16] and the FEM analysis of adhesive joints with geometrical modifications of an adherend.

In this work, experimental studies were carried out to analyze the effect of structural modifications on the front edge of the adherends on the fatigue strength properties. Peel fatigue strength tests were carried out for adhesive joints of rigid and flexible adherends. The tests were carried out at the resonant frequency of the flexible adherend. The applied modifications consisted in making a chamfer and fillet in one of the adherend, which was aimed at locally increasing the thickness of the adhesive layer in the frontal area of the joint. A comparison of the fatigue curves for the variant with the modification in the form of chamfer and fillet and the base joint was made. Fractographic analyses were carried out for selected joints using SEM microscopy.

2. Materials and methods

The research was conducted for the specimens that consist of adherends made with S235JR steel (EN 10025/2-2004). The shape and dimensions of the specimens are shown in Fig. 1. The research on the fatigue strength and the fatigue lifetime of the adhesive joints subjected to peel were carried out for particular variants. The fatigue tests were high-cyclic for a limited number of cycles 2×10^6.

The uniform methodology of preparing surfaces of adherends was used. The surfaces were sand-blasted with aloxite 95A and cleaned with acetone. The parameters of the sand-blasting operation were as follows: the size of grain a = 0.27 mm, the pressure of compressed air p_s = 0.8±0.1 MPa, and the time of exposure t_s = 60s.

Surface morphology analysis of the adherends was performed according to ISO 25178 standard using AltiMap Gold software based on the non-contact optical measurement system of Talysurf CCI Lite 3D (Taylor Hobson, England).

The example of surface morphology of flexible adherend after the sandblasting process is shown in Fig. 2. The main standard 3D parameters determined by this measurement (Table 1) are the root mean square roughness parameter Sq, the average roughness Sa, surface kurtosis Sku, surface skewness Ssk, the 10-point peak-valley surface roughness Sz, the highest peak of the surface Sp, and the maximum pit depth Sv.

Chemically hardening epoxy adhesive was used in the tests – Bison Epoxy PLUS ENDFEST (supplied by Bison International B.V., Rotterdam, Netherlands).

The hardening process took place under the following conditions: room temperature (20±3°C), the time of hardening t = 24 h, load on the area of a joint p = 0.01 MPa.

The rigid adherends were modified by making the chamfer or fillet to locally enlarge the thickness of an adhesive layer with the aim to reduce the peel stress concentration in the frontal part of a joint. The dimensions of the applied structural modifications at the front edge of the rigid adherend are shown in Fig. 3. Comparative fatigue tests were carried out for the base variant, thus without structural modifications, and variants with chamfer 2×2 (Fig. 3a), chamfer 2×4 (Fig. 3b) and fillet R2 (Fig. 3c). For each variant, 16 samples of adhesive joints were prepared.

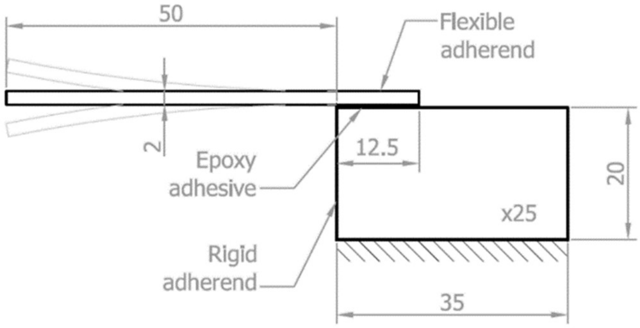

Figure 1. Shape and dimensions (in mm) of adhesive joint samples used in fatigue tests

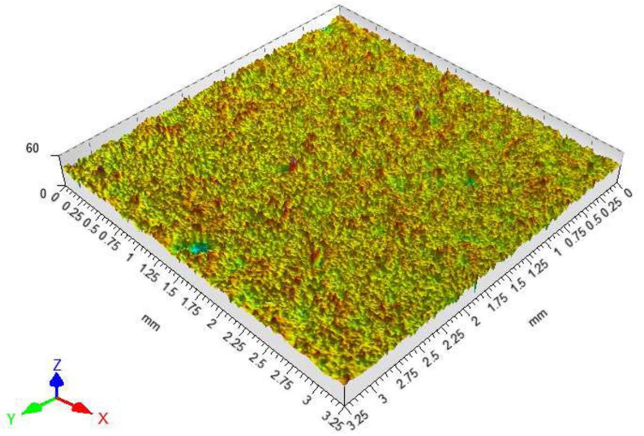

Figure 2. An example of surface morphology of the flexible adherend after sand blasting process

Table 1. Values of the basic surface roughness parameters of the flexible adherend subjected to the sandblasting process

Parameter	Sq	Ssk	Sku	Sp	Sv	Sz	Sa
Value	3.92 µm	-0.447	4.98	24.6 µm	35.4 µm	60.0 µm	2.98 µm

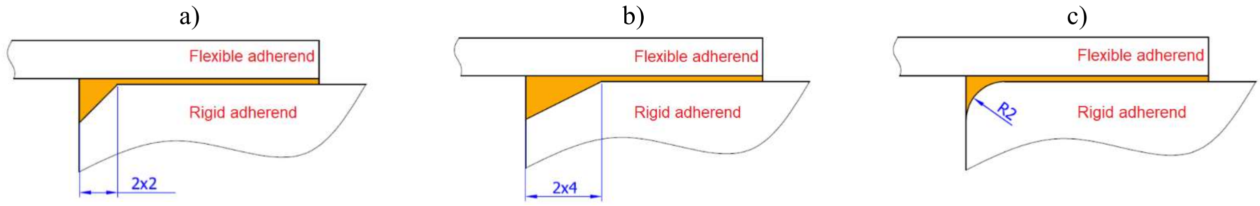

Figure 3. Dimensions (in mm) of applied structural modifications of the rigid adherend, variant chamfer 2×2 (a), chamfer 2×4 (b), and fillet R2 (c)

The research on the fatigue strength and the fatigue lifetime was carried out with the electrodynamic conductor ETS SOLUTION L Series MPA-102-L620M.

The fatigue tests were carried out at the resonance frequency of flexible adherend. The value of the resonance frequency was automatically searched by special software. The fatigue test system was equipped with the accelerometer and laser system to measure the amplitude of the vibration of the flexible adherend.

The value of the resonant frequency of the samples was in the range of 540-580 Hz. During the fatigue test, due to the process of fatigue cracking of the adhesive layer, the resonance frequency gradually decreased. Immediately before the complete destruction of the joint, it reached a value in the range of 360-390 Hz.

For a given value of the vibration amplitude of the flexible adherend tip, the value of normal stresses in the adhesive layer was determined using the FEM. The three-dimensional FEM model was made using the ABAQUS 6.10-2 software. Table 2 presents the vibration amplitude values considered in the tests with the corresponding maximum values of normal stresses determined using the FEM analysis for individual variants.

Table 2. Vibration amplitude values with the corresponding maximum values of peel stresses (according to FEM analysis) for the considered variants

Base variant				
Maximal adhesive peel stress (MPa)	20.25	17.55	14.85	13.98
Amplitude (mm)	0.75	0.65	0.55	0.5
Variant chamfer 2×4				
Maximal adhesive peel stress (MPa)	19.27	17.34	15.41	13.40
Amplitude (mm)	1	0.9	0.8	0.7
Variant chamfer 2×2				
Maximal adhesive peel stress (MPa)	20.94	19.27	16.24	14.12
Amplitude (mm)	1	0.9	0.8	0.7
Variant fillet R2				
Maximal adhesive peel stress (MPa)	22.65	19.94	18.27	16.24
Amplitude (mm)	1.1	1	0.9	0.8

All variants of specimens were tested on four levels of dynamic loading. On every level, the tests were repeated four times. The lowest level of the dynamic load was the value at which the specimen did not fail after being loaded by 2×10^6 cycles. Fig. 4 shows the view of the fatigue test stand with a sample of the adhesive joint.

The morphologies of the fracture surfaces of the adhesive joints were examined using an scanning electron microscope (SEM) Phenom ProX (Nanoscience Instruments, Phoenix, AZ, USA).

Figure 4. Setup for fatigue testing of adhesive joints

3. Results and discussion

Figs. 5-7 show the fatigue curves for the considered variants of joints in relation to the fatigue curve for the base variant. The most favorable results related to the local increase in the thickness of the adhesive layer were shown for the case in which fillet R2 was made (Fig. 5). For this variant, the fatigue strength increased by 33.1% compared to the base variant, for which the fatigue strength was Z_G = 12.2 MPa (Fig. 5). For the fillet R2 variant, the greatest increase in fatigue life was also shown. Considering the fatigue life for the fatigue stress level of 20.25 MPa, the average fatigue life for the base variant was 128×10^3 cycles, while for the fillet R2 variant, the fatigue lifetime was 562×10^3 cycles on average. Thus, a significant increase in fatigue lifetime by 337.7% was demonstrated.

For the remaining variants with a locally increased thickness of the adhesive layer, a significant improvement in durability and fatigue strength was also demonstrated. In the case of the chamfer 2×2 variant, the fatigue strength increased by more than 15% compared to the base variant (Fig. 6). Moving on to the chamfer 2×4 variant, it should be noted that in the area of low cycle fatigue, i.e. below 10^5 fatigue cycles, no significant differences were found compared to the base variant. However, in the area of high cycle fatigue, significant differences have already been shown, and the fatigue strength has increased to Z_G = 14.4 MPa (Fig. 7), which is an increase of over 18% in relation to the base variant.

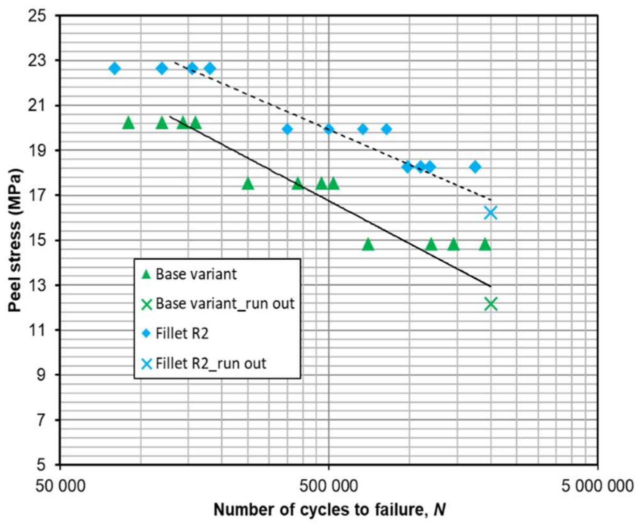

Figure 5. Comparison of the fatigue curves for the base variant and fillet R2 variant

Since the best results were shown for the fillet R2 variant, it can be concluded that this variant is the most favorable because it is devoid of edges. This is an important issue because stress concentration occurs in the frontal area of the joint, each sharp edge acts as a notch in this critical area.

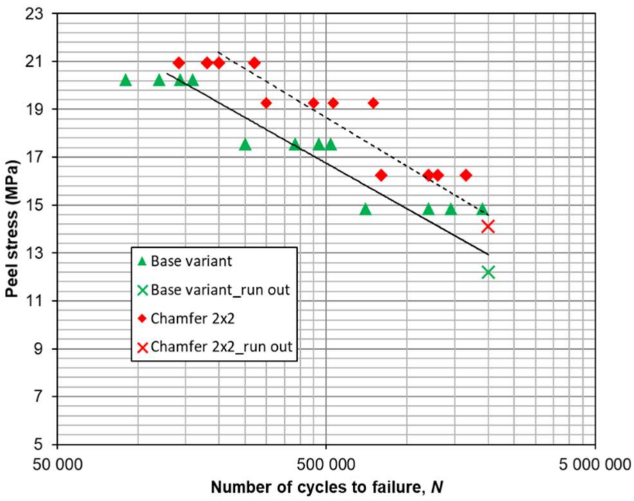

Figure 6. Comparison of the fatigue curves for the base variant and chamfer 2×2 variant

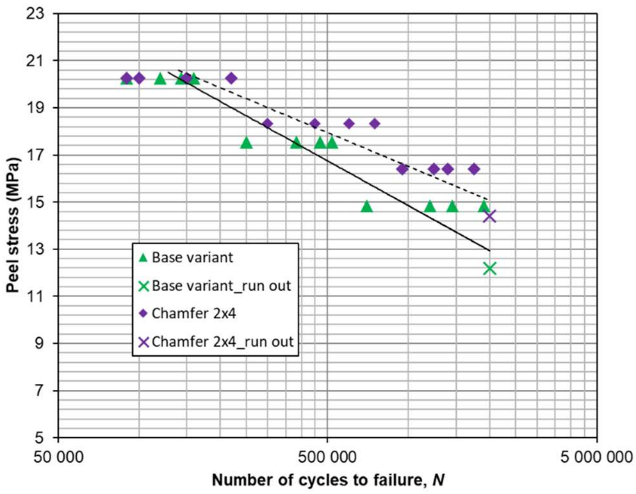

Figure 7. Comparison of the fatigue curves for the base variant and chamfer 2×4 variant

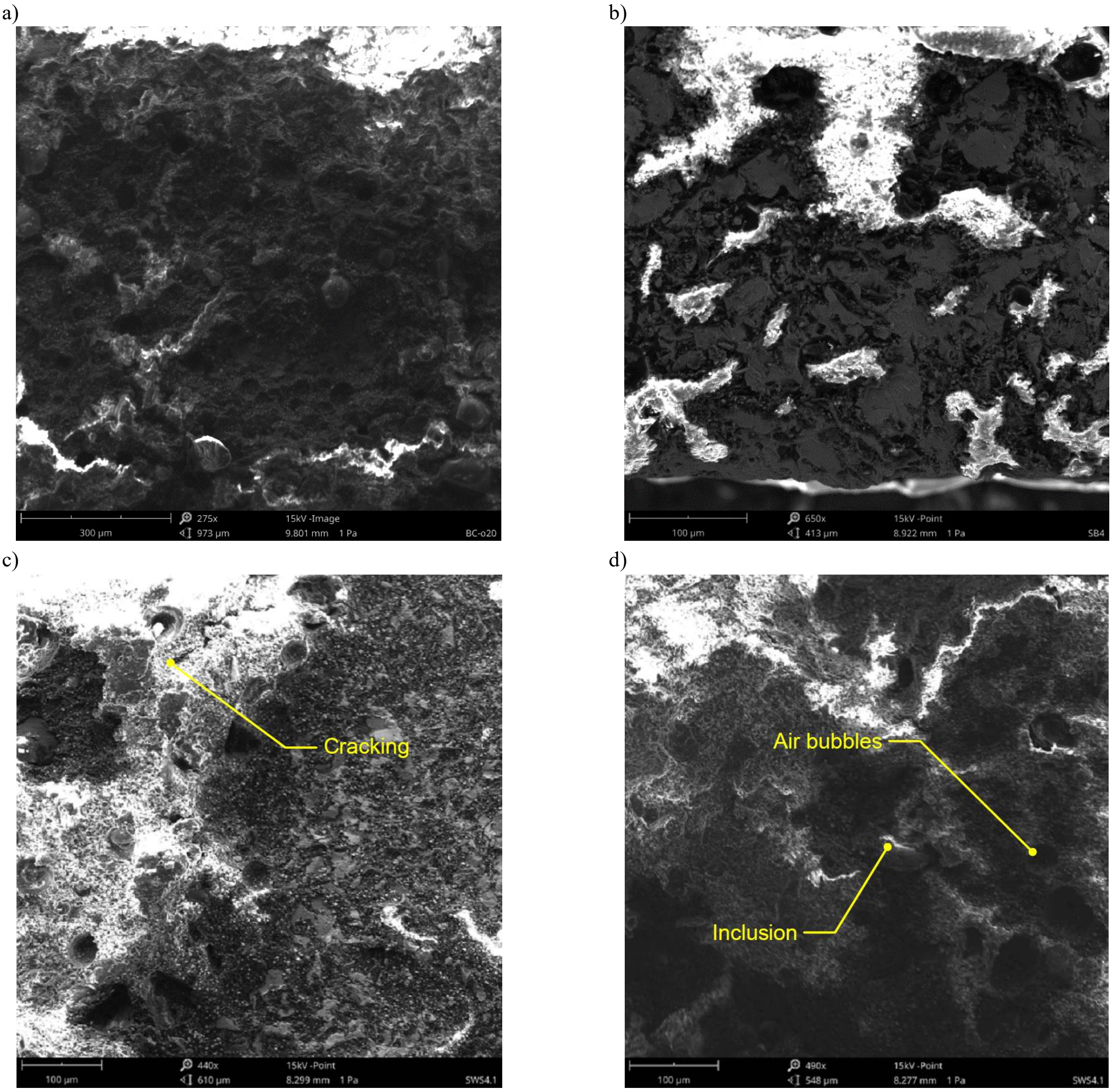

Figure 8. SEM micrographs of fatigue fractures of the front joint area for the following variants: base (a, b), fillet R2 (c), chamfer 2×2 (d)

e)

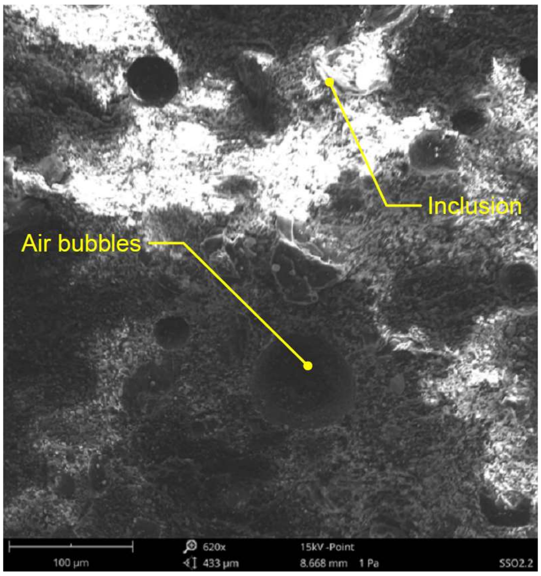

Figure 8 (cont.). SEM micrographs of fatigue fractures of the front joint area for the following variants: chamfer 2×4 (e)

When analyzing the fatigue fractures, it can be observed that for the joints in the base variant, there was generally a uniform form of joint failure in the area of its entire surface. Adhesive failure dominates here (Fig. 8a), although areas of mixed adhesive/cohesive failure also occur sporadically (Fig. 8b). Moving on to variants with structural modifications in the area of a local increase in the thickness of the adhesive layer, the space-filling adhesive is an area of greater elasticity. Therefore, with each fatigue cycle, the entire volume of the adhesive located in the frontal region is deformed in this region. At the joint face, the thickness of the adhesive layer is 2 mm, while in the main joint, the thickness of the adhesive layer is only about 0.1 mm. Differences in the nature of the deformation of the adhesive filling the front part and the adhesive layer between the sheets can also be observed on the basis of adhesive cracks appearing in areas with increased adhesive layer thickness, which are visible in the SEM micrograph for the fillet R2 variant (Fig. 8c). These cracks prove that the cyclical deformations of the adhesive layer of increased thickness absorb a certain amount of energy, thus they may influence the inhibition of fatigue cracks occurring in the proper adhesive layer between the sheets. However, it should be borne in mind that filling the space with adhesive requires great technological care, as it has been shown that in the areas filling the chamfer and fillet, there may be a high intensity of air bubbles, as well as inclusions, which is shown in the SEM micrographs for the chamfer 2×2 variants (Fig. 8d) and chamfer 2×4 (Fig. 8e).

4. Conclusions

Based on the presented experimental studies, it was shown that the introduction of simple structural changes in adherends can contribute to a significant increase in fatigue lifetime. The most important conclusions from the conducted research are outlined below:

1. The possibility of a significant improvement in fatigue strength was demonstrated by using a structural modification consisting of a local increase in the adhesive layer in the frontal area of the joint. For the fillet R2 variant, an increase in fatigue strength by 33.1% was shown in relation to the base variant.
2. For the fillet R2 variant, the possibility of a significant increase in fatigue life was demonstrated, with a variable load of 20.25 MPa, and an increase in fatigue lifetime by 337.7% was demonstrated.
3. The hypothetical reason for the improvement in the strength and fatigue life of the joints with the applied structural changes is the local increase in the thickness of the adhesive layer. In the area of a local increase in the thickness of the adhesive layer, the space-filling adhesive is an area of greater elasticity. Cyclic deformations of the adhesive layer of increased thickness absorb a certain amount of energy, thus they can influence the inhibition of fatigue cracks occurring in the proper adhesive layer between the sheets.
4. In the leading areas with an increased thickness of the adhesive layer, cracks in the adhesive

volume were observed as a result of fatigue. This proves that the locally increased adhesive layer at the joint front absorbs a certain amount of energy, thus inhibiting fatigue in the main joint.

5. The most favorable effect related to the improvement of durability and fatigue strength was shown for the fillet R2 variant, which is due to the lack of notches in the form of edges in the front part of the joint, where stress concentration occurs.

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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).

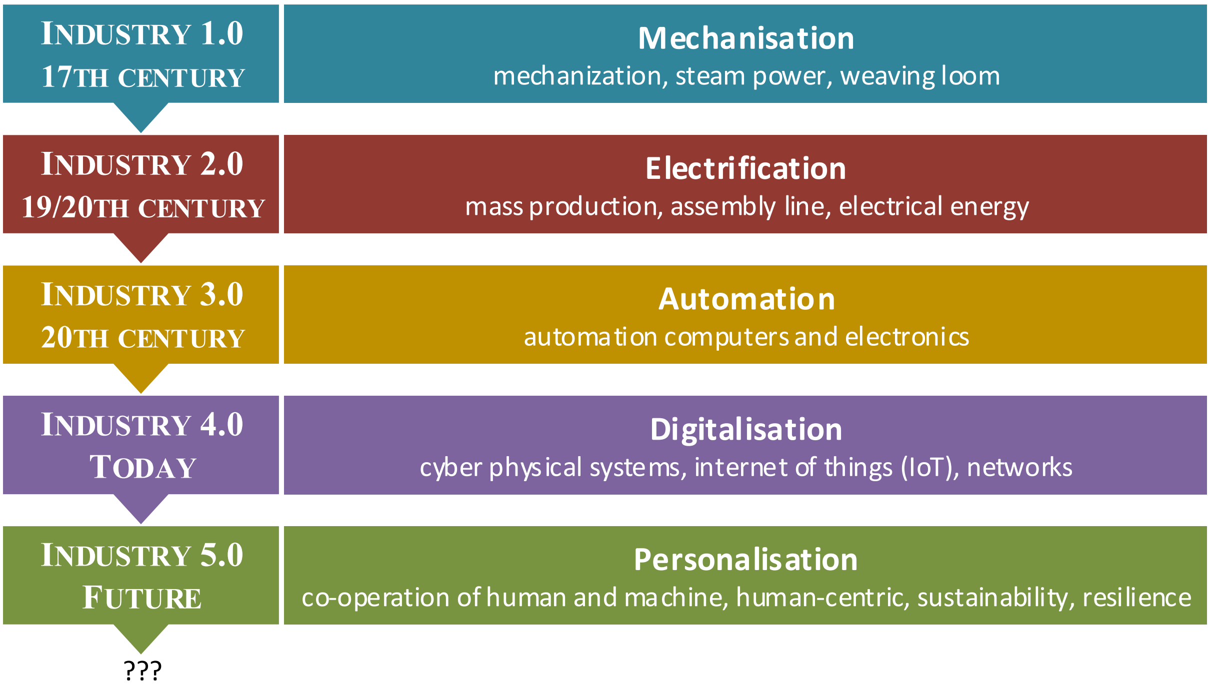

Fig. 1. Industry development phases

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).

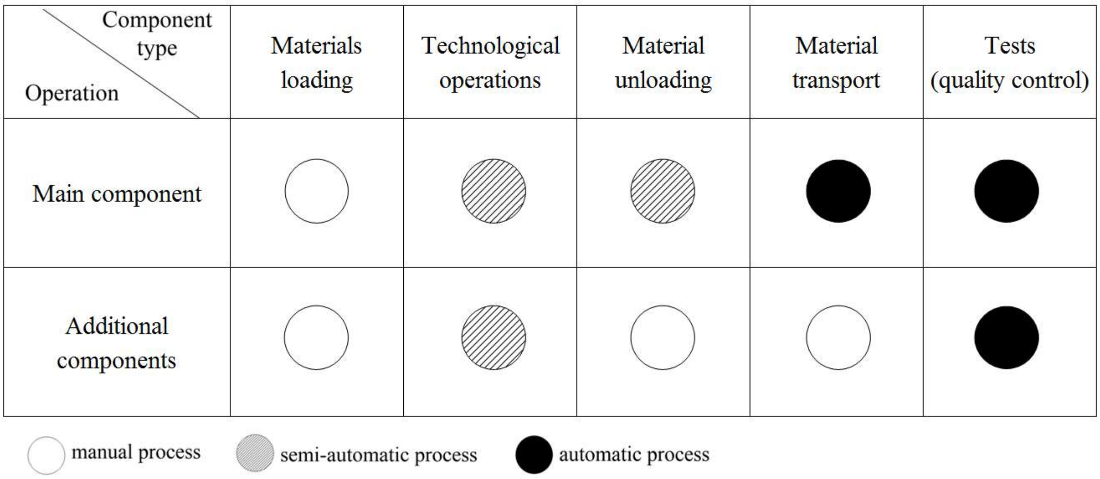

Fig. 2. The matrix of actual automation stage of production process

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.

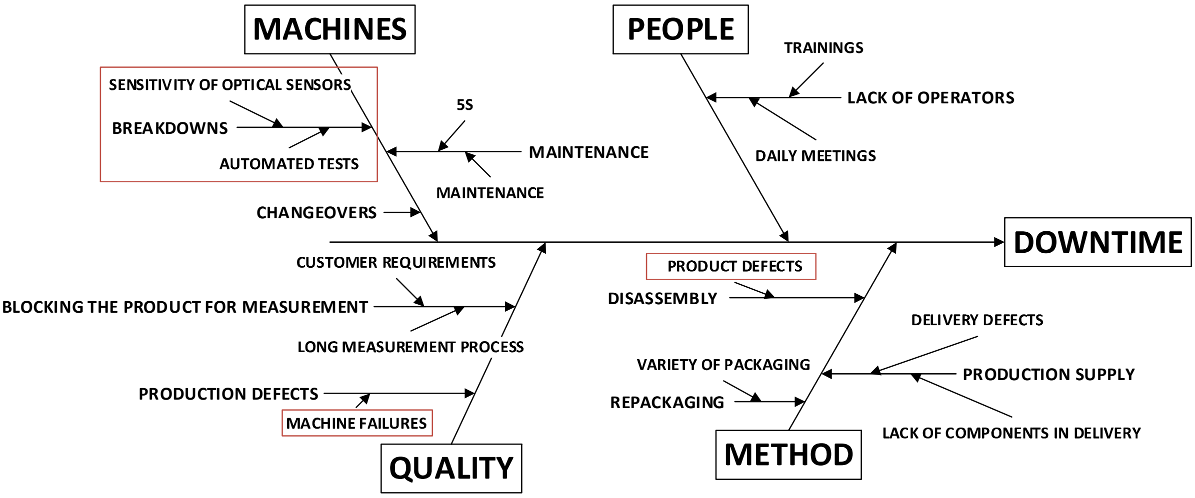

Fig. 3 Ishikawa diagram: production downtime reasons

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 require-ments. 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%.

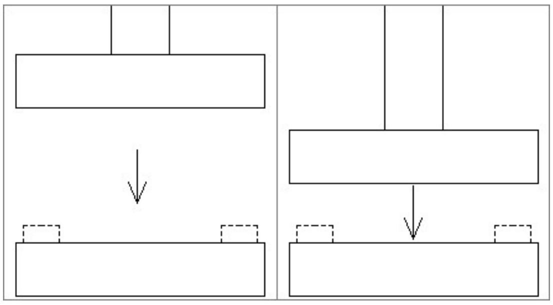

Fig. 4. The change of clamping height scheme

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.

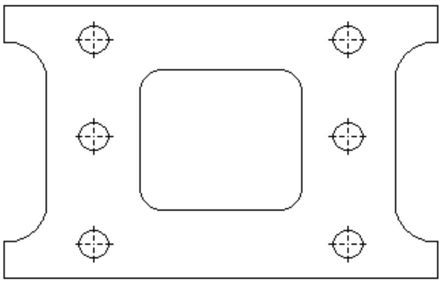

Fig. 5. Calliper general scheme (main component)

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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TECHNOLOGIA I AUTOMATYZACJA MONTAŻU
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AUTOMATIC SEMIFLUID MASS DISPENSER

AUTOMATYCZNY DOZOWNIK MASY PÓŁPŁYNNEJ

Abstract

The article presents an innovative method for hair dye dispensing and a prototype device enabling automatic dispensing of hair dyes and other semifluid substances. The dispenser makes it possible to programme colour compositions and to precisely dispense the programmed amounts of dyes from three different tubes to combine colours and achieve the desired, known or new, colour and tonal value, as requested by the client. With the dispenser's software, the hairdresser can create interlinked databases of applications and mixtures and ensure rational management of the substances used. The modern design, compact structure, and automated operation decide on the innovativeness of the dispenser.

The article discusses the genesis of the project, the functional and technical assumptions of the innovative device, as well as the design and development of the prototype and performance of functional tests, paying particular attention to the presentation and description of the following: (1) the original structural solutions; (2) the operation of functional modules that are responsible for positioning and identifying dye tubes, dispensing dyes in precisely defined amounts, monitoring the composition of the colour formula, and ensuring optimum dye use; and (3) the user interface. The structure of the device was developed by joining metal structural elements produced with the use of technologies typical for machine construction with commercial components (drives and controllers) and components produced with the use of additive manufacturing technologies responsible for the complete integration and design of the device. The original structural solution of the device is protected by intellectual property rights under patent applications.

Keywords: tube squeezing, semifluid substance dispensing, automatic dispenser

Streszczenie

W artykule przedstawiono nowatorską metodę dozowania farb do włosów oraz prototypowe urządzenie umożliwiające automatyczne dozowanie farb do włosów i innych półpłynnych substancji. Dozownik umożliwia programowanie kompozycji kolorystycznych oraz precyzyjne dozowanie zaprogramowanych ilości barwników z trzech różnych tub w celu łączenia kolorów i uzyskania pożądanej, znanej lub nowej wartości kolorystycznej i tonacyjnej, zgodnie z życzeniem klienta. Dzięki oprogramowaniu dozownika fryzjer może tworzyć powiązane ze sobą bazy danych aplikacji i mieszanek oraz zapewnić racjonalne zarządzanie stosowanymi substancjami. Nowoczesny design, zwarta konstrukcja oraz zautomatyzowana obsługa decydują o innowacyjności dozownika.

W artykule omówiono genezę projektu, założenia funkcjonalne i techniczne innowacyjnego urządzenia, a także zaprojektowanie i wykonanie prototypu oraz wykonanie badań funkcjonalnych, zwracając szczególną uwagę na przedstawienie i opis: (1) oryginalne rozwiązania konstrukcyjne; (2) działanie modułów funkcjonalnych odpowiedzialnych za pozycjonowanie i identyfikację tub z barwnikiem, dozowanie barwników w ściśle określonych ilościach, monitorowanie składu receptury kolorystycznej oraz zapewnienie optymalnego wykorzystania barwnika; oraz (3) interfejs użytkownika. Konstrukcja urządzenia została opracowana poprzez połączenie metalowych elementów konstrukcyjnych wykonanych w technologiach typowych dla budowy maszyn z komponentami komercyjnymi (napędy i sterowniki) oraz komponentami wytwarzanymi z wykorzystaniem technologii wytwarzania przyrostowego odpowiedzialnych za pełną integrację i zaprojektowanie urządzenia . Oryginalne rozwiązanie konstrukcyjne urządzenia jest chronione prawami własności intelektualnej na podstawie zgłoszeń patentowych.

Słowa kluczowe: wyciskanie tubki, dozowanie półpłynnej substancji, automatyczny dozownik

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1. Introduction

When it comes to creating mixtures with specific composition, precise dosing of individual components constitutes a major problem. This concerns gaseous, solid, liquid and semiliquid substances. The Łukasiewicz–Institute for Sustainable Technologies in Radom, Poland, carries out research to address this problem in the process of prototype device design, development and manufacture. Some of the solutions developed in response to the needs expressed by business owners and scientific institutions include the following: a painting robot (dosing of paints) [1]; chambers for gasometric testing (dosing of components of the gaseous atmosphere) [2, 3]; a chamber for concrete carbonation testing (dosing of CO2); VOC chambers (dosing of air streams of different humidity) [4, 5]; a device for erosion testing (dosing of an abrasive agent) [6]; and a production line for the production of cable moisture barriers (dosing of a powder superabsorbent) [7].

One area that requires preparation of semifluid (semiplastic) mixtures is hair colouring [8]. In the colouring process, one or a combination of different dyes can be applied. No matter what the case is, the dye use needs to be rationally managed, which means that an optimum amount of the dye needs to be used to obtain the desired end result (colour or tone).

"Kuźnia Fryzjerska Wojciech Jewuła" – a chain hair salon offering high-quality hairdressing services and related training services – approached the Łukasiewicz–Institute for Sustainable Technologies with a proposal of a project financed by the European Union revolving around the development of an easy-to-use in-salon hair dye dispenser to facilitate the hair colouring process. The device would enable any amounts of the hair dye to be dispensed from the three easily removable and replaceable tubes with commercial hair dyes placed inside. By making it possible to precisely dispense the dye in the required amounts, the control system with an intuitive user interface also enables rational management of the dye and its use. With data archived on a regular basis, the device can quickly retrieve the data about: the colour formulas specified for individual clients; the amount of each dye used; and the necessity to refill dyes to ensure undisturbed operation of the salon or chain of salons.

Thus formulated project was carried out at the Prototyping Centre at the Łukasiewicz Research Network–Institute for Sustainable Technologies (Łukasiewicz–ITEE) in Radom, in cooperation with Wojciech Jewuła, the owner of a chain of hair salons.

2. Technological assumptions

Based on the above-described functional features, the following technical assumptions were adopted to design and develop a prototype dispenser (Fig. 1):

- the dispenser shall be a portable device and in its size and design it should resemble a coffee machine;
- the dispenser shall be equipped with a cartridge with three sockets for dye tubes enabling (a) the dye to be automatically (i.e. controlled via software) dispensed from the tubes in predefined amounts, with the use of a toothed mechanism, to a container placed in a fixed position, and (b) each tube to be easily replaced manually, regardless of the amount of the dye actually used;
- the tube containing the dye should have the size of 220 mm x 50 mm (height x width);
- the tube should have the volume of 100–120 ml;
- the dye should be dispensed to a dye bowl typically used in hair salons, with the maximum size of 75 mm x 150 mm (height x diameter) placed on the plate of the electronic weighing scales;
- the amount of the dye dispensed from the tube shall be monitored based on the weight of the dye in the bowl;
- the dye should be dispensed with the accuracy of ±1 g;
- the device should be operated via a touch panel activating individual functions controlled by the relevant modules of the software of the electronic controller; and
- the power supply should have the voltage of 230 V and the frequency of 50 Hz.

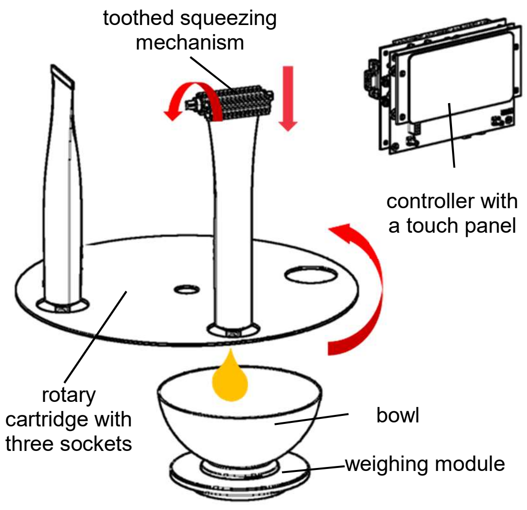

Fig. 1. Concept of the dispenser

To operate the device, dye tubes need to be placed in the cartridge sockets (dyes that are most frequently used can be stored in the cartridge permanently), and then a new or saved colour formula must be selected on the touch panel. The dye is dispensed automatically and once the process is completed, the hairdresser removes the bowl with the dyes and mixes them to obtain the desired end result (appropriate hair colour and/or tone).

3. 3D model and documentation of the system

The CAD 3D model of the dispenser was developed based on the adopted technical assumptions and concept of the device. The model built in the CAD Autodesk Inventor system [9] allowed the spatial geometric and kinematic analysis of the adopted structural solutions. The front view of the model of a complete device is presented in Figure 2. Body 1 (Fig. 2) is a metal structure made of steel sheet in which all modules and mechanisms are mounted; the front surface is protected with fixed covers (2) and a moveable cover (6). Covers (2) and (6) were made with the use of 3D printing technology and their plasticity allows them to be easily shaped to give the device an attractive design; the use of the additive manufacturing technology also means that a company logo or other branding elements can easily be placed on the cover(s). In the base of the device, under the dispensing mechanism, a weighing scales plate is mounted; this is where a bowl into which the dyes are to be dispensed is placed. Once the moveable cover is lifted, the user gains access to the cartridge and can place the dye tubes in or remove them from individual sockets. The touch panel located in the fixed cover enables the user to programme colour formulas and gives them access to the available automatic functions of the device.

Figure 3 presents the internal structure of the dispenser. In the central part of the body, under the movable cover, a rotary cartridge (3) is mounted on an axis (4) (Fig. 3) in which three squeezing modules (7) are peripherally mounted (every 90 degrees) to dispense the dye from tubes (1). The cartridge can be put into rotary motion by a stepper motor (6) with synchronous transmission (5) and it can be placed in positions enabling the dye to be dispensed from the tube directly to the bowl, or in a standby position, in which the tubes are closed by closing modules (11) protecting the dye from drying. Each cartridge position is identified by optical sensors (8) and set by a electromagnetic lock (9).

In the body, under the cartridge and directly above the weighing scales plate, a scraper (10) is mounted to separate the amount of the dye dispensed from the tube to the bowl underneath. In the base of the body, a weighing scales plate (2) is mounted – with it the amount of the dispensed dye can be monitored.

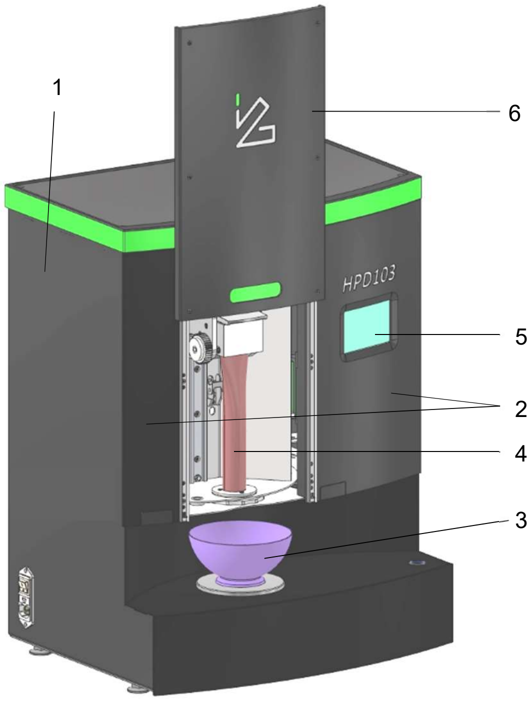

Fig. 2. CAD 3D model of the dispenser (general view): 1 – body, 2 – fixed covers, 3 – bowl, 4 – tube, 5 – touch panel, 6 – moveable cover

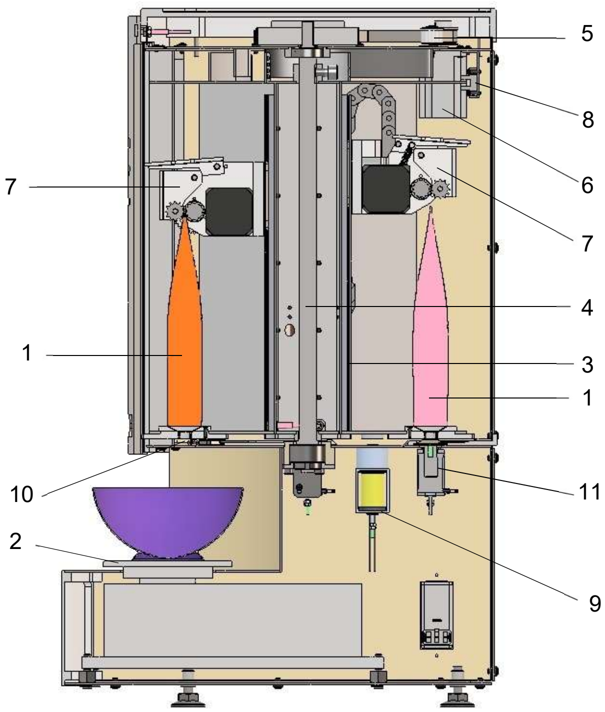

Fig. 3. CAD 3D model of the dispenser (section): 1 - tube, 2 – weighing scales plate, 3 – cartridge, 4 – axis, 5 – synchronous transmission, 6 – stepper motor, 7 – squeezing module, 8 – optical sensor, 9 – electromagnetic lock, 10 – scraper, 11 – closing module

Figure 4 presents the structure of the squeezing mechanism. The weight-bearing element of the mechanism is the slide guide composed of a sliding block (1) (Fig. 4) and a guide rail (2) connected to the rotary cartridge. The initial load of the slide guide is adjusted in a way preventing the sliding block to fall when all elements connected to it are in the vertical position. The sliding block is connected to the C-shaped module body in which the stepper motor putting a drive roller (4) into motion is mounted. An open dye tube (10) is placed in a rotary threaded socket (9) and its opening is closed off by toothed drive and clamping rollers. The rollers are placed in the clamping position by a latch (5) and a spring (6). When the drive roller rotates, the tube is placed between the toothed rollers (4 and 7), as a result of which the dye is dispensed. As a result of the gradual emptying of the tube, the sliding block (1) and the squeezing mechanism move downwards, until the proximity sensor (8) signals that the tube is completely empty. The amount of the dispensed dye can be initially programmed by means of specifying the number of the steps of the stepper motor (3).

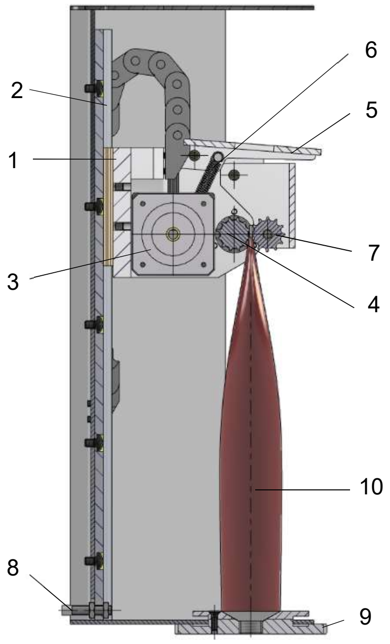

Fig. 4. CAD 3D model of the dispenser (section): 1 – sliding block, 2 – guide rail, 3 – stepper motor, 4 – drive roller, 5 – latch, 6 – spring, 7 – clamping roller, 8 – proximity sensor, 9 – socket, 10 – tube

4. Measuring and control system

Figure 5 presents a block diagram of the measuring and control system.

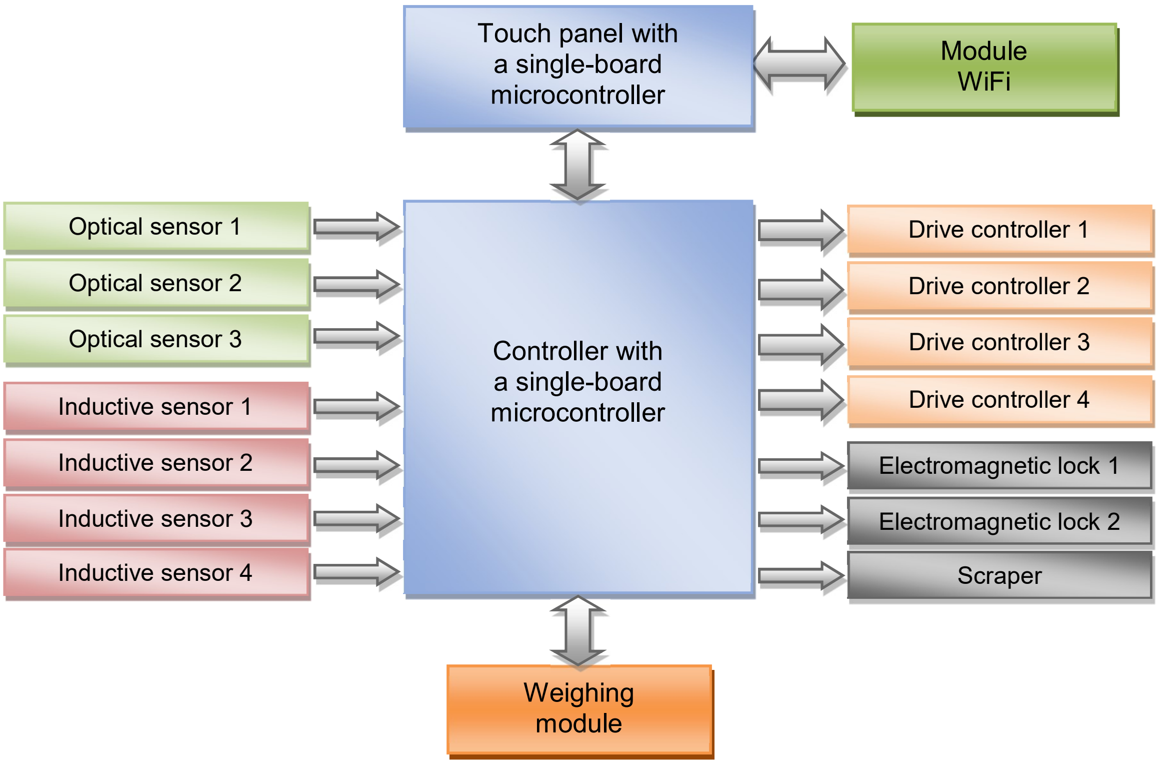

Fig. 5. Block diagram of the measuring and control system

The user panel is made of a 4” TFT display. The single-board microcontroller is responsible for displaying the properly designed graphics. The microcontroller is a programmable module (microcomputer) equipped with universal input and output ports with pin wire housings [10]. Because of the insufficient number of input/output ports and misalignment between control elements and sensors, the authors designed an additional printed circuit board (PCB) with a single-board microcontroller (Fig. 6). The board plays the role of the main controller.

Fig. 6. View of the mounted PCB of the dye dispensing controller

A dedicated control system was designed for the microcontroller. The information is exchanged between the microcontrollers of the panel and controller by means of a universal asynchronous receiver transmitter (UART). Signals from optical and inductive sensors are transmitted to the controller. The use of optocouplers enables the signals from +24 V sensors to be aligned with the operating voltage of the microprocessor system (i.e. +5 V and +3.3 V). Optocouplers also create galvanic insulation and increase resistance to electromagnetic interferences.

The use of three optical sensors enables the position of the rotary cartridge to be successfully detected. Inductive sensors are used to detect how much dye has been dispensed from and left in the tube. One of the inductive sensors informs the user about the position of the cover. The controller outputs generate signals fed to the stepper motor controllers. One of the stepper motors is responsible for rotating the cartridge with tubes, while the other three drive the squeezing rollers in each socket. The control follows a fixed algorithm in a closed feedback loop. What is used as the feedback is the information about the currently measured amount of the dispensed dye obtained from the weighing module. This information is transmitted to the controlled via RS232 in accordance with the protocol delivered by the manufacturer of the weighing module. The communication with the client database is possible via the WiFi module directly cooperating with the microcontroller of the touch panel.

5. Prototype verification

The prototype dispenser was built based on the adopted assumptions, developed model and technical documentation (Fig. 7a). The prototype was equipped with a complete set of control instrumentation and software to verify the correct operation of the individual units and software controlling the automatic implementation of functional procedures.

a)

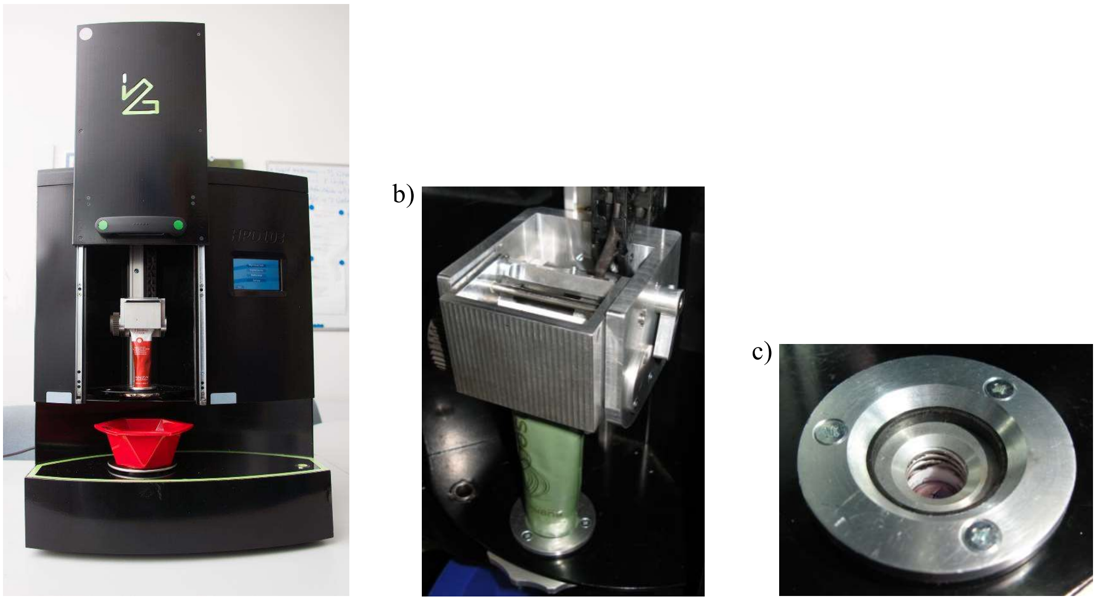

Fig. 7. Prototype of the in-salon hair dye dispenser: a) prototype, b) squeezing module with cam clamping roller mechanism, c) ealstic cut-off valve (at the bottom of the socket)

The verification and functionality tests were carried out in the actual operating conditions [11]. Particular attention was paid to the efficiency and accuracy of dye dispensing. The tests were carried out on different types of commercially available tubes and they focused, in particular, on the possibility to squeeze out all their content. During verification tests, it was found that the tube clamping mechanism located between the drive (4) and clamping rollers (7) (Fig. 4) is not stable and, in the case of some tubes, it loosens during operation, which discontinues the dye dispensing process. The faulty clatch mechanism was replaced with a self-locking cam clamp (Fig. 7b), which proved effective and reliable. The replacement of the mechanism did not solve another problem concerning the impossibility to squeeze the dye out of a tube characterised by higher rigidity (thicker steel and dye). This problem will be addressed in the future research in which modifications will be introduced to the teeth of the squeezing rollers, and torque will be increased. Yet another problem identified at the time of the verification tests concerned the separation of the dye from the tube opening, which, despite the use of the mechanical scraper (10) (Fig. 3) powered by the electromagnet, turned out to be challenging. In the case of some substances, particularly those dispensed in small amounts, the use of the scraper did not ensure that the substance be scraped into the bowl completely and in a "mess-free" manner. To make this function more effective, an elastic cross-slit valve (Fig. 7c) was used in the socket (9) (Fig. 4) to cut-off the substance dispensed from the tube. Additional tests revealed that the effective separation of the dispensed amount of the dye also requires simultaneous application of a mechanical scraper and cut-off valve. A technical assumption that we failed to achieve concerns the dispensing accuracy of ±1 g. We managed to achieve some sort of accuracy of ±3 g, which the project partner found satisfactory, but we will work on this issue in the research to follow.

The original structural solution of the dispenser developed at the Łukasiewicz–ITEE and the entire concept of the device are the subject of patent applications [12, 13, 14, 15]. and they are protected by intellectual property rights.

6. Summary

The prototype in-salon hair dye dispenser developed at the Łukasiewicz–ITEE enables colour formulas to be easily programmed and dyes (up to three) to be dispensed in the required amounts as part of an automated procedure. The concept and the modus operandi of the dispenser were developed in cooperation with and as commissioned by a company owning a chain of hair salons. The dispenser is an innovative mechatronic device equipped with electronic controllers that can be used for the purpose of in-salon hair colouring; it also has attractive design. The functional tests of the prototype confirmed that the functional parameters assumed at the concept stage were achieved, and they revealed the need for further improvement, particularly as regards the dispensing accuracy and use of dyes sold in tubes characterised by high rigidity or of untypical size. The original structural solution of the dispenser developed at the Łukasiewicz–ITEE is the subject of patent applications.

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14. Zgłoszenie patentowe P.438058 Zgarniacz, separator mas półpłynnych wyciskanych z tubek.
15. Zgłoszenie patentowe P.438059 Urządzenie do dozowania mas półpłynnych konfekcjonowanych w tubkach

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SELECTED CASE STUDIES REGARDING RESEARCH-BASED EDUCATION IN THE AREA OF MACHINE AND CIVIL ASSEMBLIES

WYBRANE ZAGADNIENIA EDUKACJI OPARTEJ NA BADANIACH NAUKOWYCH DOTYCZĄCYCH ZŁOŻEŃ STOSOWANYCH W INŻYNIERII MECHANICZNEJ I LĄDOWEJ

Abstract

The paper presents selected case studies in the area of research and teaching activities focused on technical assemblies. The aim of the work is to discuss the current trends in assembly-related research activities in partner universities of the EDURES project and to present teaching methodology related to the research. Due to the great importance of research-based education for innovative teaching methodology, research utilization into teaching process is addressed in the paper as a priority of modern teaching, which uses digital platforms and is focused on fast dissemination of the research results among both researchers and higher education students.

Keywords: research-based education, assemblies, mechanical engineering, civil engineering

Streszczenie

Artykuł przedstawia wybrane zagadnienia dotyczące problematyki złożeń w obszarze badań i nauczania. Celem pracy jest przedstawienie bieżących trendów badawczych dotyczących złożeń, które istnieją w uczelniach partnerskich projektu EDURES i metodyki nauczania w tym zakresie. W artykule podkreślono duże znaczenie edukacji opartej na badaniach naukowych oraz wykorzystania różnych platform cyfrowych i szybkiego upowszechniania wyników badań zarówno wśród badaczy jak i studentów uczelni wyższych.

Słowa kluczowe: edukacja oparta na badaniach naukowych, złożenia, inżynieria mechaniczna, inżynieria lądowa

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1. Selected challenges of assembly research and teaching

Research in the area of advanced assemblies is conducted in various scientific disciplines. The same fact concerns teaching methodologies. The significant disciplines, among others, that conduct their activities in the area of assemblies are mechanical engineering and civil engineering. The abovementioned sentences are a consequence of teaching and research experience of authors' universities. A link to mechanical and civil engineering is caused by the importance of construction problems and set-ups in various machines and their assemblies, and moreover in different civil objects such as buildings, bridges, steel assemblies, machines useful in civil engineering works. Assembly research has been an important topic of research [22] within the disciplines mentioned above.

Nowadays, assemblies are designed and developed by the use of modern computer-aided design (CAD) software and computer-aided engineering (CAE) software tools. These tools have become standard solutions for engineers and researchers. The two abovementioned disciplines are supported by dedicated software tools that utilize specific algorithms and tools. Software tools accelerate calculations performed by engineers. Software development and its wider utilization in research plays therefore an important role in research and teaching activities. Advanced software solutions such as virtual reality or augmented reality tools enable also improvements of didactic methodologies by elimination of cost, resulting from purchase of machines and physical test stands.

In terms of assembly manufacturing and maintenance processes, great importance should be assigned to combined and complex manufacturing processes including 3D printing technology, robotization of assembly lines, application of various sensors, etc. Manufacturing and maintenance of assemblies is, therefore, shaped by the complex tools and engineering approaches. Mass production of assemblies is nowadays more often replaced by short series and manufacturing research approaches should be, in authors' opinion, focused on complex issues and analyses to achieve sufficient reliability of mechanical products and civil constructions.

Moreover, international research cooperation and data exchange which can be supported nowadays by developing communication technologies resulting from mobile networks and modern methods of communication may be utilized by teachers and researchers for improvement of methodologies.

The above-described areas of research and teaching which are crucial in authors' opinion, are presented in Fig. 1 in a concise form and defined as proposed priorities.

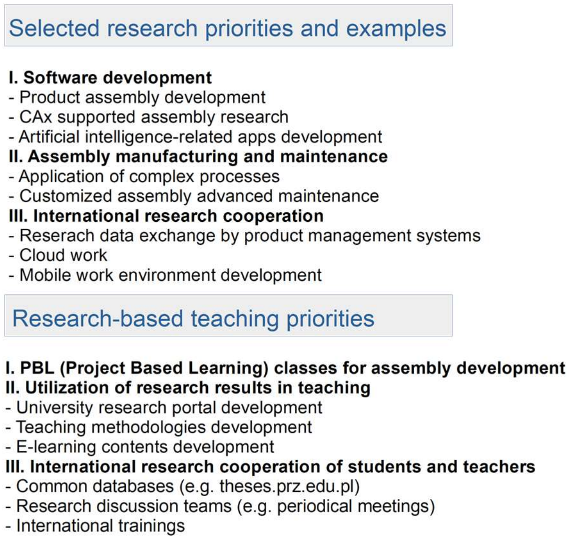


Fig. 1. Assembly teaching and assembly research priorities proposed by authors

The main aim of the paper, resulting from the proposed priorities, concerns a discussion regarding current trends in assembly-related research activities in partner universities of the EDURES project and is focused on presentation of teaching methodology related to the research.

The next chapters will focus on the description of the quality of teaching indicators and how assembly-related research could contribute to modern teaching curricula. Moreover, selected case studies regarding assembly-related research will be presented, and their application in teaching will be briefly discussed to present the general state of art to a reader. These case studies will focus on mechanical and civil problems.

The presented discussion and case studies are formulated based on the teaching and assembly-related research experience of separate authors and lead to a unique methodology useful for common teaching processes and further development of common research.

2. Quality of teaching indicators and importance of research implementation in teaching

Teaching/learning quality indicators help teachers and educational institutions measure and improve the quality of teaching activities, leading to improved student performance. These indicators provide feedback on the strengths and weaknesses of the teaching process, which can be used to improve teaching materials and methods. Importantly, the use of teaching/learning quality indicators can help allocate resources efficiently. If a particular teaching method is found to be especially effective, resources should be directed towards broader implementation of that method. By using teaching/learning quality indicators, teachers can also identify ways to better engage students in the learning process, which can improve motivation and thus student performance. Therefore, teaching/learning quality indicators are essential tools to improve education quality and provide students with the best possible educational experience. There are many indicators of teaching and learning quality; some of the key indicators are the following:

1. Graduation rate: Measure the percentage of students who complete their educational programmes. High-quality teaching and a positive learning environment are usually associated with a higher graduation rate. It should be noted that the graduation rate alone does not represent the quality of education; it is possible to achieve a high graduation rate despite poor teaching quality.
2. Student achievement – learning outcomes: the knowledge, skills, and competencies that students acquire during their education. The study [13] showed that high-quality teaching has a significant impact on the achievement rate of the intended learning outcomes. Student achievement can be measured with standardised tests, for example, the Programme for International Student Assessment (PISA).
3. Student engagement: active participation of students in the learning process. The study [11] confirmed that student engagement is positively related to student achievement and is influenced by teacher-student relationships and school atmosphere.
4. Teacher performance: measures how well teachers are able to facilitate student learning and support student achievement. Teacher performance can be assessed through analysis of students' achievement, student surveys, or classroom observations. A report [7] found that effective teacher performance is associated with higher student achievement.
5. Effective teaching strategies: high-quality instructional methods that improve student performance. A study [19] showed that appropriately selected instructional strategies, such as formative assessment, can significantly improve student achievement.
6. Professional development of teachers: refers to ongoing training and development of teachers to expand their knowledge and improve their teaching skills. In the study [8], it was shown that continuous professional development of teachers leads to better student learning outcomes.

Scientific research plays an important role in the education of engineers. Scientific research contributes to the expansion of technical knowledge and enables the learning and application of the latest technologies, methods, and tools for the design and improvement of technical products and systems. Following current scientific research develops creativity, which encourages critical thinking and independent problem solving. Incorporating the issues of current research projects into the curriculum can also help prepare students for careers in engineering. The literature provides many examples that demonstrate the positive aspects of integrating research projects into engineering education, including the positive impact on teaching/learning quality indicators due to the impact on students and teachers.

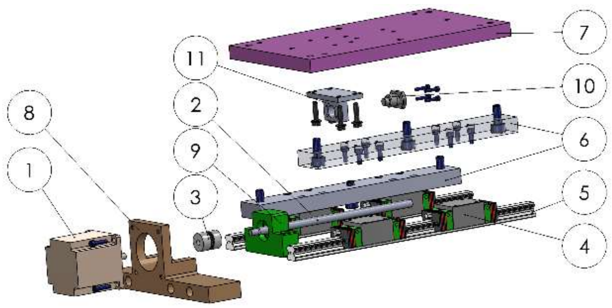
In the analysis of a research-based curriculum for an engineering course [4], it was found that the curriculum had a positive impact on students' achievement, improved knowledge of engineering concepts, and increased their engagement. In the work [24] it was shown that aeronautical engineering students who participated in research-based projects demonstrated better mastery of the course content and greater motivation to learn. The article [23] noted that students who participate in research often have a positive attitude toward their field of study and identify with the academic community. A course structure that includes research experiences can improve student engagement and achievement by connecting course material with real-world challenges [9].

Designing research-based learning activities can help teachers create more engaging and interactive learning environments, which positively impacts teacher performance [24]. Research-based pedagogical approaches can also improve teacher performance by promoting critical thinking, problem solving, and collaboration skills among both teachers and students [2]. A study [23] found that research in engineering education can improve teacher performance by providing professional development opportunities and promoting the use of innovative teaching methods.

The literature examples presented here clearly show that by providing research-based teaching and engaging students in research experiences, engineering teachers can improve their effectiveness while helping students achieve better academic performance.

3. Case study 1: CAD assembly research and general teaching methodology

Advanced CAD/CAM (*Computer Aided Design/ Computer Aided Manufacturing*) software is nowadays one of the most significant digital tools (CAx) of the digitalized manufacturing industry. Regardless of their function as independent software or modules of extended CAx platforms, they have become important tools for manufacturing environments [28]. CAD systems are useful for the design of parts characterised by various shapes, assembly design (Fig. 2), visualisation of products, technical documentation preparation, prototyping, etc. Modelling complex geometries using CAD tools, including assemblies, is quite a complex task. However, it allows to develop product effectively in a virtual environment leading to cost reduction (complex parts may be developed without necessity of prototypes manufacturing). Another issue concerns the simulation in the CAD environment. It may accelerate R&D work. Advanced software solutions such as assembly work simulation or various kinds of analysis allow for the elimination of costs resulting from the purchase of machines and physical test stands.



1	stepper motor	5	linear guide	9	bearing housing
2	drive screew	6	mounting plates	10	drive nut
3	clutch	7	support	11	drive nut holder
4	linear carrier	8	stepper motor holder		

Fig. 2. Exemplary research in the area of assembly design

The teaching process at higher education level regarding CAD product development may be inter alia based on a problem-based learning approach (PBL). Students may be asked to develop different product variants in CAD on the basis of initial assumptions, perform simulations, discuss pros and cons, and decide on the final product variant based on the defined indicators of product quality. This approach allows students to be involved in team work and also appreciates their own developments because various product variants may be developed by a single student or in very small groups. In this case, the final evaluation of every student is also reachable.

4. Case study 2: Civil construction assembly research and teaching methodology

The greatest potential in the development of civil engineering in the context of designing and assembling objects is the development of BIM (*Building Information Modelling*) technology. It allows for streamlining of the investment process for the benefit of all participating entities: investor, designer, contractor, supervisor, administrator, and user. The implementation of BIM technology will enable better (cheaper, faster) construction of buildings. The main requirement of this approach is working with a common 3D geometric model. Such a model, in addition to consistent information about the geometry model, should contain additional non-graphical data. Such data extend the knowledge about the implemented investment with current bills of materials, schedule, cost estimate, environmental impact assessment, and information for the facility manager. As part of the project, the method of assembly of all structural elements and equipment must be specified. The main advantage of such an integrated design process is the ability to coordinate the design work of all disciplines (e.g. architecture, construction). Working on the basis of a shared 3D model allows to eliminate the number of collisions that can be identified already at the design stage. This enables a reduction of errors measurable in terms of cost and time. This approach is not new, because it is successfully used in the electromechanical industry. Currently, the construction industry is trying to emulate the production process management solutions adopted there, including assembly aspects. The basic limitation of the implementation of these solutions in the construction industry is the specificity of the building objects. Most of the buildings are unique or made in small series. Serial production related to the construction industry consists of components from manufacturers of building materials. Aspects of assembly requirements in civil engineering are different and are primarily related to construction technology in the context of the construction materials used (concrete, steel, ceramics, wood). An additional aspect is the proper use of additional elements (scaffolding, formwork, connectors) as well as tools and equipment. Currently, each of the design phases is supported by computer techniques (CAx). There are suitable applications available on the market from many software manufacturers in narrow industry ranges. These software tools allow you to build geometry models of objects, perform design analyses, prepare executive documentation, and control the manufacturing and building erection process. The basic problem is data exchange between programs and their integration. The reasons for this phenomenon are mainly due to the protection of the intellectual property of software producers. The solution to this problem may be the unification and standardization of the construction process, which is being implemented in developed economies (USA, Germany, UK). In addition, the development of information technology resulting in an increase in hardware and software performance allows for modelling more complex objects containing more and more information.

Research problems in the field of construction cover a very wide spectrum of fields. Part of the research related to the aspect of assembly is related to the collision-free shaping of geometry. Parametric modelling applications are helpful in this regard. These programs use visual programming to generate entire families of models driven by input parameters (width, height, number of storeys, etc.) [3]. This approach allows for the analysis of a larger number of versions of the designed object. As part of the software, we can introduce additional geometric constraints (e.g. perpendicularity, parallelism, length) to the model. Such approaches support the work and expand the workshop of modern civil engineers.

Another challenge is the implementation of these solutions in the education process. In the context of these changes, the use of computer techniques for teaching effects is being intensively introduced in the construction industry. For example, EDURES project partner already uses 3D modelling software (Revit Autodesk) in the first-degree studies stage. By modelling simple building objects, students learn how to properly shape geometry. They practice the element of cooperation by working with a central (reference) model. This increases the awareness of co-responsibility for the created model, which is later to be built (assembled). Second-degree students who already have substantive knowledge carry out tasks related to parameterization and data exchange between programs. For example, a student creates a parametric geometric model of a steel structure in Revit Autodesk. Then export (Fig. 3) the data and perform strength verifications in the FEM (*Finite Element Method*) analysis program. The verified model is imported into the Advance Steel Autodesk program, where it prepares detailed design documentation. Such documentation takes into account all aspects of assembly (division into elements and the order of their connection). This software allows to prepare data for NC machines used in the production of steel elements. In another education module, students practice a wider range of elements of BIM technology. A joint project carried out in groups of four includes the following aspects: shaping the geometry, performing strength analyses, detailing steel and reinforced concrete, searching for collision with another industry project, preparing a schedule and cost estimate, preparing a visualisation of the facility and animation of the assembly of the structure. Execution of the project requires students to be able to negotiate the division of the scope of work into stages and to establish a plan for their implementation. The project is very complex and laborious. However, it prepares the student to work in the contemporary realities of modern construction.

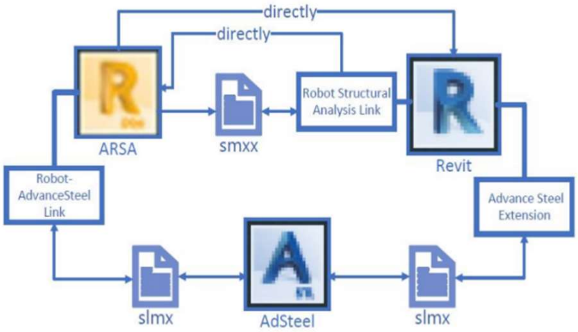


Fig. 3. Data exchange in Autodesk software tools

5. Case study 3: Research on measurement of advanced assemblies and teaching methodology

Measurements of parts of assemblies that can be found in machine industry can be carried out by means of various advanced contact and non-contact coordinate measuring systems [21, 29] e.g., coordinate measuring machines (CMMs), measuring arms and CNC machine tools equipped with scanning measuring probes. The selection of a measuring system to a measurement task depends, among others, on the shape of an investigated product, tolerances of measured parts, and time of coordinate measurements. CMMs are still the most universal and therefore very popular measuring systems [29].

The accuracy of measurements of assemblies conducted by using coordinate measuring machines depends on many elements. The review of factors that determine the uncertainty of coordinate measurements is presented in the work [20]. One of the above-mentioned factors is the measurement strategy including e.g., measurement speed, number and distribution of measurement points, filtration parameters, position of a measuring probe in relation to a measured product and exposure time when using non-contact measuring probes.

Coordinate measurements of elements of assemblies performed by means of CMMs are possible thanks to metrology software enabling measurements of e.g., products characterised by regular geometric shapes, parts composed of curvilinear surfaces, gears, and turbine blades. Metrological software may include different methods of e.g., the probe radius correction process and methods of distributing measurement points. The issue of calculating the coordinates of corrected measurement points has been addressed in many papers e.g., [1, 18]. The very well-known producers of coordinate measuring systems are the following companies: Carl Zeiss and Mitutoyo. Erkan et al. [10] presented the possibilities of two software packages of the companies mentioned in the field of the probe radius correction process.

Fig. 4. Metrological assembly used in modern research and teaching activities

The coordinate measuring technique should be taught at technical universities to increase the accuracy, efficiency of measurements and awareness of the existence of many factors determining measurement results. Moreover, knowledge in the field of the metrology of geometrical quantities may lead to a reduction in the time of coordinate measurements conducted under industrial conditions. The subject 'Coordinate metrology' should be divided into lectures and laboratories. During lectures, students should acquire knowledge regarding e.g., fundamentals of the considered technique, stages of coordinate measurements, factors influencing results of measurements and the uncertainty of measurements. In the case of laboratories, they should learn to operate coordinate measuring systems and metrology software cooperating with e.g., CMMs. They may use off-line versions of software packages to create and simulate programs controlling measuring systems. Selected programs, created and checked by students, may be run on a real machine. Labs should concern measurements of real products of machine industry.

Exemplary metrological assembly that can be used within both research and teaching activities is presented in Fig. 4.

6. Case study 4: Gluing

Lectures and laboratories are devoted to the assembly process in the field of mechanics and machine construction in the subject fundamentals of machine technology and in the field of mechatronics in the subject of manufacturing engineering. As part of the subject matter, special attention is paid to gluing operations, thanks to the possibility of getting to know the essence of the process in practice. During the classes, it is possible to observe the course of gluing, in which surface preparation operations play an important role. Methods and effects of surface preparation before applying the adhesive are discussed, i.e. cleaning of corrosion and paint layers, degreasing and washing, shaping the surface a specific roughness and geometric structure. The influence of conditions and preparation technology on the final strength of the joint is analyzed. As part of laboratory classes, glued joints are made in various variants distinguished, among others: due to the method of surface preparation selected for a specific type of material (sandblasting, sandpaper, laser, by galvanic treatment), type of glue (e.g. epoxy, methacrylic, cyanoacrylate and others), method of preparing the adhesive mixture (single or two-component, mixed in the nozzle of the manufacturer's packaging or manually according to the adopted proportions), method of connection construction (single-lap joint, butt joint), overlap size and others. Connections are tested, inter alia, for static resistance to tearing. When working with students, studies by researchers from other research centers are used [25, 26] as well as publications of own research results [5, 6].

Figures 5 and 6 present examples of used adhesives and test samples (lap joints). The subject is of great interest among students. There are also diploma theses on the subject of assembly, in which the independent implementation of experimental research is a task focused on industrial applications, due to the emergence of new construction materials and adhesives.

Fig. 5. Examples of adhesives used

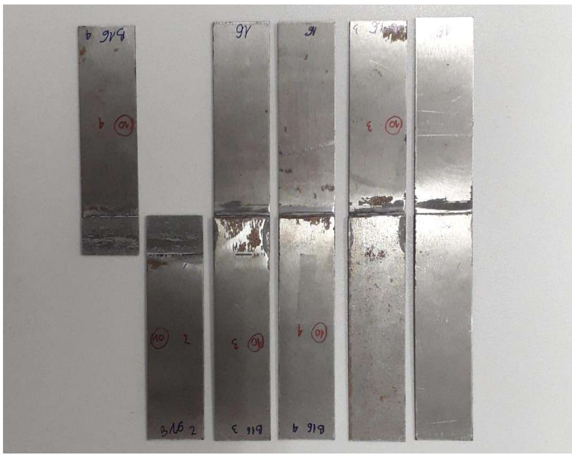


Fig. 6. Test samples – single-lap joints

7. Case study 5: Electro discharge machining process (EDM) utilization for manufacturing of precise assembly parts of machines

The following section pertains to a brief presentation and discussion regarding the non-conventional process of Electrical Discharge Marching (EDM). EDM is one of the earliest but still widely employed thermo-electrical process, which is mainly utilized in machining electrically conductive materials. The basic operation principle of EDM is considerably simple, as the material is removed through a number of rapid repetitive spark discharges in the presence of dielectric fluid. More specifically, a voltage difference is applied between an electrode and the workpiece, which typically are both submerged in a dielectric fluid and at a very close distance, but not in touch. Under the act of the voltage difference, an intense electromagnetic field is developed. At some point, most commonly where the two materials have the minimum in-between distance, the fluid's dielectric constant breaks down, causing a spark and forming a plasma channel. Topically, extremely high temperatures develop in the range of 6,000 - 12,000°C, resulting in the melting and / or ablation of the material. With the end of the voltage pulse, the plasma channel is collapsed; the melted and ablated material is removed due to the presence of the dielectric fluid and finally, the system returns to its initial state in order for a new cycle to start. The aforementioned general cycle is repeated thousands or even millions of times per second, resulting in the gradual removal of small material volumes. It is also important to note that, during the process, only an amount of melted material is removed by the workpiece, the rest being resolidified and forming a layer of amorphous material on the top of the workpiece, known as the White Layer [15].

In the relevant literature, several different process parameters have been studied and discussed to improve process quality and efficiency. In general, the most widely employed performance indexes that are commonly utilized to assess the process are the Material Removal Rate (MRR), which pertains to the material removal volume per minute, the Tool Wear Ratio (TWR), which depicts the wear of the working electrode in respect of the MRR, the Surface Roughness and finally the Surface Topography and the Surface Quality. It has been proven that all the above performance indexes are directly and strongly related to the process parameters and especially the electrical pulse characteristics, e.g., the pulse duration, the time between two successive pulses, the voltage difference, and the current density. Thus, it is scientifically interesting, but also with practical value, the in-depth understanding of the process and the underlying mechanisms, along with the further study and research concerning the process optimization. Moreover, modelling and simulation methods can be deployed in order to further study and optimize the EDM process. As an example, in Fig. 7 representative results of the EDM process are presented concerning the material removal and the temperature field in the electrode and the workpiece during a single spark [14].

Finally, from the perspective of engineering assemblies and their quality, the study and optimization of EDM process and its performance indexes, is a very important issue considering that the dimensional accuracy, the surface roughness, the surface topography and the surface quality, depend on the definition and use of proper and optimal machining conditions and parameters. Therefore, in the literature, many significant and relative studies can be found. As an example, in the work of Karmiris - Obratanski et al. [17] an extensive study has been conducted regarding the surface and subsurface quality of Titanium Grade 23 after its machining with EDM. In another similar study, the optimalization of the surface texture and machining parameters of 60CrMoV18 steel after EDM has been investigated and discussed [16]. In the work of Gong and Sun [12] a study concerning the forming consistency and accuracy in fabricating array micro-electrodes and array micro holes using EDM is presented, while in another representative example, the machining parameters of wire-EDM are optimized aiming in maximum surface hardness and minimum dimensional deviation after the process [27]. The references above clearly indicate the direct and strong correlation between the machining parameters and the obtained results regarding the quality of an engineering assembly, which all or some of its components have been manufactured utilising the EDM process.

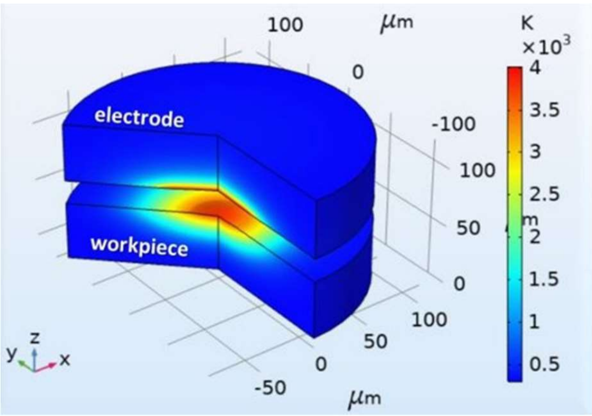


Fig. 7. Simulation results of the EDM process for the electrode and the workpiece regarding the material removal and the temperature field during a single spark

8. Case study 6: The use of advanced assemblies in measurements of machining processes indicators and teaching methodology

In the Institute of Precision Machining (KSF) at the University of Furtwangen, several research every year are conducted in machining, grinding, laser processing, simulation and Artificial Intelligence (AI). These research activities allow students to translate their effective knowledge (obtained in theoretical lectures) into practice. Students can involve in these research activities through their bachelor, master, or project work. For conducting research activities, several measuring devices are available for in situ and in process measurement. Therefore, students can use them to practically study the effect of different parameters on the measuring outputs and analyze the machinability of different materials. For example, the generated forces are one of the most important factors for evaluating the machining process. In this regard, the students are provided with a multi-component force measurement system (Kistler) for measuring and analyzing the cutting forces in different directions. The force component measuring device (or dynamometer) is available in different sizes. Figure 8a indicates an experimental setup for performing the micro-machining process and measuring the cutting force with a dynamometer in the machine tool. Furthermore, the ImageIR 8300 thermography camera (InfraTec) is used for temperature measurement during machining, as illustrated in Figure 8b. In addition to in situ measuring devices, the integrated confocal microscope in the machine tool allows for analyzing the machined workpiece (See Figure 8c). Moreover, portable tactile surface roughness measurement is used for the in-process measurement in the machine tool to measure surface roughness.

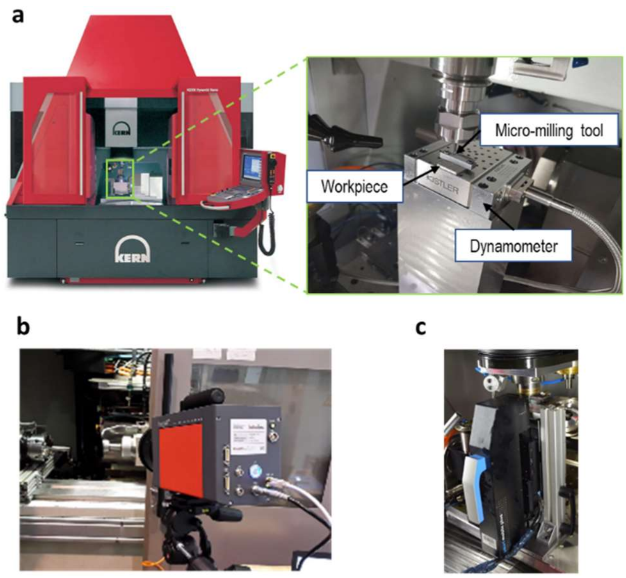


Fig. 8. Exemplary integrated measuring devices into machine tools. a) dynamometer, b) thermographic camera, c) confocal microscope

Moreover, the students in their research activities can benefit great deal from modern device for measuring and analysis of the process. A five axes CNC machine tool (Haas-Multigrind® CA) with a Siemens Sinumerik controller is used in different research studies. For the data acquisition, the machine tool is equipped with a so-called Siemens SINUMERIK EDGE (SE) Box (Fig. 9). Siemens CNC controls supply data, and SE, make it possible to record data and states of the control in a resolution of 1 ms (1kHz) parallel to the process. The SE box is, in principle, an industrial computer and has the corresponding resources to store the data. The MindSphere Capture4Analysis application enables the selection of the signals to be recorded and the trigger time from which a signal is to be recorded. According to a defined system, the data is written to a JSON file on the hard disk of the SE box with the execution of the NC program. Further, the JSON File for each test is processed through a written ETL program (Extract-Transform-Load) to obtain the tabular data in CSV format. The CSV data and post-process information from the measurement system collected in tabular data are used for further analysis.

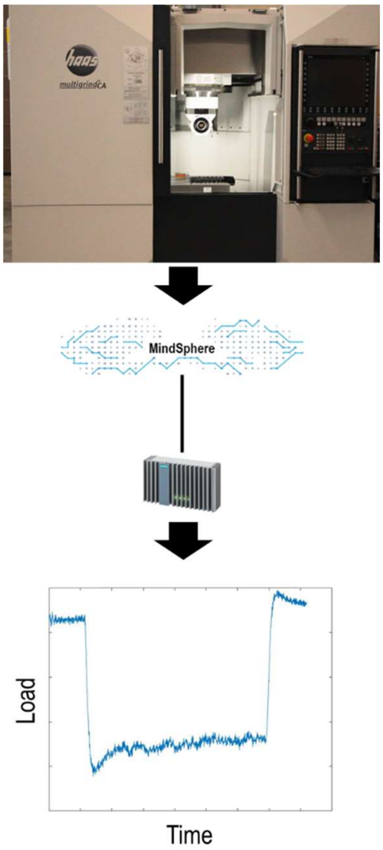


Fig. 9. In Situ measurement of load using Edge-Box

9. Conclusion

Case studies regarding research-based education in the area of advanced assemblies were presented. They reveal that research-based education can be focused on various topics in the area of assembly technology which is a current issue of research and teaching environments of partner universities of the EDURES project. The EDURES project partners have developed a methodology which is based on their research interests that supports the implementation of research results in teaching and allows for a wider discussion and further developments in this area. Based on team work effects it is visible that understanding of research based education is not understood similarly and transparency of research is a main problem which should be addressed in future analyses.

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