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Original Research/Review

CONCEPT OF AUTOMATED CAR BATTERY ASSEMBLY LINE

KONCEPCJA ZAUTOMATYZOWANEJ LINII MONTAŻU BATERII SAMOCHODOWYCH

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Abstract

This paper presents the concept of an automotive battery assembly line. The line includes in its structure fully and semi-automated assembly sockets, as well as manual assembly sockets. The transport between the sockets is carried out using an AGV autonomous trolley system. The selection of the assembly process execution method was based on an analysis of the technical feasibility of the process as well as an analysis of the occupation time of individual assembly stations. The resulting line structure indicates to what extent the automation of the assembly process contributes to a change in material flow and influences the way the process is carried out, including a variety of technical means used. The paper presents an analysis of the use of particular workstations. As a criterion for optimization, the occupation time was taken in relation to the cycle time, which translates into the optimal use of resources involved in the production process.

Keywords: automation, transport, assembly

Streszczenie

W artykule przedstawiono koncepcję linii montażu baterii samochodowych. Linia ta zawiera w swojej strukturze gniazda montażowe w pełni zautomatyzowane, częściowo zautomatyzowane oraz gniazda montażu rączego. Transport pomiędzy gniazdami realizowany jest z wykorzystaniem systemu wózków autonomicznych AGV. Wybór sposobu realizacji procesu montażu został oparty na analizie możliwości technicznych realizacji procesu jak również analizie czasu zajęcia poszczególnych stanowisk montażowych. Otrzymana struktura linii wskazuje w jakim stopniu automatyzacja procesu montażu przyczynia się do zmiany przepływu materiałów i wpływa na sposób realizacji procesu, w tym na różnorodność zastosowanych środków technicznych. W pracy zaprezentowano analizę wykorzystania poszczególnych stanowisk roboczych. Analiza ta posłużyła do przeprowadzenia optymalizacji przebiegu linii montażu komponentów. Jako kryterium optymalizacji przyjęto czas zajęcia stanowiska w stosunku do czasu cyklu co przekłada się na optymalne wykorzystanie zasobów zaangażowanych w proces produkcyjny.

Słowa kluczowe: automatyzacja, transport, montaż

1. Introduction

Every manufacturing company aims to achieve maximum production efficiency at the lowest possible cost (Więcek-Janka, Pawlicki i Walkowski, 2018). In an era of constant market volatility, technology development and strong competition, the product manufacturing process requires continuous improvement. Each improvement can affect the success or failure of a company. This means that the production process should be constantly analysed in order to eliminate imperfections and increase production efficiency and quality (Stadnicka, Lean manufacturing, 2021). It is therefore important for the proper functioning of a production enterprise to optimally design individual operations, i.e. production activities, into an appropriate sequence. Improper planning of the sequence of operations leads to unnecessary costs and increased production time. Attempts to sequence manufacturing processes have been made for a long time and are reflected in many methods e.g. Gantt charts, network planning methods, etc. (Brzozowska & Gola, 2021).

The issue of streamlining production preparation processes appears to be very important as companies strive for ever shorter production cycles. The streamlining of processes is forced not only by the desire to reduce production costs, but above all by the need to operate competitively in the market. The use of modern tools in all phases of product design, preparation and production is helpful in creating such conditions (Stadnicka, Problemy w obszarach produkcyjnych, 2021).

The end of the production preparation cycle is organisational preparation. The type of production depends on the degree of specialisation and workload of individual workstations (Gola, 2021). We can categorise basic types of production as mass production, batch production and unit production. Depending on the type of production, workstations are classified as:

- universal - operations and parts are not strictly assigned; universal equipment and tools,
- specialised - having a specific group of parts and operations assigned, together with the possibility of limited changeovers,
- special - strict allocation of parts and operations without the possibility of changeovers.

The manufacture of parts and their assembly are components of the production process. In the manufacturing process, a semi-finished product undergoes changes in shape, dimensions and other functional characteristics, and is then transformed into a finished part. In the assembly process, parts are joined together to form sub-assemblies or directly into a finished product. Fig. 1. shows the relationship between the manufacturing and assembly processes against the background of the production process. Assembly, in the sense of product and material flow, is related to the manufacturing process, while in the sense of information flow it is integrated with production control, process and production planning, product development and indirectly with marketing and product planning (Koch, 2006).

Fig. 1. Assembly as an element of the production process (Koch, 2006)

The main determinants for the selection of an appropriate assembly method at the assembly system design stage are, on one hand, the products to be assembled, the process and production characteristics, and, on the other hand, economic criteria such as manufacturing costs, the number of production shifts, etc. Based on these principles, assembly methods can be divided into six types (Koch, 2006):

- manual assembly,
- manual assembly with technical tool support,
- mechanical assembly with universal devices,

- mechanical assembly using specialised equipment,
- automatic assembly using programmable feeding systems (Domińczuk i Gałat, 2023),
- automatic assembly using industrial robots.

The analysis of a product requires the characteristics of the parts that it is composed of and the features of the connections between these parts. These characteristics affect the complexity of the assembly process and the required execution time. The design rules are based on two characteristics: shortening the number of assembly operations and simplifying them. Reducing the number of operations can be achieved, among other things, by designing modular construction of products and eliminating an excessive number of components, according to the criterion of the purpose of their presence. Assembly operations can be simplified as a result of the analysis of design rules, e.g. the main direction of assembly, the system of feeding, manipulating and consociating of objects, or good accessibility to individual components (Rudawska i inni, 2023).

A robotic assembly system is defined as a structure consisting of personnel, one or more assembly robots and flexible peripheral equipment for assembling individual objects or components into a finished product. The personnel perform functions to support and supervise assembly work, e.g. related to system implementation, pallet stock replenishment, supervision, programming and system management. Assembly robots perform operations connected with manipulation of objects in the system (Kaczmarek i Panasiuk, 2018). The peripheral equipment is responsible for the automation of the feeding of parts to the assembly, the use of appropriate tools, sensors, control systems, as well as safety (Łapczyńska, 2023).

Robotic assembly systems are built in two basic configurations (Koch, 2006):

- robotic assembly sockets; they require the use of independent units consisting of one or more robots and peripheral equipment to carry out the assembly of a product; the characteristics of this structure are a relatively long work cycle and a large number of different objects assembled by a single robot,
- robotic assembly lines; this system combines several workstations installed in a line; the characteristics of this structure are a short work cycle, a limited number of assembly of different objects by each robot and the need to transport the product between different workstations; a robotic line may also consist of several sockets, connected by a transport system, with the possibility of using buffers between them.

The choice of the degree of mechanisation and automation is primarily related to the production programme. It is obvious that it is totally different to design a technological process for a few pieces of a product and quite different for a large series or mass production. The degree of mechanisation and automation is also influenced by the requirement for quality and repeatability of the product. It is known that in order to achieve high quality and repeatability of the product, special machines or devices will most often be needed, and it will be necessary to follow certain principles of repetitive basing and fixing of individual elements of the often complex product.

The purpose of this study is to present the possibility of assembling automotive batteries using automated workstations. The achieved efficiency of these workstations means that they can be used repeatedly during the assembly process at different stages. The result is a reduction in the amount of technical means used, which reduces production costs. The paper presents the concept of a technical solution that allows the use of technical means used in battery assembly in such a way as to minimize production costs. The presented solution is designed to increase production efficiency by combining automated stations with manually operated stations in a single assembly line. The proposed solution was developed for an actual car battery. Due to commercial confidentiality, the details of the battery assembly process are not provided in the study.

2. Design requirements

A car battery is to undergo the assembly process (Jones, 2024). A general structure of an electric car battery is shown in Fig. 2. This is an illustrative scheme. The battery consists of a number of components that need to be assembled together to form a finished product (Warner, 2015). The assembly process involves various assembly methods appropriate for the task being performed.

Fig. 3. shows a block diagram of the assembly of the battery components. It takes into account the assembly of both the elements constituting the battery enclosure, a cooling system, power modules, control and power management elements and additional battery equipment. It was assumed that transport between sockets would be carried out using an AGV autonomous trolley system. Due to the quality requirements of the process, the execution of some assembly operations must be carried out automatically. This applies, for example, to the thermal compound application operation. The requirement here is to maintain a constant cross-section of the applied bend of the compound. This operation can only be

carried out using a robotic workstation additionally equipped with a process control system (Fig. 4.). This requires that the battery assembly time does not exceed 226 seconds. As can be seen from the presented diagram of operations included in the assembly process, both fully-automated, semi-automated and manual assembly workstations should be used to complete the task. The use of manual assembly is mainly related to the need to execute the assembly of flexible cables, which are not adapted to the automatic assembly process.

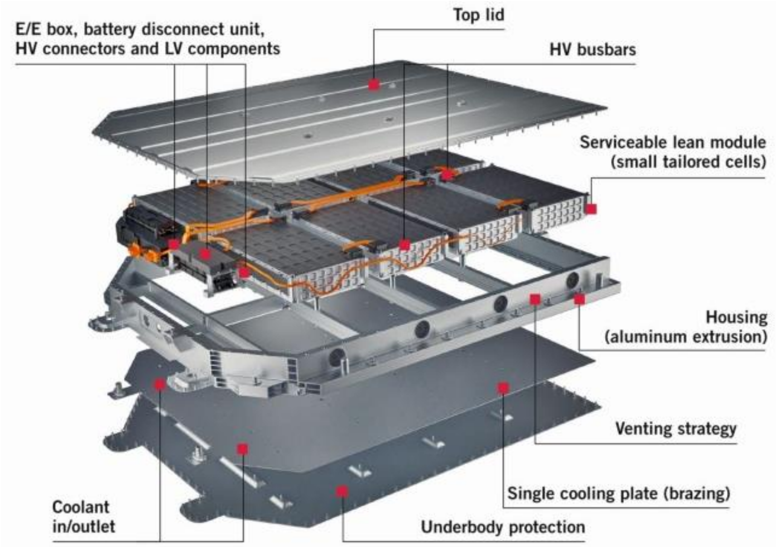

Fig. 2. Components of the electric car battery (Rudolph, Teuber, Beykirch i Löbberding, 2023)

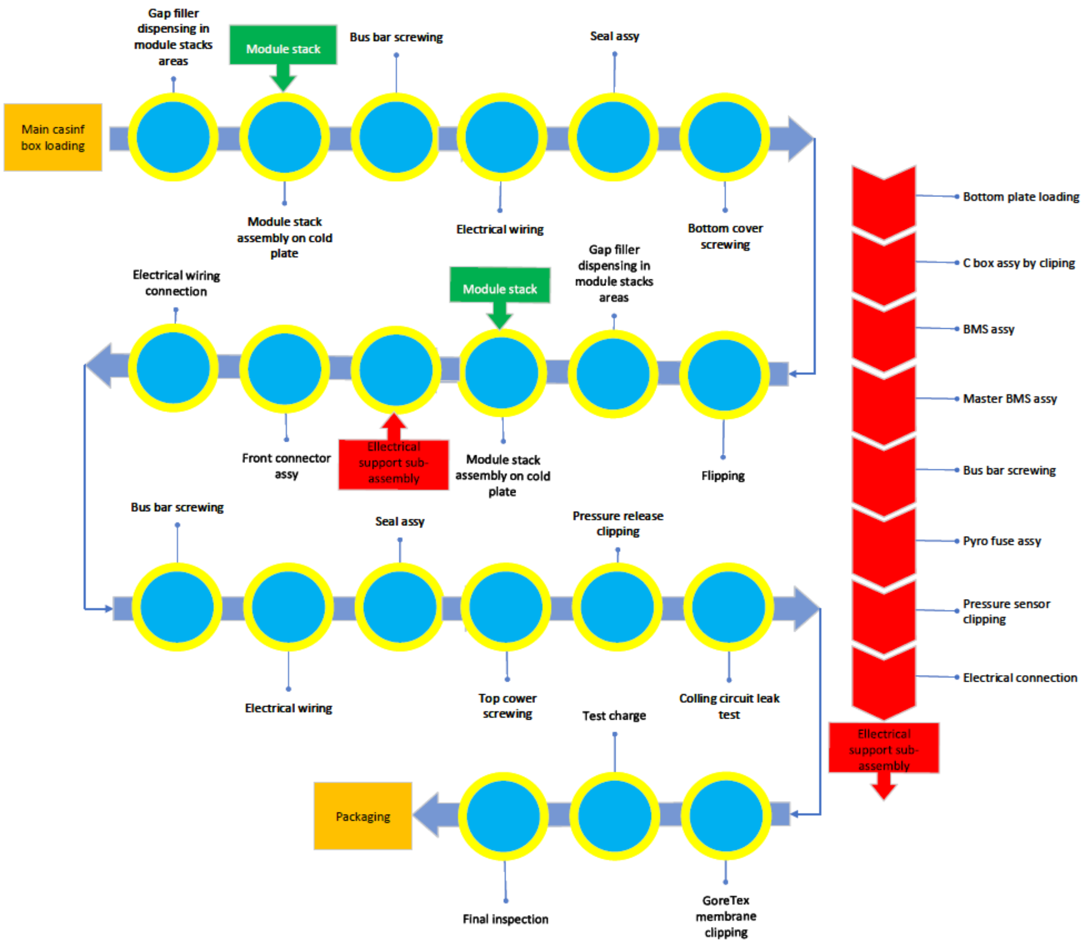

Fig. 3. Diagram of battery assembly

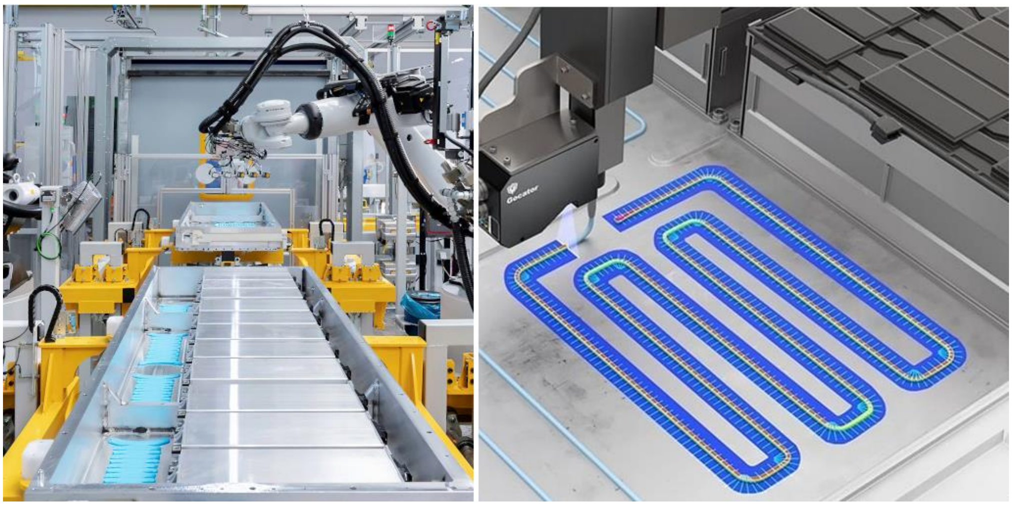

Fig. 4. Process of application of thermal compound (E-mobility engineering, 2024)

In order to optimise the course of the assembly process, a time analysis of the individual tasks was carried out (Fig. 5.). This analysis made it possible to define the course of the assembly process, taking into account the optimum use of the assumed technical resources.

STATION 1 - Loading components

Operation	Time/Qt	Qt	TIME [s]	
Unloading&Loading Bottom	90	1	90.0	M
Transfer component AMR	26	1	26	A
Total time			116	

STATION 2 - Robot Filler gap dispensing

Operation	Time/Qt	Qt	TIME [s]	
Filler gap dispensing Bottom	0.04	2179.3	87.2	A
Transfer component	26	1	26	A
Filler gap dispensing Top	0.04	2179.3	87.2	A
Transfer component	26	1	26	A
Total time			226	

STATION 3 - Robot module assembly

Operation	Time/Qt	Qt	TIME	
Module assembly Bottom	20	4	80.0	A
Transfer component	26	1	26	A
Module assembly TOP	20	4	80.0	A
Transfer component	26	1	26	A
Total time			212	

STATION 4 - Robot screwing

Operation	Time/Qt	Qt	TIME [s]	
Module screwing x4 Bottom	14	4	56.0	A
Transfer component	26	1	26	A
Module screwing x4 TOP	14	4	56.0	A
Transfer component	26	1	26	A
Total time			164	

STATION 5 - TRANSFER
Pick up top cover with modules and put on bottom cover with modules

Operation	Time/Qt	Qt	TIME [s]	
Towers fixation	10	2	20	M
Harnesses assembly	10	4	40	M
Bus bar screwing Bottom	20	3	60	M
Transfer component	40	1	40	A
Total time			160	

STATION 6 - Loading components (TOP)

Operation	Time/Qt	Qt	TIME [s]	
Unloading&Loading TOP	90	1	90.0	M
Loading seal on bottom	26	1	26	M
Transfer component ROTATION	16	1	16	A
Total time			132	

STATION 7 - Lift, Rotation

Operation	Time/Qt	Qt	TIME [s]	
Modules lift	16	1	16.0	A
Rotation + transfer	28	1	28.0	A
MODULES Assambly	20	1	20.0	A
Transfer component	40	1	40	A
Total time			104	

STATION 8 - Screwing

Operation	Time/Qt	Qt	TIME [s]	
Screwing (ground, std)	7	20	140.0	A
Robot park position + work position	8	1	8.0	A
Transfer component ROTATION	16	1	16	A
Total time			164	

STATION 9 - Rotation BATERY

Operation	Time/Qt	Qt	TIME [s]	
Modules lift	16	1	16.0	A
Rotation + transfer	28	1	28.0	A
Unloading on AMR	16	1	16.0	A
Transfer component	30	1	30	A
Total time			90	

STATION 10 - ELECTRIC BOARD PREPARATION

Operation	Time/Qt	Qt	TIME [s]	
bottom plate loading on station	8	1	8.0	M
master bms assy - screwing	8	4	32.0	M
BMS slave assy (x8)	8	8	64.0	M
P-sensor & Pyrofuse assembly	8	2	16.0	M
C-Box fixation	10	4	40.0	M
Transfer component	16	1	16	A
Total time			176	

STATION 11 TOP floor assembly

Operation	Time/Qt	Qt	TIME [s]	
TOP to BOTTOM busbar screwing	20	2	40.0	M
Main harness assembly	16	1	16.0	M
Elecric board assembly	10	3	30.0	M
36w connector fixation	10	5	50.0	M
RCS800 connector assembly	10	6	60.0	M
Transfer component	26	1	26	A
Total time			196	

STATION 12 TOP floor assembly

Operation	Time/Qt	Qt	TIME [s]	
APEX280 connector assembly	10	4	40	M
BMS to Modules harness assembly	10	12	120.0	M
Busbar assembly	20	2	40	M
Transfer component	26	1	26	A
Total time			226	

STATION 13 TOP floor assembly

Operation	Time/Qt	Qt	TIME [s]	
Busbar assembly	20	3	60	M
front connector assy	60	1	60.0	M
Transfer component	26	1	26	A
Total time			146	

STATION 14 - Manual operations - 2 operators (13 +14)

Operation	Time/Qt	Qt	TIME [s]	
loading cover on station fireman access assy	10	1	10.0	
fireman access sticking inside and outside	45	1	45.0	
Loading TOP seal assembly	26	1	26.0	
loading top cover	20	1	20.0	
cooling circuit Leak test ATEQ	160	1	160.0	
loading 4x clip on convoyer	15	4	60.0	
Transfer component	26	1	26	
Total time			212	

STATION 15

Operation	Time/Qt	Qt	TIME [s]	
Robot work position	4	1	4.0	
Screwing (ground, std)	7	22	154.0	
Robot park position	4	1	4.0	
pressure release clipping (x2) BIG	15	2	30.0	
Transfer component	32	1	32	
Total time			224	

STATION 16

Operation	Time/Qt	Qt	TIME [s]	
pack leak test ATEQ	160	1	160.0	
Gore membrane assy x 2	15	2	30.0	
Transfer component	32	1	32	
Total time			222	

STATION 17

Operation	Time/Qt	Qt	TIME [s]	
CONECTION	8	3	24.0	M
EOL tests & chargefinal	1200	1	1200.0	A
Transfer component	40	1	40	A
Total time			211	

STATION 18

Operation	Time/Qt	Qt	TIME [s]	
final inspection and labelling	10	3	30.0	M
Unloading&Loading BATERY	90	1	90.0	M
Transfer component	32	1	32	A
Total time			152	

Fig. 5. Analysis of occupation time of assembly sockets (in [s])

3. Assembly line design

The analysis of the possibility of executing the battery assembly, taking into account the optimum time of use of technical means, made it possible to develop a diagram of the assembly line (Fig. 6.). In the solution, it was assumed that the base component for the first stage of assembly will be placed on an AGV trolley on a stand with manual operation (Fig. 7.). At stands 2, 3 and 4, the assembly process will be fully automatic and will involve all the steps connected with assembling the battery modules on both the bottom and top sides of the battery (Fig. 8.). Stations 5 and 6 are manually operated due to the execution of operations that are difficult to automate. Stations 7, 8 and 9 are fully automated and the concept of their operation is based on cooperation with station 6 resulting in a partially automated socket (Fig. 9.). At the subsequent stations up to station 14, the assembly process is carried out manually. Stations 15 and 16 (Fig. 10.) are automated. Stations 17 and 18 (Fig. 11.) are manually operated with the assumption that the work at these stations will be carried out by operators from the preceding stations. This is done to minimise interruptions in or er to make optimal use of resources.

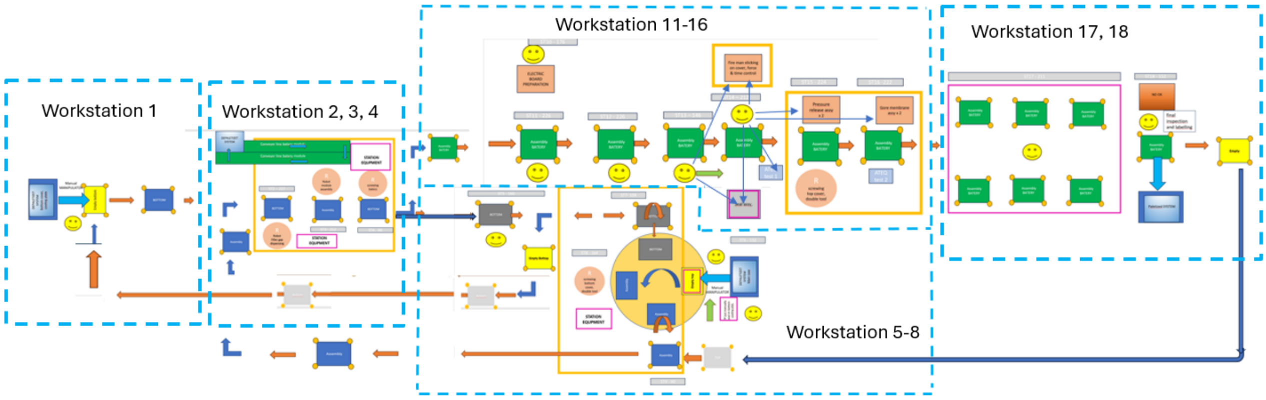

Fig. 6. Diagram of assembly line

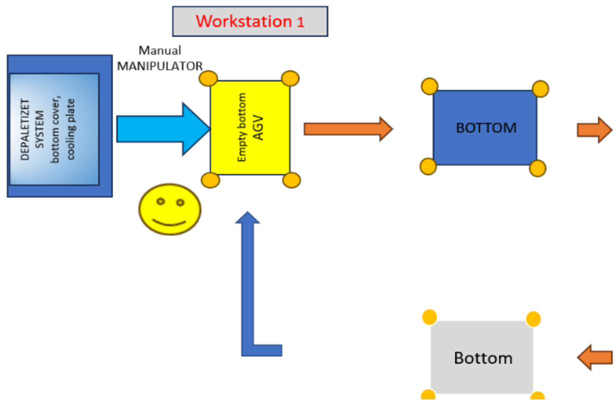

Fig. 7. Diagram of workstation 1

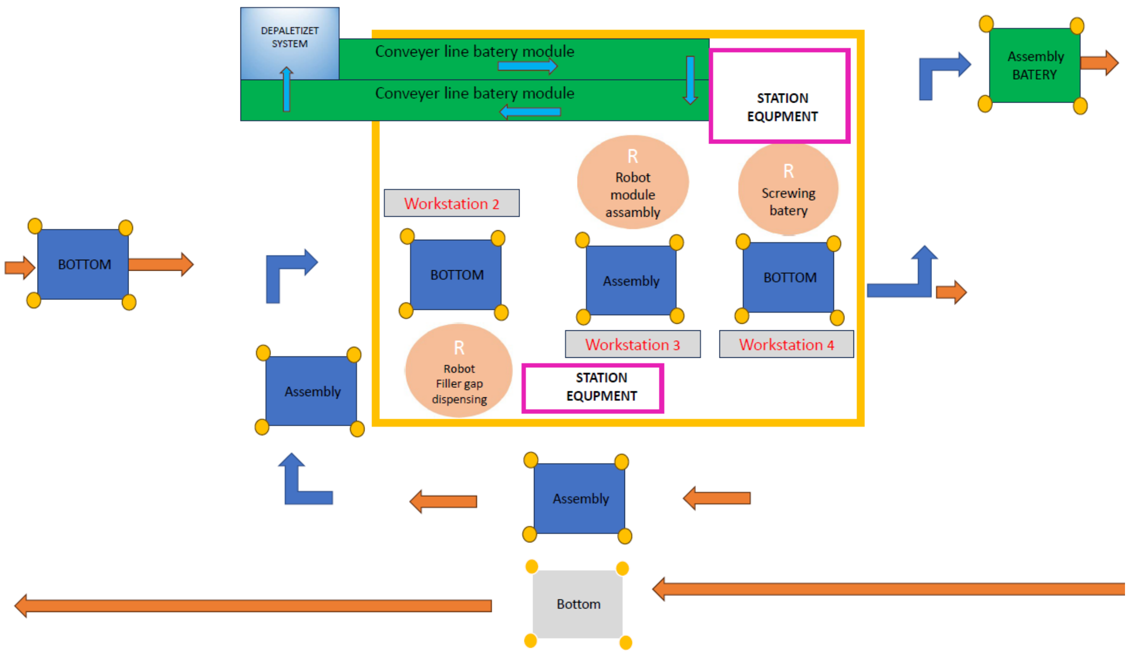

Fig. 8. Diagram of workstations 2, 3, 4

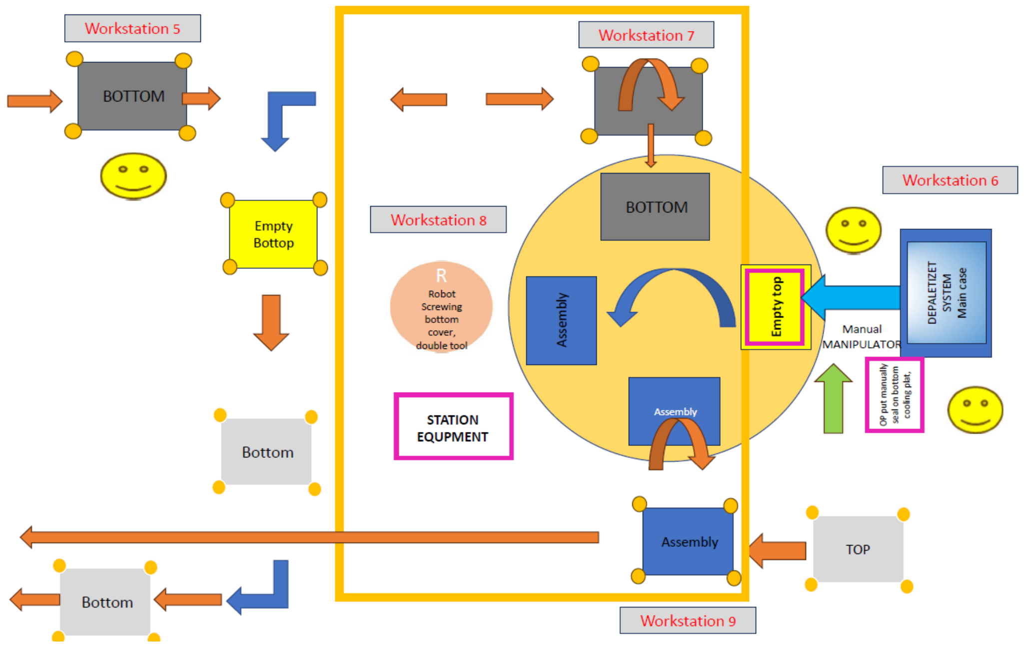

Fig. 9. Diagram of workstations 5-9

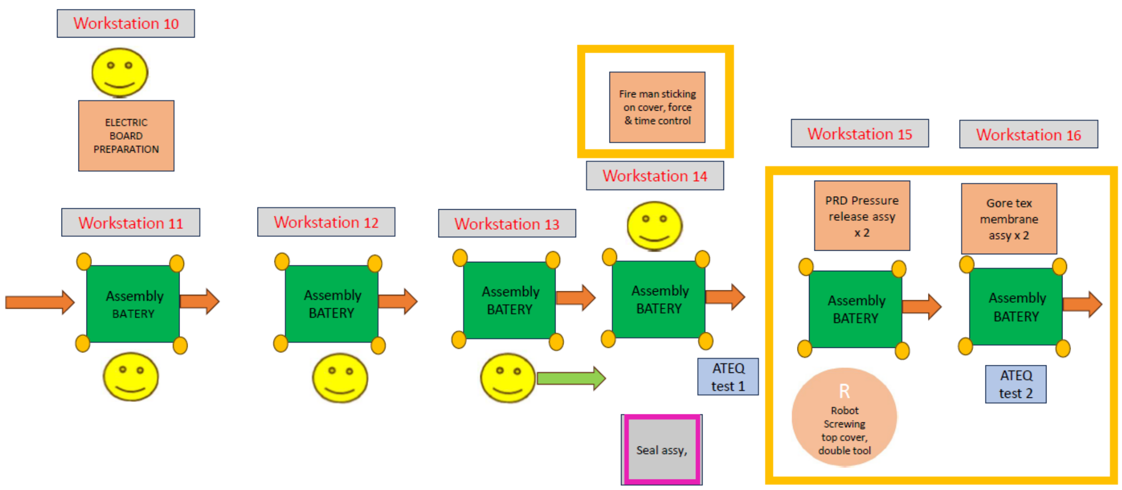

Fig. 10. Diagram of workstations 10-16

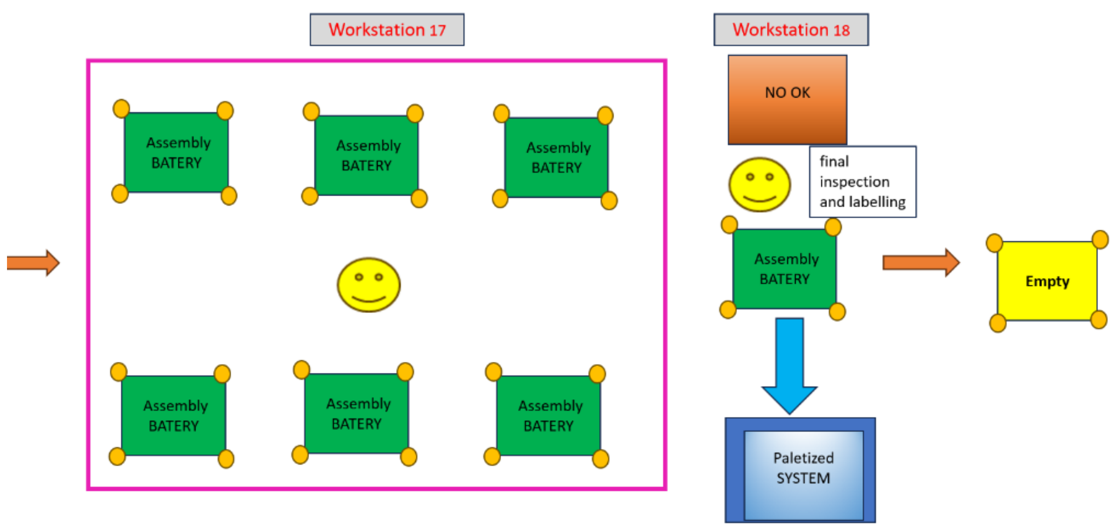

Fig. 11. Diagram of workstations 17, 18

Equal distribution of tasks between positions allows to maintain a constant work tact. At the same time, it should be noted that positions in which manual labor predominates should have additional time. This time is needed to compensate for differences in employee productivity.

4. Summary

The solution for the electric car battery assembly line presented in this paper allows to obtain optimal conditions for the process to be achieved while minimising the technical resources involved. Works that are difficult and costly to automate were left to be performed in a manual system. Those that are susceptible to automation and at the same time important in terms of the quality of the assembly process are to be carried out in automated assembly sockets. Due to the high cost of automation, the product flow was planned so as to make maximum use of the possibilities of the technical solutions used, including robots. Attention was paid to the need to use a minimum of transport means as well as tooling for moving the product along the assembly line. Thanks to the division of operations used, it was possible to separate two transport lines with independent means of transport. This division makes it much easier to manage the mobile robots and also to respond to abnormal situations.

The presented solution is an innovative solution aimed at minimising the cost of implementing a new product in the assembly process. This solution meets the expectations of Industry 4.0 (Stadnicka, et al., 2022) (Kolberg & Zuhlke, 2015) (Brzozowska & Gola, 2021). The presented solution is the result of searching for optimal conditions of process execution, which is one of the basic activities during the design of robotic production systems (Cha, Vogel-Heuser i Fischer, 2020).

The presented assembly system is based on a modular design, which makes it easily adaptable to other industrial applications. It can be scaled and adapted to new application needs. All these factors make the system concept versatile and universally applicable for a wide range of required performance variants including full automation.

The presented solution combines two assembly methods: automatic and manual. The increase in the degree of automation changes the way products flow. Due to the higher efficiency of the automated process, there is an opportunity to use robotic stations to perform repetitive activities. This results in the possibility of directing products to repetitive activities on the line. Thanks to such an assembly run, automated stations are optimally loaded in terms of their working time. In order to implement such a run, the use of AGVs is recommended. The use of mobile robots makes the presented concept a flexible solution. It can be adapted to specific applications by merely changing the product flow path. The occupation time of the workstation was adopted here as an evaluation criterion, aimed at minimizing the interruption time in the overall assembly time of 226 s. This approach provides an opportunity to reduce the amount of technical resources involved in the production process. When configuring the layout, special attention was paid to minimizing the number of workers required to operate the line. They carried out tasks that are difficult to complete in an automated process. All repetitive activities were carried out at automated stations.

The presented solution can be used during the development of car battery assembly lines. Increasing the degree of automation of the assembly process will be possible after eliminating from the battery design elements that are not susceptible to automatic assembly. This will make the assembly process more efficient. It is therefore expedient to look for design solutions for increasing the degree of automation of the process.

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