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Faculty of Mechanical Engineering
Department of Engineering Processes Automation
and Integrated Manufacturing Systems

SELECTED ENGINEERING PROBLEMS

NUMBER 8

Gliwice 2019

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ISSN 2299-954X

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DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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THE INTEGRATION OF AN INDUSTRIAL ROBOT WITH THE MANUFACTURING CELL SIMULATOR

Abstract: The paper presents the results of work concerning the hardware and software integration of an industrial robot with the manufacturing cell simulator and the transport system, which are a part of laboratory of the Institute of Engineering Processes Automation and Integrated Manufacturing Systems. The main goal was to enable the communication between the control devices, i.e. robot controller, PLC and distributed motion controllers. The paper also covers issues like the communication between the robot and personal computer, the development of the robot's control algorithm and the control program for determining the position of the object on the transport pallet.

1. Introduction

The development of the Industry 4.0 idea puts a special emphasis on the flexibility of production systems. In practice, this means the need to ensure effective communication between different devices and machines, without implementing the centralized control system [1-3]. The control systems of individual units should not only perform the assigned program, but also actively respond to signals coming from the environment and solving some simple problems. According to the Industry 4.0 standards, these conditions are fulfilled by the so-called Cyber-Physical Systems [2], however, the use of appropriate algorithms from the field of artificial intelligence is absolutely necessary to achieve the mentioned goals. The system integration in the modern industry is therefore a complex and difficult issue.

The aim of the presented work was to integrate the Mitsubishi Movemaster industrial robot with the transport system and the equipment of a robotic workcell simulator. All devices and machines are the part of laboratory of the Institute of Engineering Processes Automation and Integrated Manufacturing Systems. The preliminary activities were mainly connected with the mechanical inspection of the workcell and checking the operation of individual mechanisms. In the second stage, the hardware side of the communication was developed. The last step involved the appropriate reprogramming of the PLC controller that supervises the operation of the devices in the robot cell, the development of the robot's algorithm and to write the appropriate robot control program. The further part of the paper will present some of the mentioned aspects in details.

2. The robotic workcell and the transport system

The robotic workcell is equipped with the Mitsubishi Movemaster RV-M1 robot. It is a small machine with five degree of freedom and capable of 1,2 kG lifting force [4]. The robot is mounted on the slide plate that is driven by servomotor that gives an extra DOF and extends the workspace of the robot, what is necessary because of the cell dimensions. The complete line is shown in Figure 1, while the robotic workcell is shown in Figure 2.

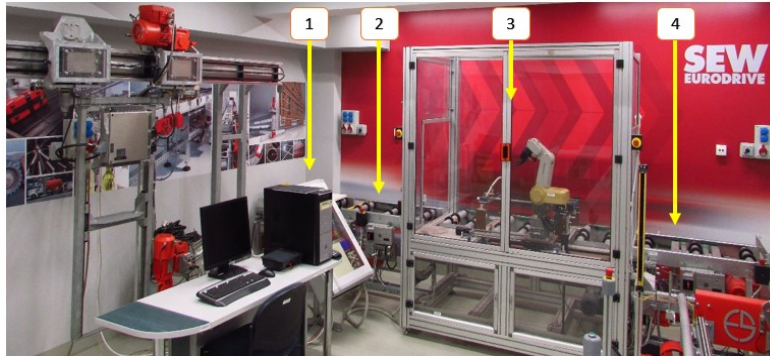


Fig.1. The complete manufacturing line simulator with the robotic workcell (3) and roller conveyors (1,2,4)

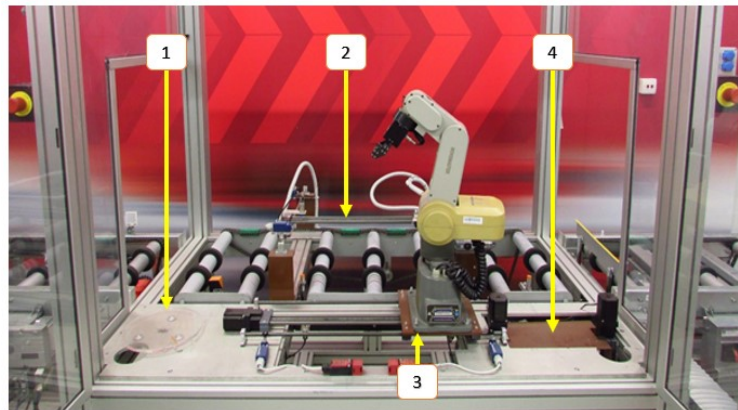


Fig.2. The robotic workcell: the turntable (1), object detection device (2), robot (3) and lift table (4)

After the thorough revision of functionality condition of mechanisms, the further step was connected with enabling the communication between the robot and a PC computer.

3. The communication between the RV-M1 robot and the personal computer

The RV-M1 robot is equipped with the Multi16 card that has two connectors dedicated for communication with a computer: Centronics and RS-232. Concerning the hardware side of communication, it should be noted that only RS-232 port enables two-way transmission (i.e. ability of sending and receiving data) [4]. It was important to set the same transmission parameters on both sides. In the case of the robot, the parameters of the RS-232 port are hardware dependant and should be set by modifying DIP-switch configuration (Figure 3).

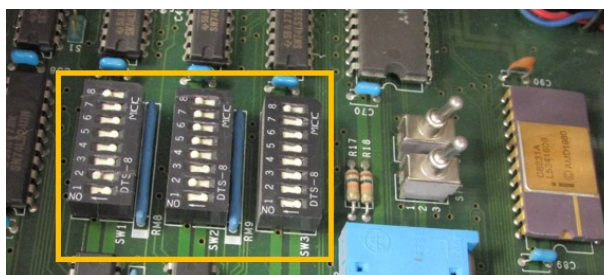


Fig.3. Group of switches on the Multi16 card of the RV-M1 robot

In order to simplify information handling between the computer and the robot's controller, the terminal emulation software has been used – because of using such application it has been possible to transfer the program for the robot's controller and (what is more important) to retrieve the information about robot status, what was particularly useful during the debugging phase.

4. The communication between the RV-M1 robot and Mitsubishi Series Q PLC

The first idea concerning the realization of information interchange between the robot and the PLC was to use the RS-232 connection, but it turned out impossible to realize because of the lack of proper hardware on the PLC side. Finally, it was decided to use the I/O communication interface, located on one of the cards mounted in the robot's controller [5]. However, it turned out that there is only limited number of bits available. After making some modifications in the PLC program, the number of bits needed to transmit the information was significantly reduced – the information has been coded using binary digits. The signals were sent between the robot's controller I/O card and QY80/QX80 output/input modules of the PLC controller (see Figure 4).

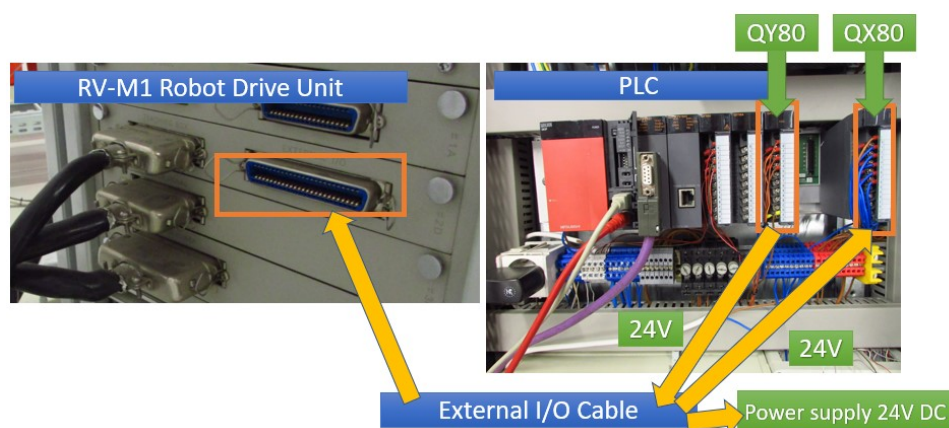


Fig. 4. The principle of binary communication between the robot and the PLC

The Mitsubishi Q controller has been programmed to set the 24V signal on the appropriate output module pin when certain conditions are met. The input module of the PLC receives signals from the robot. The physical connection between the QY80/QX80 modules and the robot's I/O card has been made using a cable with 50-pin Centronics plug on one

robot's side and loose connectors on the PLC side. The 24V signal is equivalent to a high logic state (binary 1).

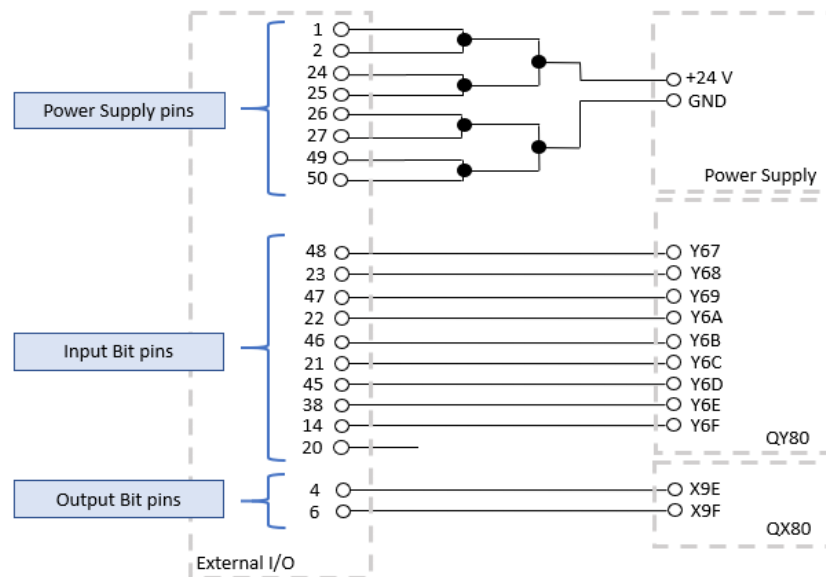


Fig. 5. The diagram of connections between the robot's controller I/O card and the PLC modules

The communication between devices has been based on the mutual expectation of appropriate signals [5]. The robot operation depends on the appearance of a high state of several input bits that are set on the PLC output module, while the PLC depends on the state of the two output bits transmitted from the robot's I/O card. The Figure 5 shows the wiring between the robot's I/O card and the PLC modules.

5. The robot control algorithm and the PLC program

After execution, the first activity of the robot's control program is to check the state of the indicated input bit in the loop until it is in a high state. If the condition is met, then the code fragment is executed. After completing the actions indicated in the program, the robot again waits for the permission to continue the work by checking the status of the corresponding bit at the binary inputs. During manipulation, the robot's controller announces the "busy" state by setting the output bit. In this manner the PLC program execution is suspended until the robot completes the manipulation activities. The schematic representation of the cooperation between the robot and workcell equipment is shown in the Figure 6.

As it can be seen, there are no contraindications for the robot to work at the same time as other machines in the cell, however, due to the presence of most necessary sensors only, the alternate execution of the robot and PLC programs increases safety by minimizing the risk of possible collisions.

6. Determination of the object position on the transport pallet

The method of acquiring the coordinates of the place where the object is located and from which it should be collected by the robot has been developed, using some simplifications. First of all, the flat area of the pallet has been divided into small, square fields, where the

object should be (randomly) placed. The second simplification assumes that the manipulator will be positioned exactly in front of the “column” in which the object is located, by moving the slide plate. The task of the robot’s controller will therefore be to pick an item from the appropriate “row”.

The number of the row, where the item is located, is determined in the simple way. First, the plate is scanned using the inductive sensor, mounted on the simple X-Y manipulator, driven by servomotors. Next, the object position is determined by the PLC. The X coordinate is sent to the slide plate controller and the manipulator is moved to the proper position. The Y coordinate is coded in the form of the three-bit digit, where the consecutive bits determine the one of the three rows. These bits correspond to the 4th, 5th and 6th binary input of the robot’s I/O card. The gripper positions for every row are hard-coded and after recognizing the position of the object, the right coordinates are copied to the area of robot’s controller memory used by the procedure of picking/placing the manipulated item [5]. The relevant algorithm is shown in Figure 7.

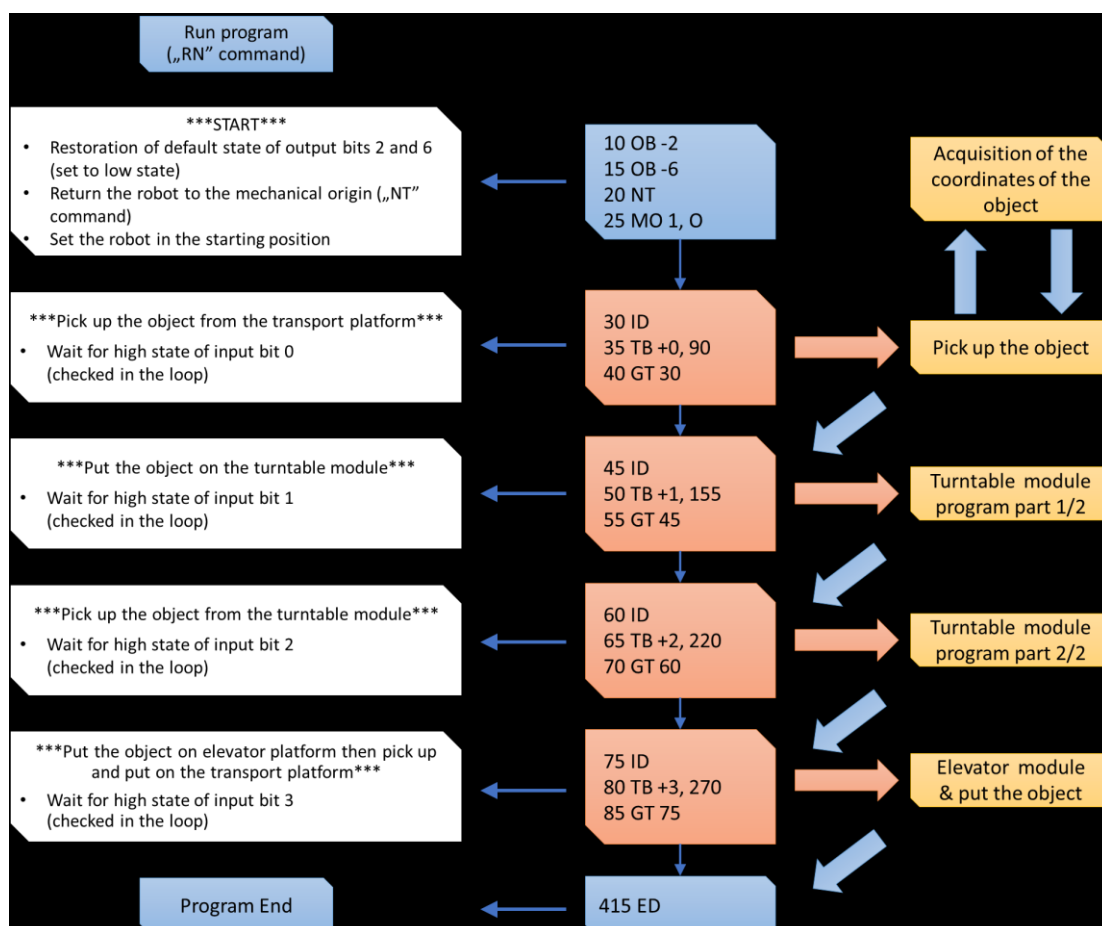


Fig. 6. Schematic representation of the cooperation between the robot and workcell equipment

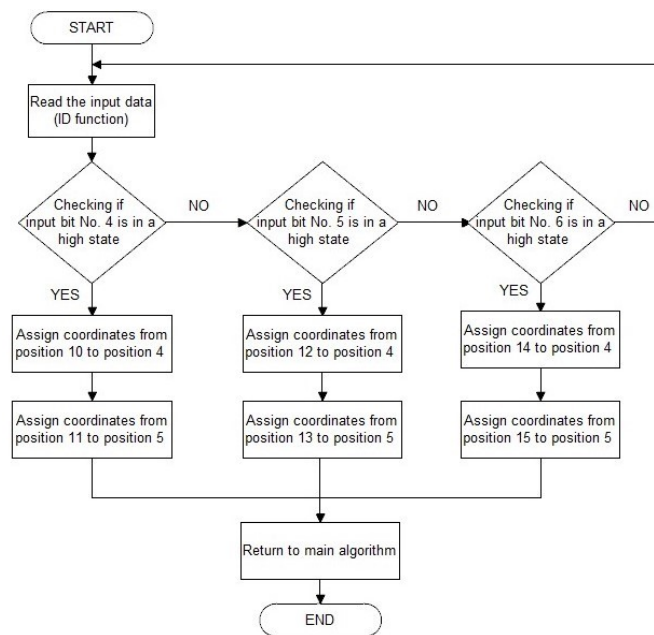


Fig. 7. The fragment of robot's control algorithm – dynamic assignment of the predefined rows coordinates

The position 4 is the location of the robot gripper above the object, while position 5 is the exact place from which the object can be retrieved by closing the gripper. After completing the above steps, the robot's controller continues the realization of the main program.

7. Conclusions

The presented modifications of the laboratory station allowed the implementation of software and hardware integration of the industrial robot with the transport system and remaining equipment of the robotic cell. The basic difficulty in accomplishing this task was the inability to use typical protocols related to industrial networks. Finally, the communication was implemented using binary I/O on the robot and PLC side. Because of many limitations of this solution, the work on the implementation of the RS-232 standard on the PLC side as well as the development of control algorithms along with the use of additional sensors will be continued.

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DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
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A PROJECT OF A TYPICAL PROPORTIONAL AMPLIFIER BASED ON THE ARDUINO PLATFORM

Abstract: In the paper was presented a possibility of application an Arduino controller as a core of a proportional amplifier for the hydraulic proportional valves. The proportional amplifier is an electronic module to drive the proportional valve via energizing the coils of its proportional solenoids. The characteristic features for this type of amplifier are: adjustable nominal current of proportional solenoid, internal feedback loop of the coil current, current offset and correction of the valve deadband. The authors' goal was to implement the basic functions of a typical proportional amplifier due the software method using a cheap Arduino controller. The attempt to use the Arduino controller as basic module of proportional amplifier was a success.

1. Introduction

The main task of article authors was to build a system that will act as proportional amplifier, and will be able to control the current flowing through the coil of proportional solenoid. The value of the current should be proportional to the control signal given by means of the potentiometric adjuster.

The purpose of the work was to create a working proportional amplifier model, based Arduino platform. For this purpose, Arduino Mega microcontroller and additional components (for output amplifier and command signal generator) were used to build the system. After building a working model of amplifier tests were carried out using the program written in C.

2. Arduino platform

Arduino is a programming platform for embedded systems (Figure 1). Intended for microcontrollers mounted in a single printed circuit, with built-in input-output support and standardized programming language. The Arduino programming language is based on the Wiring environment and basically on the C / C ++ language.

The Arduino platform was very well received by electronics enthusiasts. It is easy to use. It can be serve by people who want to carry out projects related to electronics in the future. Arduino controls devices connected to its connectors. It can turn the motor or light on and off. That is why Arduino is often called as a cheap PLC controller.



Fig.1. Arduino Uno as the example hardware element of Arduino platform

Arduino was founded in 2005 at the Institute of Interaction Design in an Italian city Ivrea. Professor Banzi was looking for an economic solution having make it easier for students to contact with a techniques of PLC control. He shared his doubts with David Cuartielles - a visiting researcher from the University of Malmö in Sweden, which was also looking for a similar solution. And that's how it was born Arduino.

The new controller was called Arduino to commemorate the local bar visited by the staff and students of the institute. The controller was sold to students in self-assembly kits. The first series was quickly sold out, so more were produced to meet the demand. Designers of other specialties heard about Arduino and also wished to use it for their projects. Its popularity grew rapidly when more and more creators were convinced that Arduino is an inexpensive and easy-to-use system that can be used in their projects, and that it is a perfect introduction to the world of microcontroller programming. The project has been refined and new versions of the controller have been introduced. The sale of the original Arduino has already exceeded 300,000 and it is offered by numerous distributors around the world.

2.1. Microcontroller of Arduino

The main element of Arduino is the microcontroller. Other elements on the circuit board deal with system power supply or allow the system to communicate with the PC computer. The microcontroller looks like a small computer stored on a board. It has all the elements that the first computers had for human use. Arduino has a processor, Flash, SRAM and EEPROM memories, input and output connectors. All these elements are used to connect the microcontroller with other electronic elements.

Central Processing Unit is the most important element in the construction of a microcontroller. The CPU is responsible for the execution of the program written by user.

Another important element are the memories, differing in the speed of access and data capacity. Other necessary elements are peripheral devices that are used to communicate with the environment. Input / output ports are often used. The data flow between the modules can be seen on Figure 2.

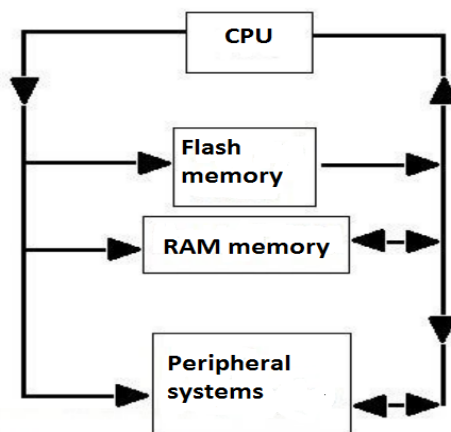


Fig.2. The most important elements of the microcontroller

3. Hardware and software of proportional amplifier based on Arduino

An proportional amplifier is an electronic device that control the value of coil current of proportional solenoid. Amplification of the amplifier is measured as the ratio of the output current and input signal. The form of a prototype proportional amplifier is shown below (Figure 3).

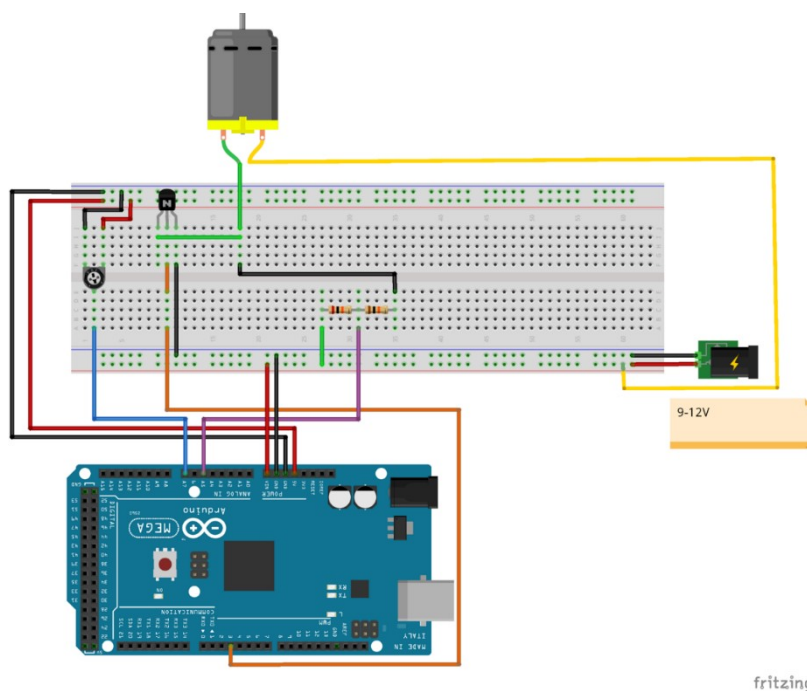


Fig.3. The form of prototype of the proportional amplifier

The project used a program written in C, which is used to implement the function of the PID controller for coil current of the proportional solenoid. The controller compares the set point value for coil current on the input with the output value, and when the error is positive or negative reduces or increases the PWM filling.

The most important variables defined in the above program:

- Setpoint, a value from 0 to 4 based on normalized values with a potentiometric adjuster,
- FeedbackValue voltage value from the measuring system. When using a voltage divider, it takes values from 0 to 4 for a maximum value of 12 V,
- OutputValue value calculated by a function that is part of an external library that meets the PID controller's tasks. The value assigned to this variable is modified on an ongoing basis by algorithms being part of the above-mentioned library in order to obtain the FeedbackValue value as close as possible to the Setpoint variable. Output value is sent to transistor amplifier as PWM signal.

The PWM signal sent to the base of the transistor allows direct voltage control which will be applied at the motor input. The same voltage value after transmission through the voltage divider can be sent without any harm to the microcontroller to one of the analog input ports in order to measure the output voltage.

4. Conclusion

The attempt to use the Arduino controller as a proportional amplifier showed that it is possible and relatively simple.

In order to obtain a fully functional proportional amplifier, the Arduino controller alone was not enough. The Arduino module had to be supplemented with a potentiometric adjuster, elements of current feedback loop and the output amplifier.

Tests, which made on real prototype of the proportional amplifier based on Arduino Mega, have shown the correctness of the script written in C. The prototype has fulfilled its task and allowed correct control of the proportional solenoid.

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SELECTED ENGINEERING PROBLEMS

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DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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CALCULATION THE MOMENTS OF FORCE EQUATION, WITH USE METHOD T6, INCLUDING KINETIC INTERACTION

Abstract: This article presents the possibilities of the popular T6 method in robotics, bring this method to the designers of mechanics, technology and architects. Presented description of the method concerns the moments equation for different classes of robots, but it can be used wherever it occurs need to calculate the working force for arm. The T6 method can significantly accelerate and simplify calculations, which are also more reliable, with less the possibility of appearing an error. The T6 method also allows the calculation of much more complicated equations, like calculation the acting force of arm, which is not possibly making in the classic way.

1. Introduction

In time of creating software systems for robots with very different parameters, we often have a problem changing the parameters, when is change direction of movement of the robot arm. When arm is moving up, the moment of force is slow down movement, and during downward robot arm significantly speeds up. Not all systems make a solution of this problem equally well. Especially when designing a new system, solve of this problem can be taken to the robot arm operating program. We count the moments on the plane of the arm symmetry (OXZ), so we can omit the translation that determines rotation of the robot arm at the base (OXY) and does not flow on static moment of force (A1). Interesting is also, how the influence of the weight of object is flows on the problem described above. How changes parameters of move the load and unloaded arm.

2. Translations T6 method in moment of force calculation

When we calculate the robot's equation, we know all its input translations, and the result translation T6, which is his multiplication. Creation T6 equation is descript in "Essentials of robotics" [1].

$$T6 = A1 * A2 * A3 * A4 * \dots * E \quad (1)$$

The same input translations can be used to calculate the moment equation. Acting force is equal:

$$F = m * g \quad (2)$$

The moment M_1 for the arm section l_1 is calculated as the product of half the arm, because the center the weight is in half the length. The force component must be also multiplied by $\cos \beta_1$ because is perpendicular to the arm.

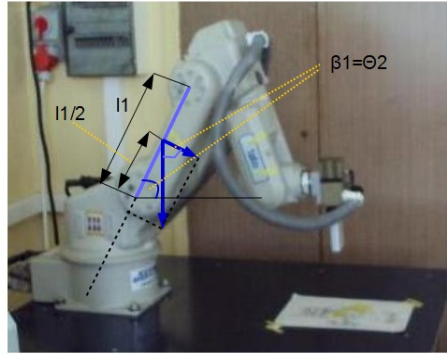


Fig. 1. Gravity force working on arm section l_1

$$M_1 = \frac{l_1}{2} * m_1 * g * \cos \beta_1 \quad (3)$$

In this case: $\beta_1 = \Theta_2$

$$M_1 = \frac{l_1}{2} * m_1 * g * \cos \Theta_2 \quad (4)$$

A_2 translation for the M_1 moment can be written:

$$A_2 = Rot(y, \Theta_2) * Trans(l_1/2, 0, 0) \quad (5)$$

After saving in matrix form, we get:

$$A_2 = \begin{bmatrix} \cos \theta_2 & 0 & -\sin \theta_2 & 0 \\ 0 & 1 & 0 & 0 \\ \sin \theta_2 & 0 & \cos \theta_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 & l_1/2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

After multiplying the matrixes:

$$A_2 = \begin{bmatrix} \cos \Theta_2 & 0 & -\sin \Theta_2 & 0.5 * l_1 * \cos \Theta_2 \\ 0 & 1 & 0 & 0 \\ \sin \Theta_2 & 0 & \cos \Theta_2 & 0.5 * l_1 * \sin \Theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

In the last column we get for a_{14} the coordinate x, for a_{24} the coordinate y, for a_{34} the coordinate z of the result function. In the formula for the moment M_2 , resultant is sum of the projection of the section l1 and the section l2 of robot arm on OX and OZ axes.

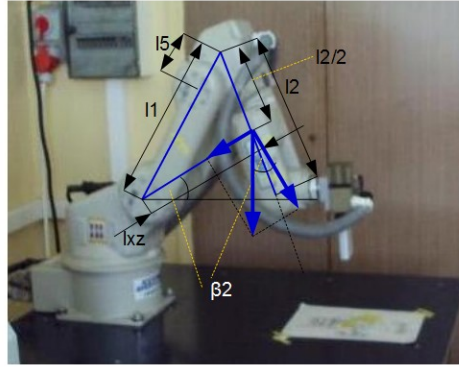


Fig. 2. Gravity force working on arm section l2

$$M_2 = l_{xz} * m_1 * g * \cos \beta_2 \quad (8)$$

Therefore, we can use A2 translation for the full length of the arm, in addition multiplied by A3 translation.

$$A3 = Rot(y, -\Theta_3) * Trans(l2/2, 0, 0) \quad (9)$$

In matrix notation:

$$A3 = \begin{bmatrix} \cos \theta_3 & 0 & \sin \theta_3 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta_3 & 0 & \cos \theta_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 & l2/2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (10)$$

After multiplying the matrixes:

$$A3 = \begin{bmatrix} \cos \Theta_3 & 0 & \sin \Theta_3 & 0.5 * l2 * \cos \Theta_3 \\ 0 & 1 & 0 & 0 \\ -\sin \Theta_3 & 0 & \cos \Theta_3 & -0.5 * l2 * \sin \Theta_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

After multiplying A2*A3 translations, we get:

$$A2 * A3 = \begin{bmatrix} \cos \Theta_2 & 0 & -\sin \Theta_2 & l1 * \cos \Theta_2 \\ 0 & 1 & 0 & 0 \\ \sin \Theta_2 & 0 & \cos \Theta_2 & l1 * \sin \Theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos \Theta_3 & 0 & \sin \Theta_3 & 0.5 * l2 * \cos \Theta_3 \\ 0 & 1 & 0 & 0 \\ -\sin \Theta_3 & 0 & \cos \Theta_3 & -0.5 * l2 * \sin \Theta_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (12)$$

To simplify the equation, we take $C2 = \cos\Theta_2$, $C23 = \cos(\Theta_2 - \Theta_3)$, $S23 = \sin(\Theta_2 - \Theta_3)$

$$A2 * A3 = \begin{bmatrix} C23 & 0 & -S23 & 0.5 * C23 * l2 + C2 * l1 \\ 0 & 1 & 0 & 0 \\ S23 & 0 & C23 & 0.5 * S23 * l2 + S2 * l1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (13)$$

Because the moment of force is working over result section

$$l_{xz} = \sqrt{l_x^2 + l_z^2} \quad (14)$$

in the pattern

$$M_2 = l_{xz} * m_1 * g * \cos \beta_2 \quad (15)$$

Variables l_x and l_z calculated by matrix method, as resultant projection of arm sections l1 and l2 on the axis OX and OZ.

$$l_x = 0.5 * C23 * l2 + C2 * l1 \quad (16)$$

$$l_z = 0.5 * S23 * l2 + S2 * l1 \quad (17)$$

In next step we calculate β_2 :

$$\beta_2 = \arctg\left(\frac{l_z}{l_x}\right) \quad (18)$$

Now we have all the data and can calculate the moment M2.

3. Universal formula for moment of force calculation

Similarly, we can calculate the moment M3 and generally Mj.

$$M_j = l_{xj} * m_j * g * \cos \beta_j \quad (19)$$

To calculate arm of force for Mj, the translations product should be calculated:

$$T(M_j) = \prod_{i=2}^j Ai \quad (20)$$

$$T(M_j) = \prod_{i=2}^{j+1} (Rot(y, \Theta_i) * Trans(l_{i-1}, 0, 0)) \quad \text{for } l_j = l_i / 2 \quad (21)$$

Then substitute for l_x and l_z corresponding element of the result matrix $l_x = a_{14}$, $l_z = a_{34}$. After calculation arm of force is equal:

$$l_{xzj} = \sqrt{l_{xj}^2 + l_{zj}^2} \quad (22)$$

$$\beta_j = \arctg\left(\frac{l_{zj}}{l_{xj}}\right) \quad (23)$$

We can calculate moment of force M_j :

$$M_j = l_{xzj} * m_j * g * \cos \beta_j \quad (24)$$

The resultant moment is the sum of moments M_j :

$$M_c = \sum_{i=2}^j M_j \quad (25)$$

Resultant moment is calculated for corner $\Theta 2$, which is change from current position $\Theta 2_o$ to new position $\Theta 2_n$. For calculation of time rotation is need mean moment $M_c(\Theta 2)$ as a function of angle $Q 2$. Initially, I tried to use the integral of the moment of force function in the limits from $Q 2_o$ to $Q 2_n$, but integral was not take expected result. In next step I was use estimate of moment of force for corner $\Theta 2$ which is change from the angle $Q 2_o$ to the angle $Q 2_n$ with step 2° .

$$\overline{M_c}(\Theta 2) = \frac{1}{n} * \sum_{j=1}^{n \leq \frac{\Theta 2_n - \Theta 2_o}{2}} M_c(\Theta 2_o + j * 2) \quad (26)$$

The formula for the time of rotation of the arm for angle $Q 2$ with use estimate is therefore:

$$t_{obr} = \frac{\Delta \Theta 2_j}{\omega} \pm k * \frac{\overline{M_c}(\Theta 2)}{l_k} * \sin \gamma \quad (27)$$

Note: These calculations apply to corner $\Theta 2$ between the robot base and the section arm l1. For the angle $\Theta 3$, the arm section l1 and A2 translation should be omitted in the calculations. For corner $\Theta 4$, similar l2 and A3 must be omitted.

4. Kinetic interaction in moment of force calculation

The resultant moment M_c is acting through a toothed wheel with a radius l_k on worm gear. Moment of force acting on the cogwheel is equal:

$$M_c = F * l_k \quad (28)$$

Then we can calculate the force:

$$F = \frac{M_c}{l_k} \quad (29)$$

It also acts on the worm gear with the angle γ :

$$F = \frac{M_c}{l_k} * \sin \gamma \quad (30)$$

To calculate dependence of time rotation robot arm section for a given increase the angle $\Delta\Theta_j$, we can take the proportional dependence of increase speed to working force.

$$t_{obr} = \frac{\Delta\Theta_j}{\omega} \pm k * \frac{M_c}{l_k} * \sin \gamma \quad (31)$$

ω - middle angular speed.

In practice, we see that the value of coefficient k in this case is 1. In moving down direction, equation was working well. However, when arm was moving up, the equation of moments should take an additional kinetic component. Is effect of the conversion of potential energy into kinetic energy.

$$m_j * g * h = \frac{m_j * V^2}{2} \quad (32)$$

Then substitute for $h = l_{xj} * \sin \beta_j$ and simplify m_j :

$$g * l_{xj} * \sin \beta_j = \frac{V^2}{2} \quad (33)$$

Then we calculate V :

$$V = \sqrt{2 * g * l_{xj} * \sin \beta_j} \quad (34)$$

At the same time, for calculate the speed in a circular motion I calculate the proportion:

$$\frac{\beta_j}{l} = \frac{2 * \pi}{2 * \pi * r} = \frac{1}{r} = \frac{1}{l_{xj}} \quad (35)$$

Arc length l for the angle β_j is equal:

$$l = \beta_j * l_{xj} \quad (36)$$

Speed in move on the circle:

$$V = \frac{l}{t} = \frac{\beta_j * l_{xj}}{t} = \omega_j * l_{xj} \quad (37)$$

From the above and (32) equation we calculate increase angular velocity:

$$\Delta \varpi_j = \frac{\sqrt{2 * g * l_{xzj} * \sin \beta_j}}{l_{xzj}} \quad (38)$$

After simplifying:

$$\Delta \varpi_j = \sqrt{\frac{2 * g * \sin \beta_j}{l_{xzj}}} \quad (39)$$

After substituting to the general formula for the time of rotation arm section, we get:

$$t_{obr} = \frac{\Delta \Theta_j}{\varpi + \Delta \varpi_j} \pm k * \frac{\overline{M_c(\Theta)}}{l_k} * \sin \gamma \quad (40)$$

The obtained general formula takes all moments flows on the system in the time of arm rotation, and including the kinetic component occurring at upward movement.

5. Conclusion

The use of the T6 method significantly speeds up calculations, also with significant level of complications. It reduces the risk of error in calculations. For calculation the robot's moment of force equation, can be use fragments previous calculations of the robot arm equation descript in my article [2] "Robot SX-300 equation, with using New Gauss, and Parametric method" .

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SELECTED ENGINEERING PROBLEMS
NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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MAKE A SIMULATION, SAVE TIME AND YOUR MONEY

Abstract: Planning and implementation of automated processes can be improved by means of a previously prepared simulation. The article presents an example of simulation of the welding process of car body parts made in the Process Simulate program. Performing earlier planning allows you to verify the concept, solve technical problems and prepare programs at the stage of project creation.

1. Introduction

Designing automated technological processes is a multistep operation. Issues related to spatial planning, mechanics, electrics and programming are discussed. Thanks to the simulation and technical documentation, it is possible to plan the work and solve problems before installing the devices. In the era of increasing demand in the electronics, automotive and household goods industry as well as reduced professional activity of manual workers, the automation of production processes is firmly developed. Robotisation affects the increase of product quality, reduction of labour costs and motivates people to improve their professional qualifications.

The beginnings of robotics applied in the industry date back to 1962 in the United States. In the 90's, the most robots were used in Japan, and now the most robots are being used in China.

Currently, all large production automation projects are supported by advanced computer programs that are designed to help engineers make decisions. The main processes that are automated in the automotive industry include gluing, welding, cutting, bolting, riveting, handling, casting, assembly and quality control.

2. Selection of tools

A well-made analysis is based on the proper selection of robots for the process and proper modelling of the mechanisms in the station, where parts of the body will be folded.

Choosing the type of robot and the weight of the tool it is needed to perform the operation, the speed of movement of the robot's links and the market price of the manipulators.

The choice of the tool is significantly influenced by various parameters. In the case of spot welding, the pressure, welding time and space availability on the vehicle body are important to the tool. Having a properly selected tool, we know its geometry. This is one of the most important information, because in the next step we are able to verify the robot's reach.

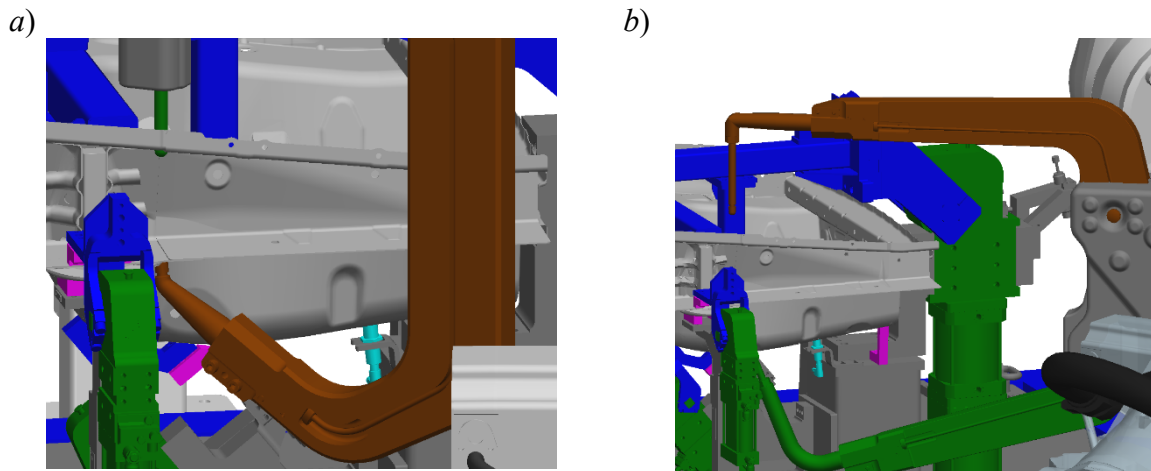


Fig. 1. Two guns compared: a) wrong, b) correct

On the pictures above (Fig. 1) we can see wrong and correct selected gun. The first one is wrong, because space between two electrodes is too small even when the gun is open to the maximum value. The second one is correct, because the gun has enough space to perform the operation.

With such an analysis, the risk of making a mistake is very small and eliminates the costs of incorrect selection of devices, possible returns / exchanges and a prolonged process of production implementation.

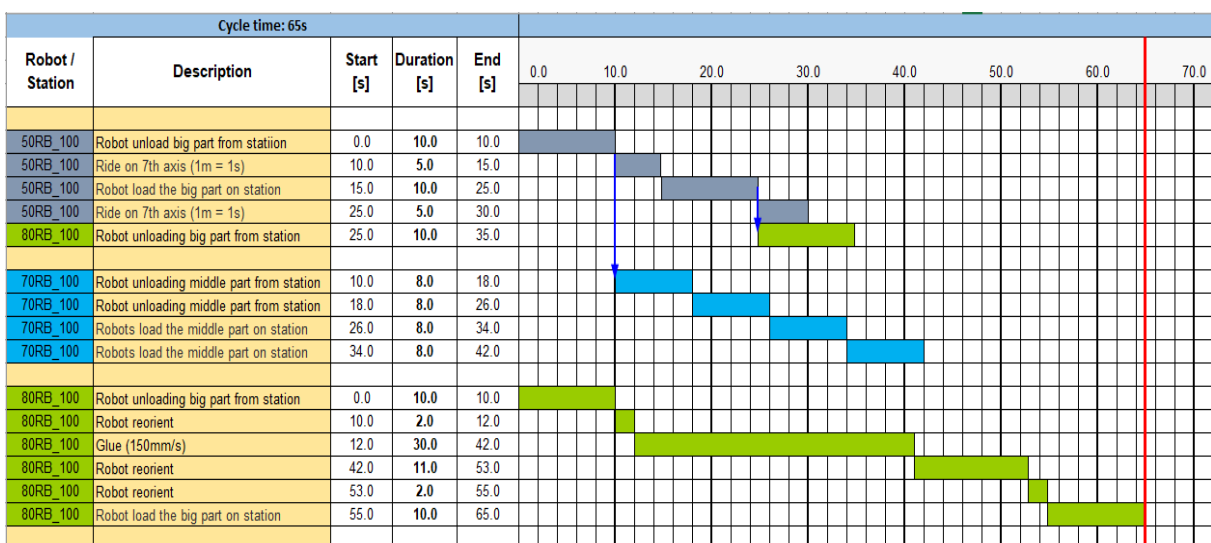


Fig. 2. Time diagram

Cycle time is one of the ways to optimise production. It provides information on how often one product leaves the production line. The length of this time varies and depends on the customer's demand for a certain number of products. In the process of determining the cycle time, the time diagram is usually helpful (Fig. 2).

"Collision Set" is a tool used to detect collisions between data structures. It performs well in creating paths for the robot in tight spaces. Thanks to it you can observe the dynamic course of the simulation with the update of the distance and immediately correct the incorrect path. In this way it is easier to verify and document a bad construction for the construction department.

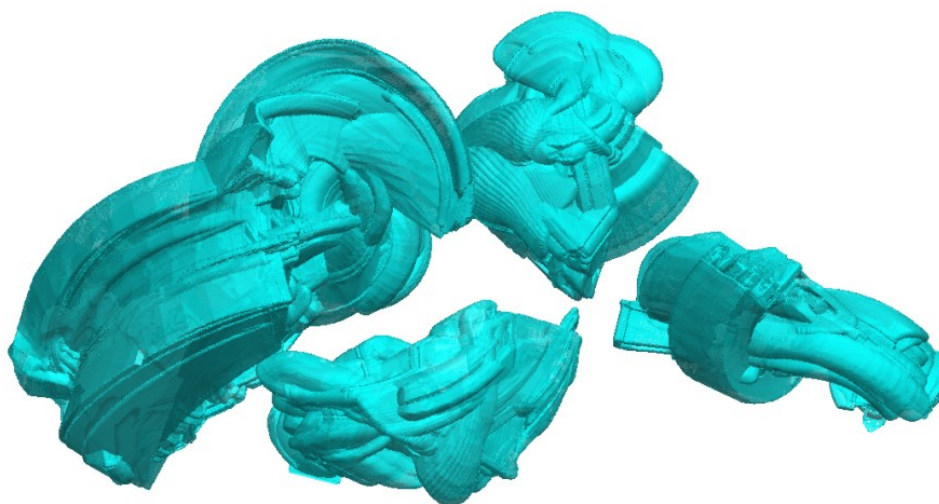


Fig. 3. Points cloud

In simulation programs, it is possible to generate a point cloud (Fig. 3). It is created based on the path of passage. This cloud determines the robot's field of work and then it is easy to estimate how many space in the cell remains to be used.

OLP is a short form of Off-Line Programming. In this phase, robots paths are created, the paths to the stations and paths to service positions. Then signals for the exchange of information between the robots and from a robot to a PLC are added. Signals controlling robot mechanisms and other mechanisms in its area have also been added.

Additionally in this phase all main positions and other points are named according to the client's standard.

3. Simulation of process for customer

MRS (Multi Resource Simulation) or SOP (Simulation of Process) is a movie showing the real time and flow of parts on the line. The process simulation aims to visualise the entire production process for the customer. Also it is a proof that it is possible to perform all operations at a given time.

The most attention when starting automated devices should be given to the safety of people who will work in their environment. For this purpose, we use curtains and safety switches. In the case of robots, tools based on generating work areas are applied. They use geometric

limitations and speed. On the basis of signal exchange with the PLC, the robot is able to determine whether it enters the employee's work zone. The 3D environment creates solids and saving vertices in the form of points in the robot program. On this basis it is possible to determine when a given robot can work in a given sphere, or block it so that it never appears there (e.g. blocking cell boundaries from the fence).

The question arises whether we need robotics programmers implementing the process. Despite a well-prepared simulation, the position of Online Robotics Programmers is an integral part of the production launch. Below it is explained why.

One of the first tasks belonging to robotics on the line is the first commissioning of a given robot. This involves calibrating the axes, determining the load on the arms, weighing the tools, comparing the home position with the offline values, and even checking mounting the robot to the floor. The second task is to configure the network. Checking and adding devices that work in cooperation with the PLC and robot.

The next task is to verify the correctness of connecting devices with Eplan, e.g. sensors on the gripper (grip check), passing the loaded paths and checking their collision-free (with and without part) and teaching the process positions. The robots also check the exchange of signals between the PLC and the robot. This is included in the virtual start department (WINMOD) in which all irregularities should be captured.

The last tasks are matters related to the safety check in a given cell and eventually inclusion of dry run (production without parts at 100% speed), test production, support.

4. Conclusion

Thanks to all these components, it is possible to plan the integration of the new model on the current line, without having to stop production. This integration can take place on non-working days, weekends and holidays. Thanks to the simulation it is possible to design a collision-free path for all robots and to optimise the cycle time. This is a great convenience because one can design a workstation or more workstations on the factory even if there are not needed components. In simulation programs it is possible to compare different sizes of devices and stands, conveyors. One can adjust the clamp sizes and their positions.

Above all, however, offline simulation gives the opportunity to design the factory equipment while it is being built. And when the factory already exists, it is easy to reflect the location of the elements from the simulation on the real object.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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FLEXINOL PROPERTIES STUDY

Abstract: This article contains study concerning flexinol wire's contraction time and length. During the research, to stimulate the wire, a modulated PWM signal was used. Changes in PWM duty cycles were causing greater heat accumulation which led to faster structural transformation of the wire and in result different contraction times and lengths. The research stand and control system that were used to stimulate the flexinol wire (regulated PWM wave stimulation) and measure its contraction times, and lengths, were also described in this article.

1. Introduction

In modern technical solutions, especially in the scope of mechatronics, SMART materials are becoming more and more widely used. The most attention is concentrated on smart materials that change their properties in a controlled way (being usually stimulated by a dedicated control system). Thanks to their properties, they can be used both as actuators and sensors. The most popular and commonly used group of SMART materials contains: piezoelectric materials, magneto and electrostrictive materials and also shape memory alloys[2,3,4]. One of the materials that is included in the group of shape memory alloys is the flexinol. It is a type of nitinol alloy that contains nickel and titanium in a 54:46 proportion and is used in a form of wires with very small diameters (25 μ m – 510 μ m). The characteristic property of flexinol wires is their ability to contract after being heated to a temperature of their structural transformation. The wire's good conductance is allowing small voltages to pass through it, but its resistance (50 Ω /m for 150 μ m diameter) is sufficient enough for relatively small currents of around 150mA to heat up 1m of the wire to 70°C in around 2 seconds time. The wire's contraction is caused by a transformation between martensitic and austenitic structure and ordering of structural bonds. After cooling down the wire's structure becomes martensitic again and is susceptible to deformation which allows it to stretch back to its former length after a strain of around 69MPa has been applied. Flexinol wire can contract to around 8% of its total length, although it is recommended that a maximum of 4 – 5% contraction should be forced on the wire during its regular and elongated work to avoid risks of permanent damage to the wire's contraction capabilities.

The wire during its contraction generates around 172MPa of strain without the risk of loosing it's physical and material (structural) properties. The expected maximum strain that flexinol wire can hold while contracting is approximately 345MPa. In case of many duty cycles it is not recommended to surpass 2/3 of this value to avoid damage that the wire can sustain while repeatedly working under high loads. The most common flexinol wires on the market are wires with transformation temperatures of around 70°C or 90°C although it is possible to manufacture wires with transformation temperatures higher than 100°C and significantly lower than 70°C [5].

2. Aim and range of the study

The aim of this study was to designate the course of change of contraction length relative to time for the flexinol wire under standard load and in relation to changing PWM (Pulse Modulated Wave) signal that was used to stimulate the wire.

To conduct the study a research stand was made (fig. 2.1) where the flexinol wire could be put under stimulation of PWM signal that could be also modulated.

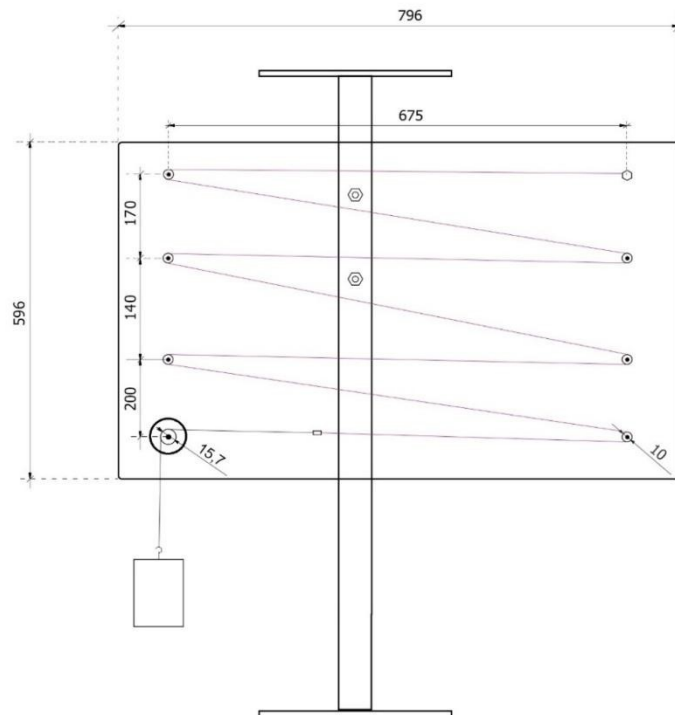


Fig. 2.1. Stand for measuring flexinol wire contraction

To achieve that, a dedicated control system was made which diagram was shown on the fig. 2.2. The research stand was also capable of registering flexinol wire's contraction time and length in intervals of 10ms and with an accuracy of 10 μ m. A flexinol wire bought at Muscle Wires® [5] was used in the course of the study. Wire's properties are represented in the table 2.1.

Tab. 2.1 Properties of the flexinol wire used in the study [4]

Diameter	Resistance	Nominal contraction force	Required current	Contraction time	Transformation temperature	Cooling time (70°C)
[mm]	[Ω/m]	[N]	[A]	[s]	[°C]	[s]
0.15	55	3.21	0.41	1	70	2

The experiment was based upon recording contraction measurements of a flexinol wire, under a fixed load to maintain its steady strain, stimulated by PWM signals with varying duty cycles. The characteristics of the stimulating signal were as follows : voltage – 18.5V, current - 410mA, frequency of PWM signal - 50Hz, PWM duty cycle – regulated in range of 20% ÷ 100%.

2.1. Control system and measuring stand

To measure flexinol contraction length and time, a measuring system was designed, (fig. 2.2) that incorporated an angular encoder with a resolution of 5180 impulses per revolution, that was coupled with X20CP1301 PLC controller of „B&R” company. Wire contraction was measured by using the equation 1 [1]:

$$\Delta W = \frac{i}{n} 2\pi R \tag{1}$$

where: ΔW – flexinol wire contraction length [m], i – encoder impulse count, N – encoder resolution $\left[\frac{1}{rev}\right]$, R – measuring wheel diameter [m].

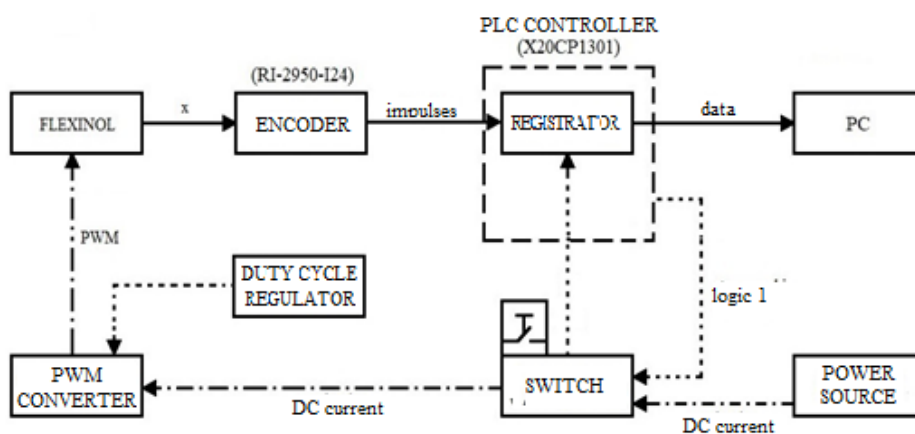


Fig. 2.2. Diagram of measuring system and power system of the research stand

Flexinol wire contraction time was measured by the PLC controller with an accuracy of 0.01s. To synchronise the simultaneous activation of PWM generator and data recorder, a button was used in a form of a gate, that was wired to the signal cable leading to data recorder and also to a power cord leading from the PWM generator to the flexinol wire. The stand consisted of a plexiglass pane with dimensions shown on fig. 2.1. On the pane, six rolling cylinders with bearings were placed to create supports for 1000mm of flexinol wire that was stretched between them. On the top right corner of the plexiglass pane, a rigid attachment was placed, to fix one end of flexinol wire. One end of the power cord was also attached to that point. The bottom left side of the plexiglass pane was prepared to mount the angular encoder with a measuring wheel of 0.0157 m diameter. The other end of flexinol wire was attached to steel cord and a thin power cord. A steel cord was moving on the measuring wheel being attached to the flexinol wire on one end and to a 321g weight on the other. The weight was responsible for generating constant optimal strain on the flexinol wire.

2.2. Flexinol wire contraction study based on PWM duty cycle

The study consisted of 9 series of measurements, each consisting of 20 measurements. Each of the measurement series was conducted for different PWM duty cycle starting with 100% and ending on 20% with 10% decrements. A reason for ending measurements on 20% PWM duty cycle was that the flexinol wire contraction was negligibly small and very slow for duty cycles below 20% (continuous stabilization of length [5]). All min, max and mean wire contraction measurements for each of duty cycles were presented in tab. 2.2. All the measurements were conducted in the ambient temperature of 36°C.

Table 2.2. Wire contraction lengths in relation to different PWM duty cycle

Contraction length after heating with PWM signal						
PWM duty cycle [%]	Contraction length [mm]			98% of max contraction [mm]		
	MIN	MEAN	MAX	MIN	MEAN	MAX
100	42.52443	42.57299	42.66726	41.67394	41.72153	41.81391
90	42.34351	42.38779	42.44825	41.49664	41.54003	41.59929
80	42.04834	42.13451	42.17212	41.20737	41.29182	41.32868
70	41.67699	41.74174	41.83886	40.84345	40.9069	41.00208
60	41.01998	41.12472	41.19137	40.19958	40.30223	40.36755
50	39.88689	40.10589	40.2868	39.08915	39.30377	39.48107
40	37.32552	37.8097	38.34435	36.57901	37.05351	37.57746
30	4.056293	4.407172	5.66548	3.975168	4.319029	5.552171
20	1.199749	1.28973	1.609187	1.175754	1.263935	1.577003

Columns described as „98% of max contraction” were created to determine wire contraction times in further calculations. Wire contraction time was designated as the time of the most dynamical wire contraction period up to the point of its final contraction length, that is the state when wire stabilized its contraction length.. To designate the wire’s contraction time a value of 98% of maximum wire contraction length was taken to compensate for wire’s very long time of contracting the last 2% of its length (follow-up stabilization also occurring

for PWM wave duty cycles below 20%). Wire contraction times were calculated based upon table 2.2 and shown in table 2.3. Acquired data shows that when a 100% PWM duty cycle was used the wire's maximal contraction length reached 42.67 mm, which accounted for 4.27 % of the total wire's length. The approximate wire contraction time was 2s. The table 2.4 shows flexinol wire contraction times depending on used PWM duty cycles.

Table 2.3. Wire relaxation time in relation to PWM duty cycle

98% contraction time	
PWM duty cycle [%]	Time [s]
	MEAN
100	2.01
90	2.25
80	2.63
70	3.21
60	4.11
50	6.05
40	16.42
30	12.81
20	5.56

Table 2.4. Wire contraction time in relation to PWM duty cycle

98% relaxation time	
PWM duty cycle [%]	Time [s]
	MEAN
100	6.42
90	6.39
80	6.17
70	6.12
60	5.87
50	5.5
40	5.08
30	3.76
20	4.07

Fig. 2.3 and fig. 2.4 show the courses of flexinol wire's relaxation and contraction periods from where the data in tables 2.3 and 2.4 was calculated.

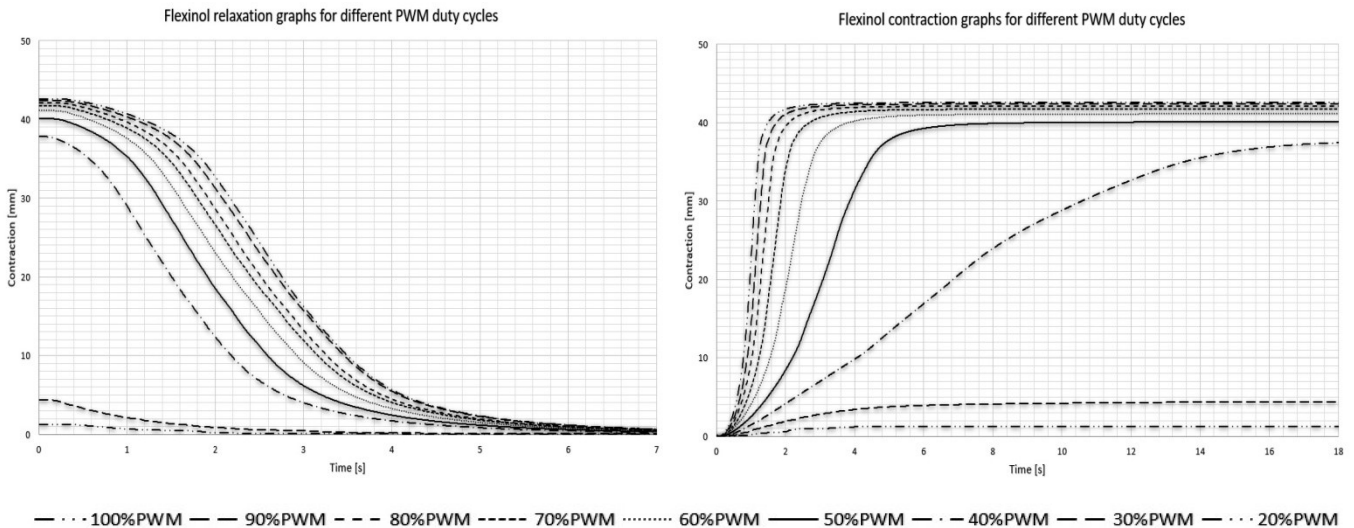


Fig. 2.3. Courses of flexinol wire's relaxation cycles in relation to PWM duty cycle used

Fig. 2.4. Courses of flexinol wire's contraction cycles in relation to PWM duty cycle used

In case of measuring and calculating flexinol wire's relaxation time, 98% of maximal wire's relaxation length was also used to compensate for very long periods of wire's relaxation up to its final length. Mean relaxation time of flexinol wire reached 6.42 seconds. That is six times more time for full relaxation than specified in wire's documentation. That result could be explained by very high ambient temperatures during the study which caused lower heat exchange between flexinol wire and surrounding air and thus contributing to its slower cooling and relaxation.

3. Conclusions

The first and most noticeable change in flexinol wire's behavior when changing the PWM duty cycle was its slow decrease in maximal contraction length following the decrease in PWM duty cycle. The most noticeable drop in wire's contraction length occurs between 40% and 30% of PWM duty cycles. Accordingly to decrease in flexinol wire's contraction length an increase in its contraction time also occurs. This increase is also the most noticeable between 30% and 40% of PWM duty cycles.

The fastest contraction time and the longest contraction length of flexinol wire occurs when stimulating it with a PWM wave with 100% duty cycle which is basically a DC current. In this case mean contraction length was 42.57 mm and accounted for 0.043% of the overall wire's length. The time to contract 98% of this length was taking averagely around 2 seconds.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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CONTROLL OF AN ELECTRIC STEPPER MOTOR USING THE SIEMENS SIMATIC S7-200 PLC CONTROLLER

Abstract: The article is focused on the system dedicated for controlling an electric motor (the Siemens Simostep drive) using the SIEMENS S7-200 PLC. The authors have extended the research scope by specifying the electric drive sequence and to visualize the process using the HMI panel. The main goal was to design different motion sequences of the stepper motor, whose parameters can be set using the HMI panel.

1. Introduction

The dynamic development of industry and modern technologies as well as striving to increase security have contributed to the automation of many production processes.

PLCs belong to the most dynamically developing area of industrial automatics. In modern industry more and more complicated production processes are used, which brings with a greater interest in PLC controllers. Such state is caused by easy connection with PC, software availability and lower installation costs of innovative automatic control systems [1,2]. The basic principle of PLCs operation is sequential processing of an algorithm, the controller carries out individual signals in the order in which they were saved in the program.

Control of stepper drives is one of the challenges of many production plants. The stepper motors are characterized by [3,6,9]:

- high precision positioning outputs,
- wide range of applications, among other things: usage in general arrangement of drives automation systems, positioning drives, robotics, etc.,
- optional holding brakes for fixing the position after switching off,
- positioning realized by dedicated controllers.

For the group of disadvantages of stepper motors can be included [3,6,9]: low efficiency, torque drop, low accuracy, prone to resonances, requirement micro stepping to smooth movement, no feedback to indicate missed steps, low torque to inertia ratio, low output power for size and weight. Despite many disadvantages, stepper motors are still a solution that enjoys popularity in many industrial applications.

2. Description of the laboratory stand and software

The laboratory stand (Fig. 1) has been built on the basis of industrial automation components, among which can be distinguished:

- the Siemens PLC Simatic S7-200XP (CPU 224XP),
- the Siemens EM 253 Positioning Module,
- the FM-STEPDRIVE/SIMOSTEP Power Controller,
- the Siemens Simostep Stepdrive 1FL3041,
- the Siemens TP 177micro Touch Panel.

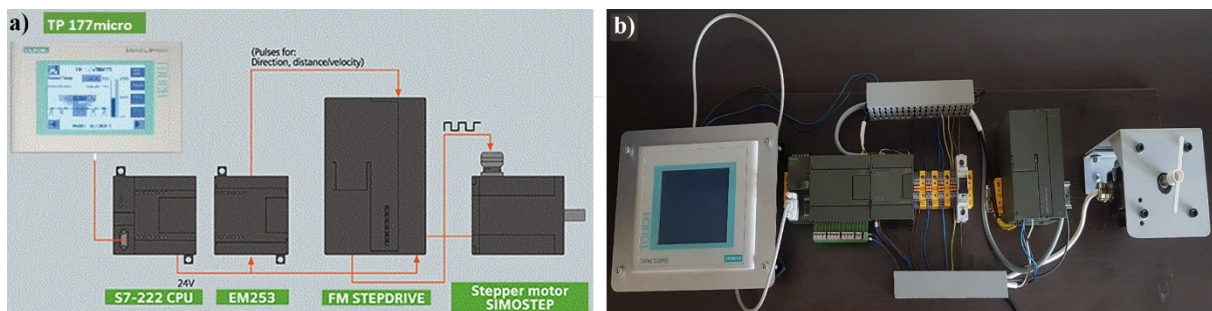


Fig. 1. Views of: a) the schematic layout of the system [4], b) the real layout of the laboratory stand

The S7-200 PLC is an example of controllers family designed to automate machines and small devices. The controller's task is to handle the main control algorithm, supervise the connected modules, distribute and download data from the HMI panel. The STEP 7 Micro/WIN software has been used for the purpose of developing algorithms.

The EM 253 Positioning Module [4,5] is a function unit for simple positioning tasks. The module can control stepper motors and actuators through high frequency pulse output. The Siemens FM-STEPDRIVE Power Controller can be used for stepper motors with torques within the range $2\div 15\text{Nm}$. The FM STEPDRIVE power section controls the motion of the stepper motors in the SIMOSTEP 1FL3 series with high precision. In combination with the S7-200 and the EM 253 function module, it performs highly accurate positioning tasks in the lower output range of 600W [5].

Depending on the program, the positioning module EM 253 generates specific pulses (that define a direction, a distance and a speed). The transfer of these impulses to the inverter and the stepper motor takes place via two outputs (P0 - speed and P1 - direction of rotation).

The hybrid SIMOSTEP Stepdrive motor is a combination of a stepper motor with permanent magnets (a permanent excitation type) and a reluctance stepper motor.

Easy and clear reading of not only the PLC input and output states, but also the current motor movements are possible thanks to the Siemens TP177 Micro touch HMI panel. Communication between the panel and the controller enables visualization of inputs or outputs status, as well as controlling of motor movements [7,8].

The SIMATIC WinCC flexible 2005 micro programme was used to create the visualization structure. Described software is a part of the SIMATIC WinCC platform. This package, as a visualization software, is efficient and optimized for applications where a local control and reliable monitoring is required. The WinCC flexible is designed for all industrial branches and is the most optimal software solution dedicated for SIMATIC HMIs.

3. The PLC programme in the Step7 Micro Win environment

The PLC program has a tree structure. The main block uses *Call* functions that call subroutines located in the other blocks. This way of writing the program is characterized by transparency and allows the use of local variables. The controller program consists of 10 networks. Each network has its purpose to control the Siemens Simostep Stepdrive motor. Table 1 presents a list of subprograms with a short functional characteristics.

Tab. 1. The list of subprograms used for movement control of the Siemens Simostep Stepdrive

Subprogram name	Functional characteristics
POS0_DIS	<ul style="list-style-type: none"> • used to enable or disable the <i>DIS</i> output positioning module (it allows to use this output for the pulse edition for the STEPDRIVE FM drive unit), • the program is started by stating the input <i>I0.0</i> (PLC) or <i>M0.0</i> (HMI),
POS0_CTRL	<ul style="list-style-type: none"> • activates and initializes the EM 253 positioning module (this is done by automatically sending the command to the EM253 positioning module to load the configuration each time), • the S7-200 automatically goes into the RUN operating state,
POS0_MAN	<ul style="list-style-type: none"> • sets the positioning module for manual operation, • in this mode, the drive can be operated at different speeds or in positive or negative pulse mode direction, • the program is started by stating the input: <i>I0.2</i> (PLC) or <i>M0.2</i> (HMI) for RUN mode, <i>I0.3</i> (PLC) or <i>M0.3</i> (HMI) for JOG in positive direction mode, <i>I0.4</i> (PLC) or <i>M0.4</i> (HMI) for JOG in negative direction mode,
POS_RUN	<ul style="list-style-type: none"> • subroutine instructs the position module to move within a specific profile described by the user, • turning on EN bit allows to execute the desired instruction, turning the START parameter on sends the RUN command to the EM 253 Position Module, • it is a parameter that causes turning on the START parameter to perform the intended motion with a stepper motor, • the program is started by stating the input: <i>I1.1</i> (PLC) or <i>M1.7</i> (HMI) for START mode of Profile 0_0:VB646,
POS0_GOTO	<ul style="list-style-type: none"> • sends the positioning command to the EM 253 module to go to the desired position specified by user, • the program is started by stating the input: <i>I0.6</i> (PLC) or <i>M1.2</i> (HMI) for START mode of movement in position specified by user using HMI, • the program can be stopped by stating the input: <i>M1.1</i>(HMI),
READ_RTC	<ul style="list-style-type: none"> • used to provide the current time value on the HMI, • using VB0 address and Tag user can get the real time on Touch panel.

4. Cycles programming

The Step Micro/Win software allows to program cycles to control the stepper motor. On the other hand wizards are a very useful tool, which in a graphical way enable the exact programming of a given profile (calling via a digital input) of moving the motor. The wizard included in the software allowing adjustment the parameters of the engine's operation and to program the relevant parameters or entire work cycles [4,5].

In order to perform the parameterization of the motor, basic parameters should be set between the others (Fig. 2): the speed (a maximum, an initial and the final speed), JOG parameters (JOG_INCREMENT - the distance to move the tool with each JOG command, JOG_SPEED - the maximum speed obtained, when the JOG command remains active), acceleration and deceleration times (ACCEL_TIME - the time required to accelerate the engine from SS_SPEED to MAX_SPEED, DECEL_TIME - the time required for the engine to be released from MAX_SPEED to SS_SPEED).

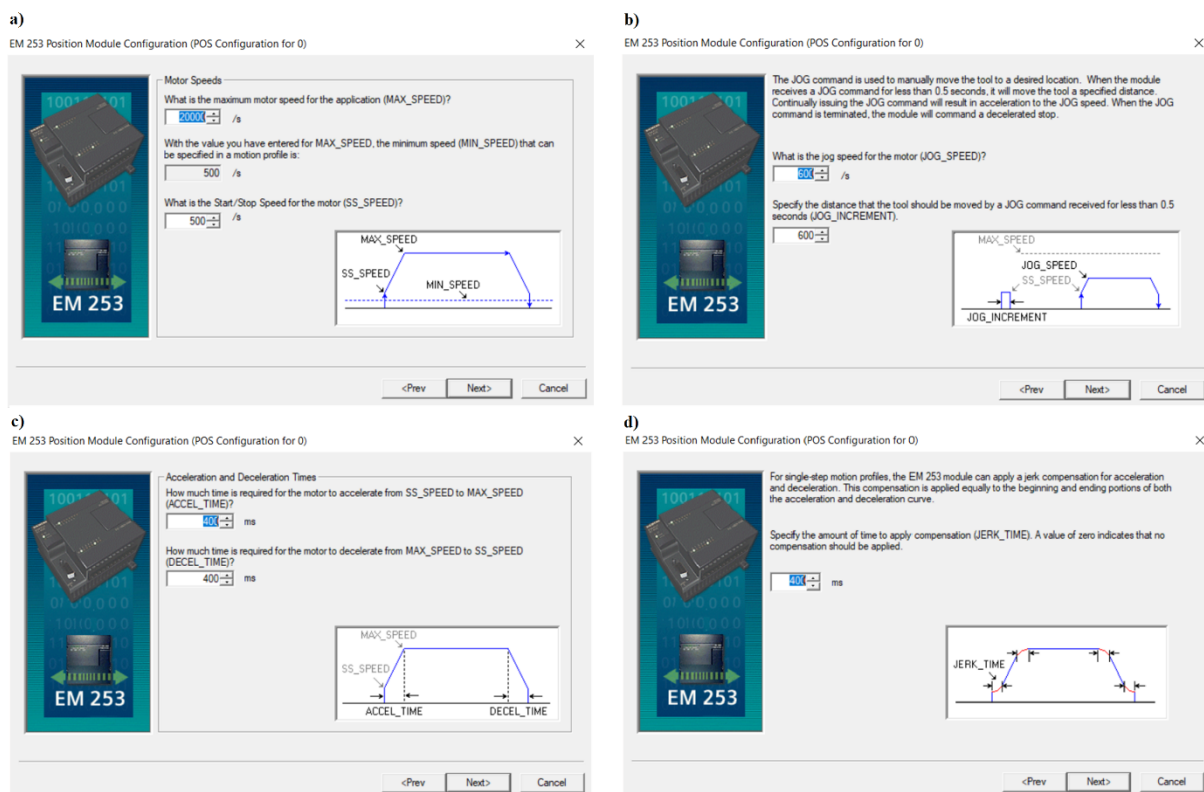


Fig.2. Views of: a) engine speed configuration window, b) the jog speed and jog increment definition window, c) acceleration and deceleration times window, d) jerk time parameters configuration window

As a result of the work, eight different cycles of the stepper motor were made. The relative position mode is presented to indicate the programming characteristics. In relative position mode, the motion profile block should specify from one to four steps, with each step containing both the position (POS) and the speed (SPD), which describes the traffic segment. Figure 3 shows definition window of cycle programming.

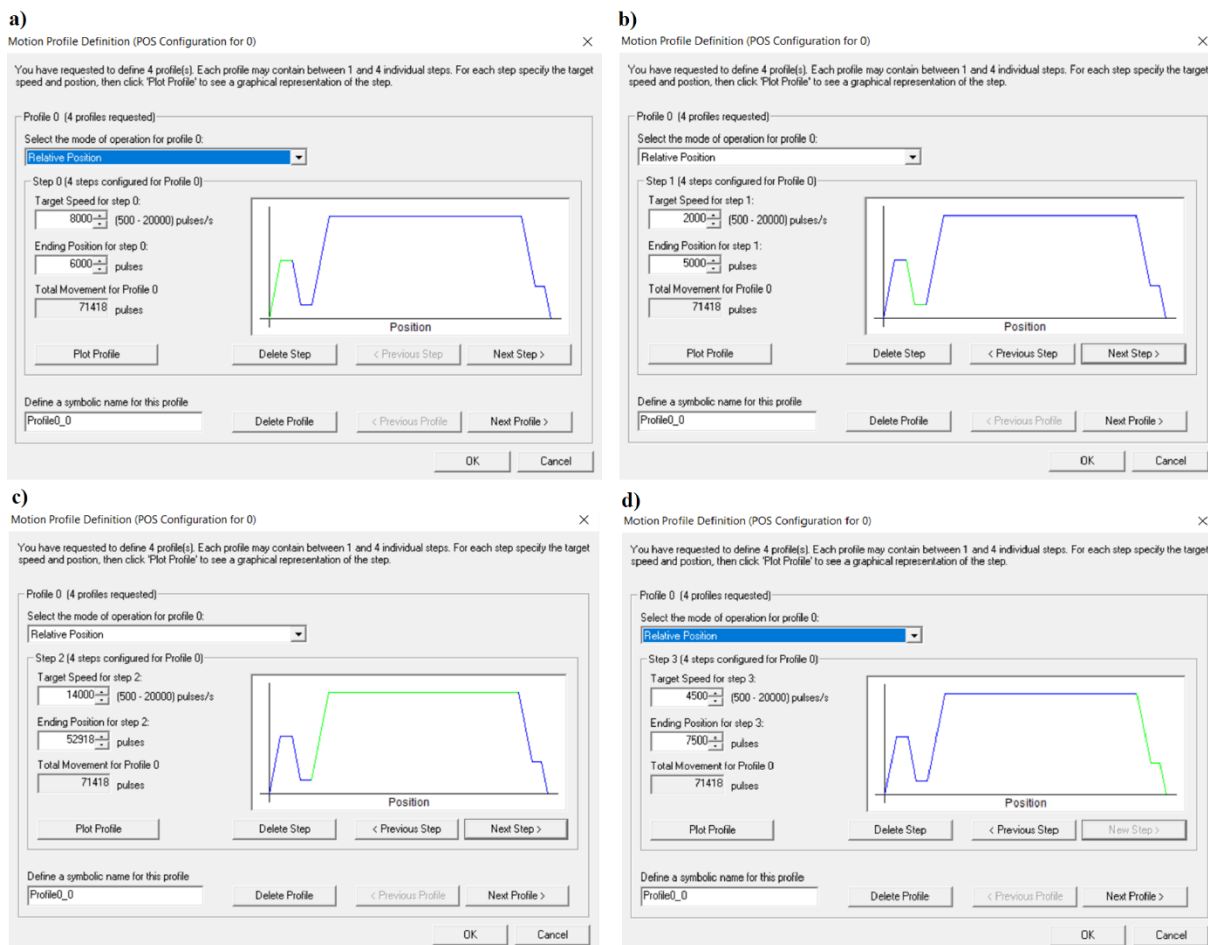


Fig.3. Views of cycle definition: a) first, b) second, c) third, d) fourth

The idea of creating visualization in the Siemens WinCC flexible software involves linking elements such as switches, text boxes, and controls with appropriate areas in a PLC memory.

The program in the device consists of screens that support individual subprograms. The most important element in the entire program is the correct configuration and assignment of the tag for each element displayed on the screen. The tag is used to recall a specific item on the screen with the S7-200 controller memory register [4÷7].

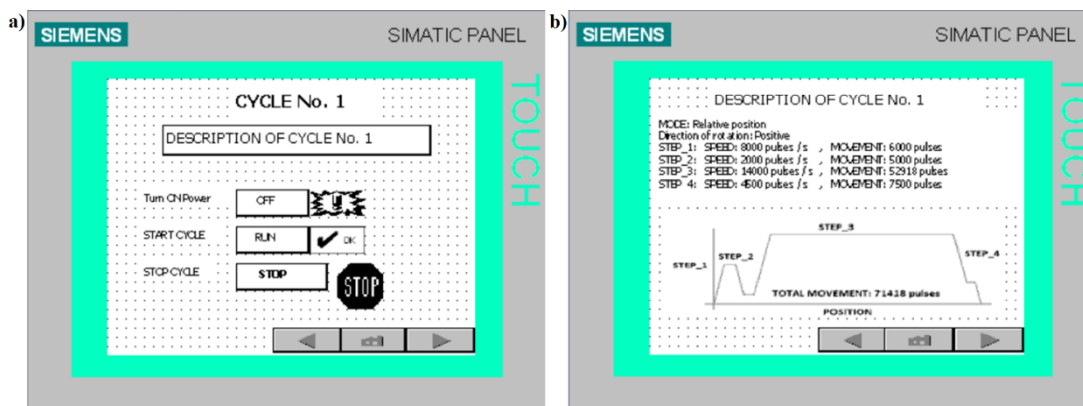


Fig.4. Views of: a) the main screen of an exemplary cycle, b) visualization of motor movement

Using the screen, which enable to start the engine work cycle using the function buttons. User can easily read the parameters of each step of the engine's work, speed and displacement. Using the keys at the bottom of the screen, it is possible to go back to the previous screen or return to the main menu.

5. Conclusions

The PLC controllers are finding more and more applications, not only in the classically understood machines, but also among other applications related to an automation. This is due to the drop in their prices and broad application possibilities.

Programming the PLC controllers requires a lot of knowledge and experience, which allows to eliminate such phenomena as, among others, overwriting registers, confusing the logic of the program, implementation of an algorithm that causes damage to machines or production lines, etc.

The software for programming PLCs and the wizards included in it, make programming very easy, which shortens the programming time in a significant amount. All programmed cycles have the possibility of an emergency stop due to which the engine operation is safe.

The ability to control the motor with a touch panel and physical switches located on the PLC gives the possibility to control the motor in two ways and enables operation in case the touch panel fails.

The disadvantage of the software used to program the TP 177micro Touch Panel is that user cannot create a backup program located on the device, if operator does not have a project file, it is impossible to get it from the device. It may induced serious problems during making changes to the device program.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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COMPOSITE MATERIALS APPLICATION IN AUTOMOTIVE INDUSTRY

Abstract: This article presents the possibilities that provide modern composite laminates used in the automotive industry provide [1]. The use of appropriate engineering software allowed the definition of epoxy carbon laminate for the purpose of strength verification. The passive safety element made of materials commonly used in car production together with modern laminate has been compared. This verification shows the behavior of the car bumper beam during a simple road collision.

1. Introduction

The dynamic development as well as favorable forecasts of the automotive industry's expansion obtained on the basis of car market research constantly pose new challenges for manufacturers. These challenges apply to materials used in their construction, ranging from bodywork and plating to finishing materials, the type of drives and systems used. The automotive industry opens a wide field of development opportunities, combining electronics, mechanics and many other fields of science. Decreasing the weight of the vehicle along with the increase in safety is undeniably one of the better steps towards development. It is analogous to replacing steel with lighter aluminum, as well as composite materials that are increasingly displacing the raw materials used so far. Wide application and countless possibilities make their shares in car construction surely will be bigger and bigger. The safety of travelers is the key aspect when designing a car for serial or mass production. This is what makes engineers look for new materials for passive safety components. Ensuring proper car aerodynamics or reducing the load on the drive system, and finally reduced combustion, require specific properties from the materials used. The use of composite materials instead of materials used in recent years has many benefits.

2. Epoxy resin laminate reinforced with carbon fiber

Composite materials with an epoxy resin matrix and carbon fiber reinforcement are popular due to the successes achieved in the aerospace industries. The variety of methods of their production provides manufacturers the possibility of obtaining shapes and unattainable strength using conventional materials. To ensure the desired properties, it is very important to choose the right warp and reinforcement. In addition to choosing these materials, one must also choose the form of the reinforcing phase. In the case of composite materials, there is a whole range of different materials that successfully play the role of the reinforcing phase. The most common are glass, aramid and carbon fibers. The next step after choosing the material is to choose the form of reinforcement. Depending on the properties, which should have the finished product, it is needed to choose the right form of reinforcement. The best strength properties are exhibited by long continuous filaments. They allow to transfer almost all loads without transferring them to the matrix. Short continuous fibers, staple fibers, dispersions, reinforcing mats or fabrics are just a few items from the range of possibilities provided by the reinforcing phases. The fiber diameter, the cross-sectional shape of the fiber and the positioning of the fibers relative to each other are also available. Both long and short fibers can be laid unidirectional or bidirectional. The bidirectional arrangement allows different fiber interleaving combinations. For the purpose of determining the properties resulting from the laying of reinforcing fibers, a coefficient of the efficiency of fiber utilization was introduced. Figure 1 shows the value of this coefficient depending on the distribution of the reinforcing phase. It was assumed that successive layers are located one above the other at an infinitesimal distance.



Fig. 1. The values of the fiber utilization coefficient depending on their arrangement

We use this coefficient when we want to determine the strength of the material with the reinforcing phase in a specific direction for a given type of load. By substituting the load parameters to the appropriate formula and multiplying the whole by the value of the coefficient, we are able to determine the yield limits of the material. The mathematical dependence is defined by equation [2].

$$\sigma_k = \gamma[\sigma_w V_w + \sigma_o \varepsilon_w (1 - V_w)] \quad (1)$$

where: σ_k - tensile strength of the composite [MPa]
 γ - coefficient of reinforcement use
 σ_w - tensile strength of fibers [MPa]
 V_w - volume fraction of fibers
 σ_o - tensile strength of the matrix [MPa]
 ε_w - distortion of fibers

After selecting the appropriate reinforcement, it is also important to choose the appropriate warp. Depending on the type chosen, for example, increased resistance to high temperatures, flexibility, stiffness or resistance to aggressive substances can be achieved. The substance that shows the best properties on the matrix material is epoxy resin. Unlike other types of resins, this material exhibits the lowest shrinkage after hardening, has very good strength properties and provides quite high geometric accuracy after forming. The disadvantage of the resins is their thermosetting. This excludes recycling to the original form. It is recommended, however, to use thermoplastics to make it possible to re-use the raw material after its period of use. However, polymers belonging to the group of thermoplastics as the matrix material have worse properties than duroplastics. Their plasticity is higher and their durability is lower. Unfortunately, all fibrous composites in the polymer matrix are characterized by a relatively low maximum working temperature. Increased working temperature leads to the destruction of the matrix, which after some time is destroyed as a result of material fatigue. Regardless of the type of warp or reinforcement, many defects of the structure are possible already at the production stage. Figure 2 shows the structure of the laminate with a reinforcing phase.

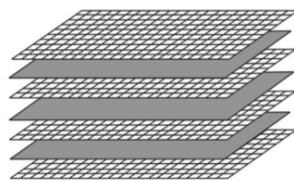


Fig. 2. Laminate structure

The high costs of components made of carbon composites make them only used in luxury cars. Car manufacturers, trying to limit the price increase of the product, try to use these materials in places where their properties will be properly used. In addition to decorative elements in the interior, external covers, there are also composites forming load-bearing structures. For these purposes, ultra-strong fibers and warps with improved strength properties are used. The implementation of the correct composite requires time and precision, and machining or joining is also difficult. All this makes prices of such products often exceed the prices of traditional elements several times

3. Strength testing

In order to carry out the strength verification of the element made of laminate, it is necessary to be able to correctly model the laminate in a computer program. The Siemens NX computer program with its laminate modeling module provides excellent opportunities for this type of research. This software enables not only verification of isotropic, but also anisotropic materials. Proper definition of the laminate allows, therefore, to examine the properties of the element made, for example, of a carbon fiber reinforced composite. The structure of the modeled and real laminate is shown in Fig. 3.

4. Conclusions

In order to obtain the right strength of the material, it is important to choose a warp and reinforcing fiber. The configuration of the position or thickness of individual layers also reflects on the strength properties. Thanks to CAE engineering programs, it is possible to carry out strength tests of both isotropic and anisotropic materials. Proper definition of the material allows to obtain information on the distribution of stresses in individual layers. This knowledge will allow you to properly prepare the laminate before starting production. Computer research should be confirmed by research of real elements, because only they can make us sure that the obtained results are correct and are reflected in real conditions.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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APPLICATION OF ADVANCED CA_x SYSTEMS FOR DESIGN AND PERFORMANCE OF TILTING TABLE IN VERTICAL MACHINING CENTRE

Abstract: In the article design process of tilting table, which is additional tooling of triaxial, vertical machining centre Harnaś R550, has been describe. Thanks to this modification, a possibility of machining axial-nonrotating elements by means of various angular positions – so-called indexed machining, was gained. The proposed tooling in CAD environment has been modeled. After calculation of the forces, which may arise at the machining, strength test by FEM has been carried out in order to select appropriate components of the designed tooling. Based on developed structure the prototype has been built, which on real machine has been mounted. Afterwards, machining accuracy of control items has been compared, carried out by three different methods, including use of tilting table and CAM software.

1. Introduction

In the era of progressive globalization of the world-wide market economy, basically all production spheres are under the pressure of rationalization, striving to obtain better and better products in the shortest possible time. Changing market trends force manufacturers to quickly introduce new products on the market. It causing that engineers who create new solutions must use efficient IT tools that are able to significantly speed up their activities while maintaining the profitability, quality and durability of new products. Modern CAD/CAE class programs have great opportunities in relation to conducting advanced strength and fatigue tests, kinematic and dynamic analyses or analyses related to product vibroactivity [9 – 14]. They allow to simulate and then analyse many phenomena that occur during the work of devices. Thanks to such tools, we can consciously shape the properties of objects at the early stages of the design process. We can very quickly carry out initial tests on the considered device, which in turn allows to reduce the scope, time and costs of research conducted on real objects (prototypes).

In reference to mechanical engineering, competitive production conditions force the modernization of existing process chains to obtain more favorable technical and economic results.



Fig. 1. Vertical machining centre R550 (left) [5] and rotary table used as a drive (right) [7]

To enable an increase in machining efficiency, while preserving the requirements setted for shape, dimensional accuracy and surface quality, it is necessary to develop machines not only in terms of construction but also in terms of the control system [3, 6, 8].

The designed tilting table has been run on vertical machining centre R550 AFM DEFUM with FANUC 0i_MD (Fig. 1.) control system. As a drive, rotary table CNC 170R of production GSA+ was used (Fig. 1.).

2. Project and implementation

The tooling in the form of tilting table was designed in CAD environment, in Autodesk Inventor program. In the first step, individual parts of table has been modeled and next the virtual assembly of entire tooling has been created. In further stage carried out strength analysis with application of numerical method - FEM - to determine the degree of strain of selected components.

Before starting the strength calculations and selecting the cross-sections of the designed parts, it was necessary to determine the forces acting on the entire mechanism during machining (machining forces). They were determined by theoretical way. It was assumed that the machined material would be 42CrMo4 steel. HSS high-speed steel tools will be used for machining. Three liminal variants has been assumed:

- drilling in full material with a drill $\text{Ø}30\text{mm}$ (purposeful, nontechnological assumption),
- face milling with a $\text{Ø}80\text{mm}$ cutter with carbide inserts,
- peripheral milling with a $\text{Ø}30\text{mm}$ cutter.

After the calculations were made, it was determined that the greatest strain occurs during drilling, when the theoretical axial force exerted during this process is 7103 N. The obtained results are shown in Table 1.

Tab. 1. Calculated values of forces in relation to the analysed cases

Kind of machining	Tool parameters	Calculated value of force, [N]
Drilling	HSS drill Ø30	7102,88
Face milling	Cutter with carbide inserts Ø80	1152,8
Peripheral milling	HSS cutter Ø30	676,65

The strength analysis by FEM was carried out in Autodesk Inventor. Fig. 2. presents sample result from the analysis.

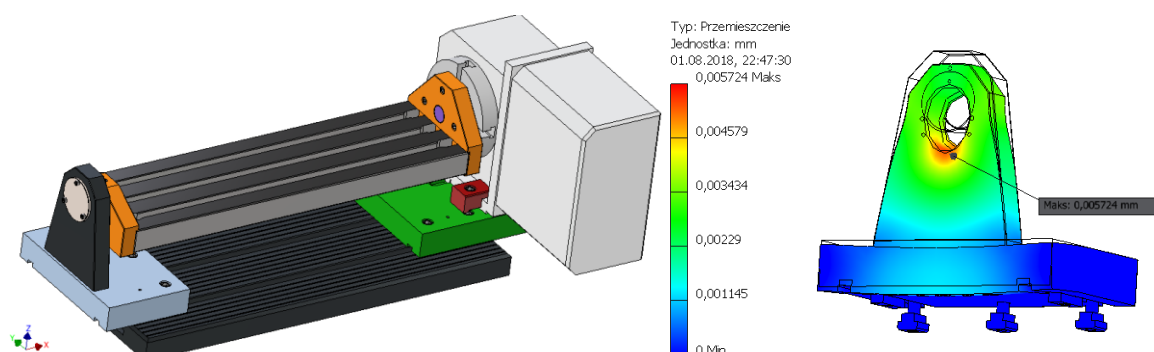


Fig. 2. Model of tilting table and strength test by FEM in Autodesk Inventor

The material used to build the tooling was mainly EN-GJS-500-7 ductile iron. It is resistant to abrasion and compression and insensitive to variable strains. Due to high cohesion, it dampens vibrations well (Fig. 3.) [1].

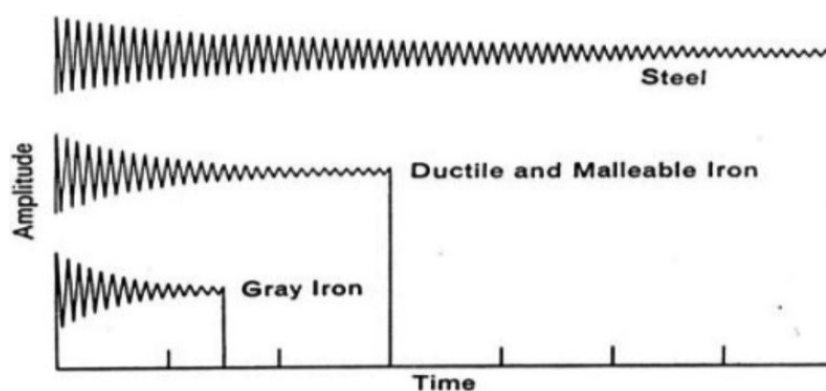


Fig. 3. Amplitude of vibrations of various materials [4]

In the next step, the model was analyzed for the proper functioning of the machine, possible collisions of parts and assemblies and the possibility of implementing the assembly process. After correct verification of these activities, technical drawings were accomplished, simultaneously developing production technology.



Fig. 4. Ready assembled tilting table in machine with example vise

In order to check the quality of the evolved tooling, the accuracy obtained in three different machining methods was compared in reference to a control items, specially designed for this purpose (Fig. 5.). It was necessary to make a planes at an angle of 30° and 45° , a perpendicular groove 8H7 and two holes M6 with countersinks, inclined at an angle of 25° .



Fig. 5. Model and 3 series of control items: series 1. (left) made only with the help of angular vise; series 2. (middle) produced by peripheral milling method and also with the help of angular vise; series 3. (right) made only with help of designed tilting table.

The carried out tests consisted on production and measurement of a total of twelve control items in three series:

- a series of four items machined using an angular vice, where each plane, groove and holes are made separately at different fixes,
- a series of four items machined in such a way that the 30° and 45° planes are machined in one fixing using a peripheral milling method with end mill, remaining elements in an angle vise,
- a series of four items machined using a developed tilting table only, in one fixing.

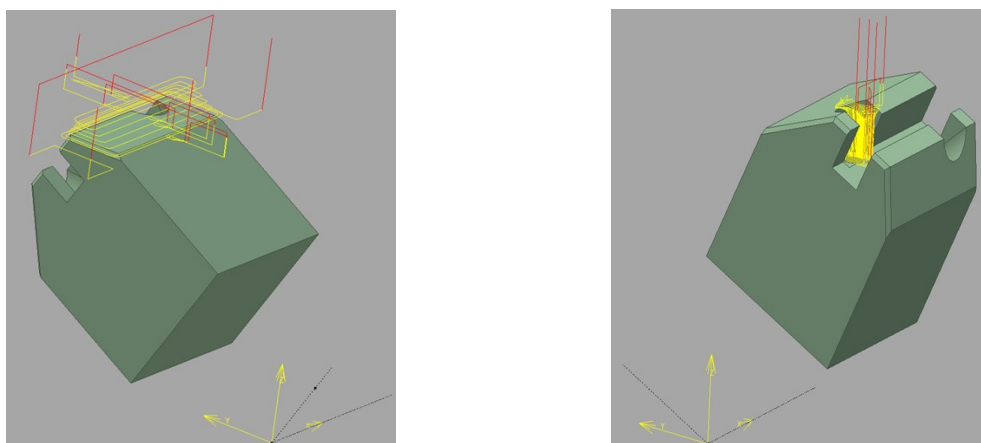


Fig. 6. Tools paths generated in CAM – hyperMILL

For create a program needed to produce control items in third series, the hyperMILL - CAM software - was used. Unfortunately, used software does not have the possibility of programming five axes, and only such allows for continuous control of the fourth axis. For this reason, when the program was generated, made use of machining at a given angular position, so-called indexed machining.

The graphs presented in figure 7. show the compared times needed to complete each series. The last of them took the most time because of the very long preparing-completion time (t_{pz}). However, if we take into account a series of 40 pieces, the third method turns out to be the fastest, because the preparing-completion time t_{pz} occurs here only once. Dimensional accuracy was also compared and it was found that the 3. series was made most accurately and had the most repeatable dimensions. The made tilting table significantly contributed to the improvement of the quality of the items being made, and also - in the case of series - to shorten the machining time.

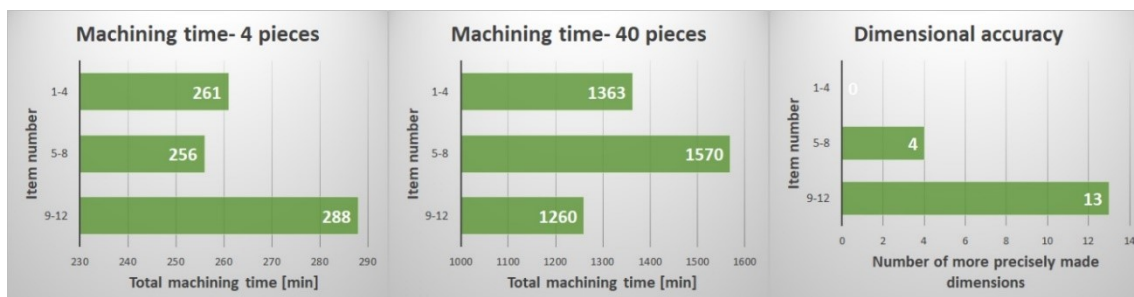


Fig. 7. Findings

3. Conclusions

The realised task was to increase the functionality of the machine, which translated into a reduction in the required number of fixings in the context of manufactured goods. The use of advanced CAD/CAE class programs during the design and engineering process significantly accelerated the creation of a new solution. The conducted tests allowed to estimate the benefits related to the time of realising manufacturing processes as well as the benefits related to the obtained dimensional accuracy of the manufactured items. Conclusions resulting from the conducted tests show that 23,53% of the dimensions were made better with the second method, so this one, where the planes at an angles were milled peripherally and the holes were drilled in an angle vice, while 76,47% of the dimensions were more accurate in the case of machining with help of the tilting table. The items made with this method were more accurate by 52,94%.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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COMPUTER SIMULATION OF MANUAL OPERATED AND ROBOTIZED TECHNOLOGICAL LINES IN FLEXSIM SOFTWARE

Abstract: The article present current research realized during works on production planning and manufacturing system quality improving with use a methods of computer modelling and simulation techniques. Except that, the functional analysis of simulation software FlexSim are shown in context of manual operated and robotized technological lines. At realized tests, the possibility of the selected application were examined in the optimization of material flow through internal system, especially in the context of automated and robotized medium-series and high volume production. During research two models were created and compared, at the end some conclusions were presented. The article was created on the base of master thesis [1].

1. Introduction

The beginning and development of the 4.0 industry philosophy, obliged the producers to look for the better manufacturing solutions, even more than before today [2,3]. Contemporary production processes and internal logistics requires use of modern solutions in a different aspects of material flow, especially in context of inter-operational breaks and Lean Manufacturing [4,5], which involves the need to analyze a lot of industrial data. In this situation, only the use of a computer simulation, with the use of software available on the market, seems to be appropriate. In our research, FlexSim software was used, because it is designed, among others, for modeling and analysis of flexible manufacturing systems with discrete flow of materials [6]. During ours works, related to the preparation of the master's thesis [1] and other parallel realized research [7], the comparison of the production line efficiency with the assumption of two types of the inter-operational transport was focused. In the first stage a manual handling and transport, with the use of an operator, was modelled and analyzed, in the second stage an industrial robots were used.

2. Modelling and virtual simulation of technological lines in Flexsim

The first step of the activities started with the review of the existing and available 3D VIMS simulation software (Visual Interactive Modelling System). By verifying the available components, parameters and analytical capabilities of the production logistics software, already at the outset, FlexSim and Enterprise Dynamics were selected, as suitable for carrying out research in the aforementioned scope [8,9]. Both software have a similar modelling philosophy and simulation capabilities, but FlexSim was finally decided, especially due to the availability of the full version, at the Institute of Engineering Processes Automation and Integrated Manufacturing Systems. Next step was creating two models of production line: with human operated transport and its modification by using industrial robots. Partial models are presented on Fig. 1.

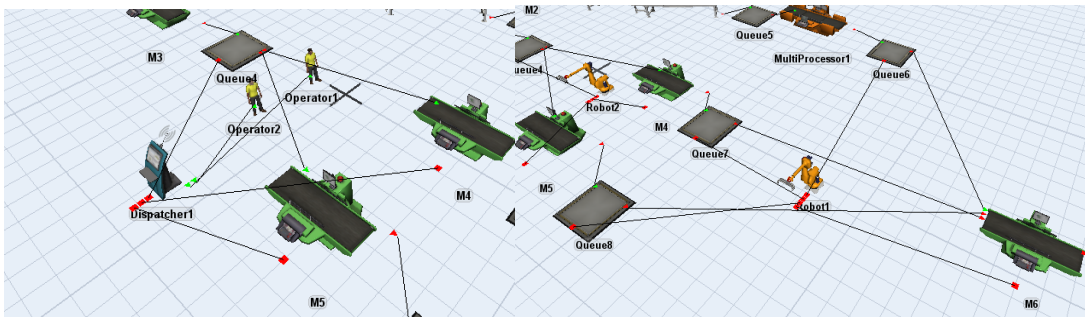


Fig. 1. Two partial models: human-operated and robotized cells

The following FlexSim elements [8,9] were used when we built the models: *Sources* of raw materials, *Queues* - inter-operational buffers, *Processors* and *Multiprocessors* - technological machines, *Conveyors*, *Transporters* - e.g. forklifts, *Rack* - final product warehouse and of course *Operators* and industrial *Robots* - which were most important during research on material manipulation and handling tasks and so called "short transport" processes inside the system. The final layout (here only for robotized part) is presented below on Fig. 2.

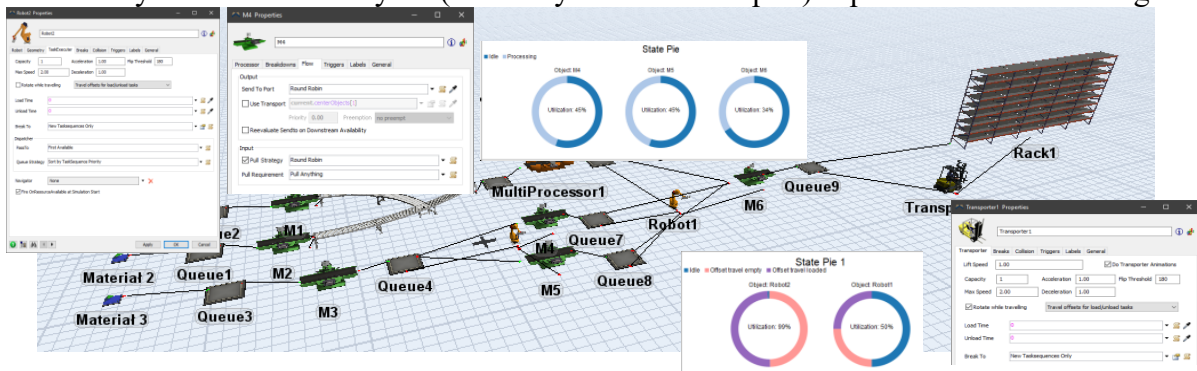


Fig. 2. The FlexSim model of automated and robotized manufacturing system

After optimization of the layout (correct locations of all production devices) connections between elements were created. The connections give information about materials flow through the production system.

The most difficult task, during modelling is correct description of main and auxiliary parameters of production system elements with use of FlexSim existing internal functions or macros created by user in FlexSim programming language. It was necessary to reproduce the real model. When research was conducted on comparison of human operated and robotized transport we focused on parameter of the two elements, because the properties of another devices are the same in first and second model. On the Fig. 3 some properties of *Operator* and *Robot* are presented, and described below the picture.

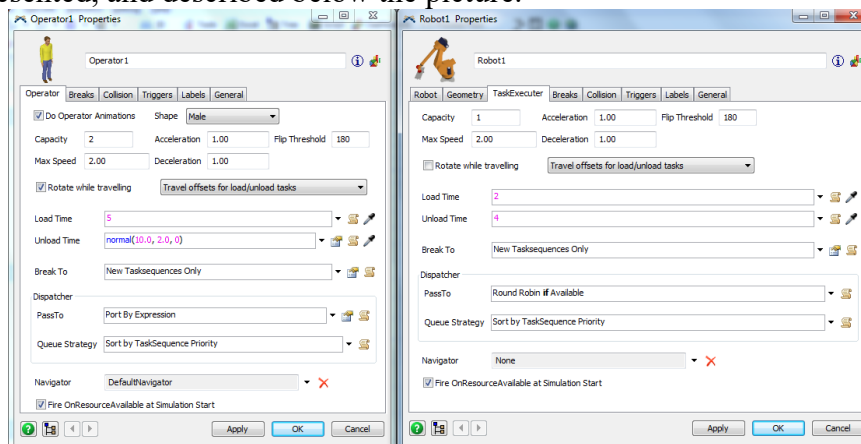


Fig. 3. Main and auxiliary properties for Operator and Robot

In that case chosen parameters (grouped in specific menu: *Operator/Robot*, *Geometry*, *Task Executer*, *Breaks*, *Collision*, *Triggers*, *Labels*, *General*) are similar but some are different. Identical parameters are connected with *Load/Unload Time*, *Queue Strategy*, *Flow*, *Speed* and *Acceleration*, *Capacity*, *Dispatching* rules, *Collisions*; of course these real values for operator and robot can be different. Other parameters, like *Geometry* and *Trajectory* are specific only for industrial robot or other automated device, but another properties e.g. for human are difficult or not possible modelling in FlexSim software - e.g. skills, experience, psychophysical capabilities.

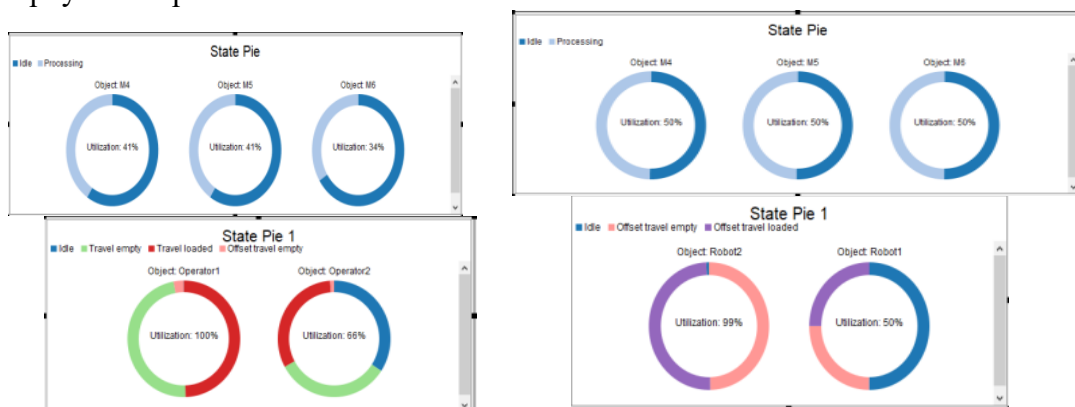


Fig. 4. Comparison of improved models: machines efficiency and humans/robots utilization

After simple modelling process it is possible to start simulation research. In this case, we focused on the analysis of the work efficiency of the production cell (technological machines) supported by operators (1st model) and by robots (2nd model), as well as checking the utilization of the transport and manipulation subsystem (human operated and robotized).

On the Fig. 4. the results described above are presented, of course, we show only final results after multistage improvement process of the model.

3. Conclusions

The application of different computer simulation software (e.g. FlexSim) and making any tests of designed and existing production systems e.g. in the aspects described here in context of improving the efficiency of the system working is currently one of the most important activities aimed at optimizing the flow of materials, reducing inter-operational breaks, and thus reducing the costs related to selected functions of internal logistics. In further research, the analysis area should be extended to the entire integrated production and logistics environment paying particular attention to the optimization of material flow, especially in relation to the ergonomics of operators work and off-line planning the trajectories of robots (but these may involve the use of other specialized software - e.g. Process Simulate).

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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IMPROVEMENT OF THE ASSEMBLY WORKSTATION WITH THE USE OF VISUAL MANAGEMENT METHODS

Abstract: The performance of human operators and manually operated processes can be improved with the use of visual management methods. An example of improvement of assembly station is presented. Detailed analysis of the work process has identified some places, in which time losses and reduced efficiency occur. Therefore, a new project of the workstation has been developed. According to lean manufacturing principles, the visual management methods, including 5S, have been used. The detailed design of human workspace was prepared with the CAD software NX 10. The use of digital human models allows 3D visualization and can be used to improve the ergonomics of human workspace. Although, the improved assembly workstation will have much greater productivity, also training for employment is required.

1. Introduction

The development of production companies is directly linked with the need to adapt to the current market. Technological and process improvements make that competitiveness take on a completely different dimension. Thoughtful and effective use of Lean methods in management and manufacturing, makes a company be able to control and manage their resources in the best way [1, 2]. It is also important to the quality of the products and the minimization of the waste generated by the process [4]. Therefore, to ensure the ergonomics of work and avoid human errors, attention is given to the appropriate design of workplaces and human work processes [3]. For this purpose, visual management is used, which is one of the most important elements of the lean management philosophy [1, 5].

Visual management allows you to clearly define the system statuses, so that each employee can interpret the current states. Visual management helps in maintaining a working environment within a certain standard. It is a facilitation for production workers because it is easy to constantly monitor the process. An important advantage of visual management is maintaining safety in the enterprise and minimizing accidents at work [5].

2. Visual management methods

Visual Management is said to be the practice of using visualized information to manage work. Any tool that increases efficiency or safety using visual methods can be considered a desirable visual management action.

Visual management incorporate the 5S method, which includes five areas of improvement [1, 2]:

- Sort (Seiri) - sorting through all items in a location and removing all unnecessary items from the location
- Set in order (Seiton) - putting all necessary items in the optimal place for fulfilling their function in the workplace
- Shine (Seiso) - sweeping or cleaning and inspecting the workplace, tools and machinery being used on a regular basis.
- Standardize (Seiketsu) - standardize the processes used to sort, order and clean the workplace.
- Self-discipline (Shitsuke) - sustain the developed processes by self-discipline of the workers. Also translates as "do without being told".

The examples of visual tools can be as follows [1, 2]:

- 1S – a red tag area containing items waiting for removal,
- 2S – simple floor marking,
- 3S – cleanliness point with cleaning tools and resources,
- 4S - use of photos and visual controls to help keep everything in right place,
- 5S – visual team board.

The implementation of 5S method requires [1, 2]:

- Organizing of training sessions,
- Performing regular audits to ensure that all defined standards are being implemented and followed,
- Implementing improvements whenever possible. Worker inputs can be very valuable for identifying improvements,
- When issues arise, identifying their cause and implementing the changes necessary to avoid recurrence.

3. The description of the problem

The problem concerns the improvement of the assembly station in a production company that specializes in the production of automotive components, i.e. shock absorbers [7]. Two main activities are performed on the analyzed station: assembling of the package boxes and packaging of the finished product (shock absorber) to the box. One employee is currently working on the job, who carries out all activities, starting from collecting semi-finished products to packaging the ready-made product on the pallet. The layout of the actual workstation is presented in the Figure 1.

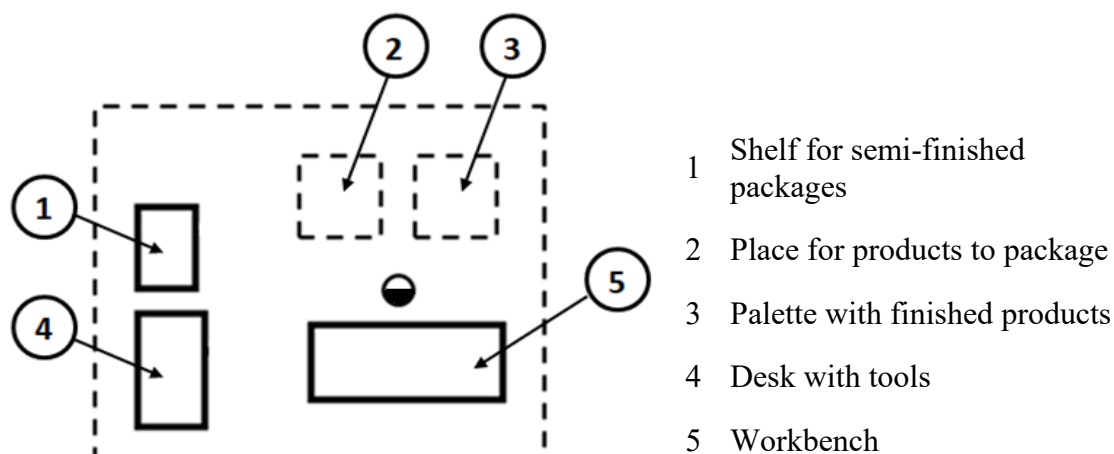


Fig. 1. Actual workstation layout [6]

The worker's responsibilities include (according to the photograph of the working day) [6]:

- Organizational activities,
- Preparation of the workplace,
- taking of the semi-finished products from the warehouse - the employee downloads semi-finished products needed to execute the order, such as cartons, sets of metal components, sets of plastic components as well as glue and necessary tools,
- taking the right number of products from the warehouse according to the order - front and rear shock absorbers,
- assembling the boxes by the employee and packing the finished goods into the box, then putting the finished product on the pallet,
- After the production batch ends, transporting the ready-made pallet to the finished product warehouse,
- Sorting the workplace,
- Filling the documentation, submitting a report to the supervisor at the end of the shift

The main problem is that the shock absorbers differ in dimensions and components with which they are packed. The front shock absorber is larger and contains a different set of components attached to the packaging (a washer and a nut made of plastic). The rear shock absorber is smaller, and the set of components included in the package is a metal washer and a nut. When performing his work, the employee must check on the order card whether the item requires packing additional components. Such system creates the possibility of mistakes when packaging the items.

Other problems were identified as:

- Excessive transport,
- Bad layout - excessive worker movement,
- Lack of 5S – not effective work,
- Possibility of employee error,
- Bottlenecks in the production process.

4. Project of improved workstation

Due to the increased demand for products from customers, various options to improve the assembly station with the use of visual management methods were considered. The main improvements include:

- Increasing the position cast and division of labor,
- Shadow board being a part of the work station, that allows assigning tools and elements necessary for the position of appropriate places,
- Layout of the workbenches in the L-shape,
- The division of the table surface into zones,
- Placement of containers for packaging in an easily accessible place under the table top,
- Extracting storage locations for two types of products,
- Removal of unnecessary elements.

Basing on the proposed improvements, a new layout of assembly station was designed, and is presented in the Figure 2. There are three workers and each of them has different task. The first worker is preparing the package boxes, and the two other workers are mounting shock absorbers with components and packing into cartoon boxes. Each one of them is working only with one product type in order to prevent human errors.

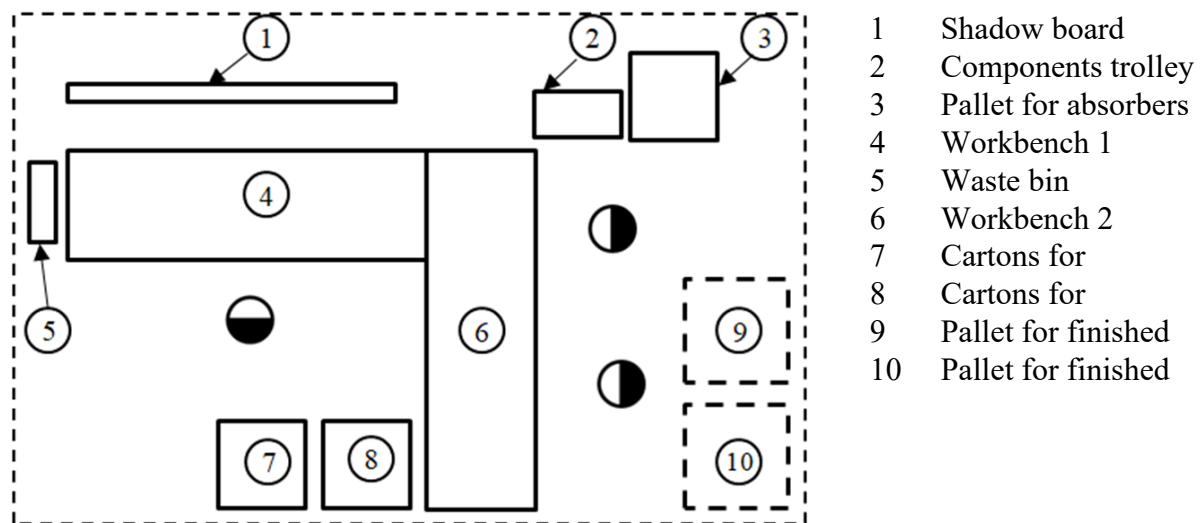


Fig. 2. Layout of the projected assembly workstation [6]

The detailed design of the assembly station was created in the Siemens NX program, which enables 3D visualization. Three employee models were added in order to visualize the complete workstation and to evaluate work ergonomics. One employee is preparing the boxes for packing and the second and third one, are packing different sort of products into boxes in order to avoid mistakes.

With the use of visual management, it is possible to train employees faster. It is estimated, that the proposed improvements will reduce time losses and increase production efficiency at the analyzed assembly station by about 300 percent.

The general view of the workstation is shown in Figure 3.

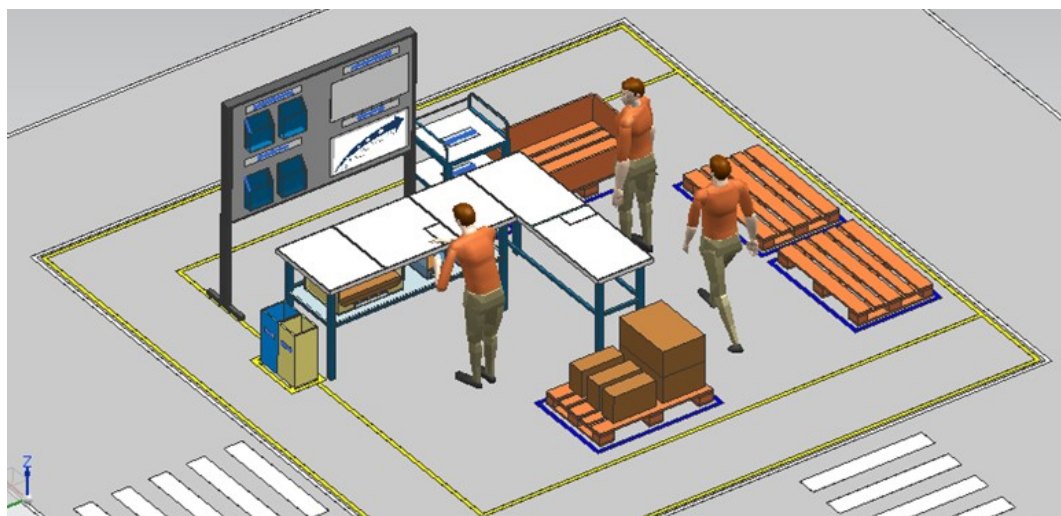


Fig. 3. Visualization of the projected assembly workstation in NX10 [6]

An important part of the workstation is the shadow board presented in the Figure 4. It is a device for organizing a set of tools; the board defines where particular tools should be placed when they are not in use. Shadow boards have the outlines of the work station's tools marked on them, allowing operators to quickly identify which tools are in use or missing. The boards are commonly located near the work station where the tools are used. Shadow boards are often used in the manufacturing environment to improve work process with the 5S method.

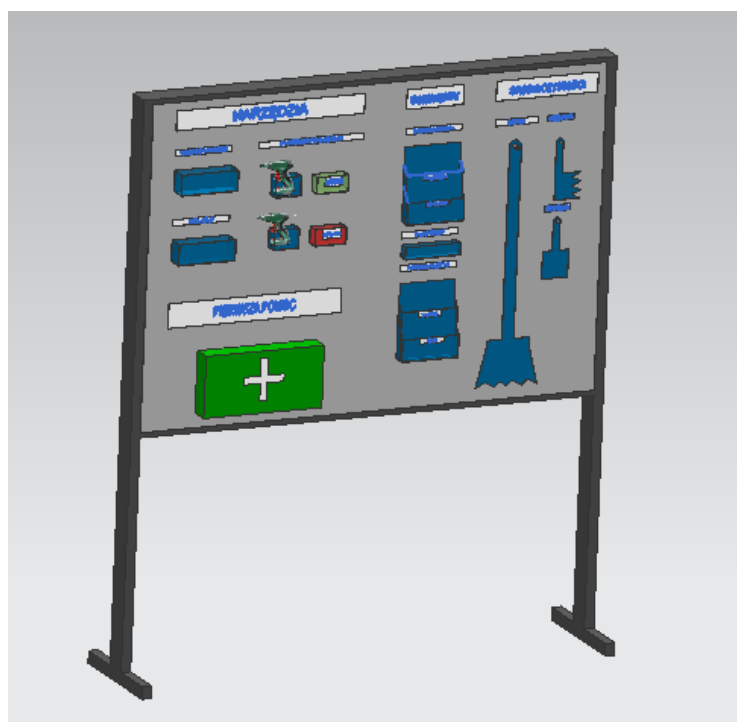


Fig. 4. Shadow board - rear view [6]

The assembly operation begins on the first table (Fig. 5). This position is supported by one employee.

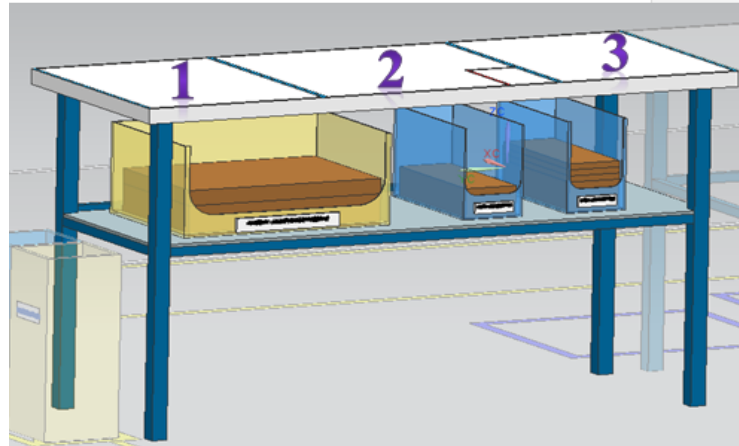


Fig. 5 Mounting table with three designated zones [6]

Three zones have been designated on the tabletop in which the employee performs certain activities including; 1 - zone of packaging distribution, 2 - zone of gluing, 3 - buffer. This arrangement is conducive to maintaining order in the workplace.

5. Conclusions

Lean manufacturing is not only a way to make improvements that can be observed based on a comparison of the past states with the future state. In order to obtain the best results, the way of working and thinking of employees should be changed through appropriate training.

Well-used visual management allows to quickly recognize the occurrence of errors or wastage. Identified problems are easier to eliminate from the process thanks to the applied standards. Visual management can be related not only to the arrangement and standardization of certain elements on the site, but also to the management of employees. According to lean philosophy (Gemba Kaizen) small improvements of each workstation can bring large positive effects to the whole enterprise.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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DESIGN AND EXECUTION OF A PNEUMOTRONIC LABORATORY STATION USING PROPORTIONAL CONTROL

Abstract: The paper presents the construction process of a pneumotronic station for exercises in the field of proportional technique in pneumatics. The stages of selecting elements, designing of the frame of the station in the Siemens NX system, writing software and creating visualizations for the HMI panel are presented. The stand was equipped with a proportionally controlled pneumatic axis, with a pneumatic cylinder mounted on it, equipped with a vacuum generator, which allows for lifting flat elements. The next stages of creating software for station control are also presented. The process of creating an algorithm controlling the automatic cycles of the station and the stage of building the visualization on the HMI panel are presented.

1. Introduction

Initially, the proportional technique was used only in hydraulic systems. It was not until the 1980s that a control system proportional to pneumatics was introduced. This technique combines pneumatic systems with electronic control systems. Progressive changes are aimed at increasing the simplicity of pneumatic systems application while improving their accuracy [1-3]. The proportional technique allows to control the process using analog signals. Proportional elements of pneumatic systems allow for continuous change of the pressure or flow rate directly proportional to the analog signal given to the control element. Proportional technology is widely used in industry. Practical examples of using this technique are [1,2,4]:

- adjustment of the paper roll tension in the paper industry. In this system, the electrical signal from the controller is converted into a pneumatic signal that causes the adjustment cylinder to be displaced so that the appropriate paper tension is maintained on the roll supporting the sheet of paper.
- the pressure control system, where the transmitter converts the current pressure in the pipeline, into an electrical signal, based on which the control signal is determined, causing the control valve to open or close properly.

- filling of liquids in the food industry by control of the actuator with a bottle filling tube. A vertical displacement of the tube is carried out so that it is lifted with the increasing level of liquid in the bottle.

- applying an adhesive, in which, depending on the transporter's speed, the adhesive must be applied to different surfaces in an appropriate quantity. The signal informing about the change of the transporter's speed, causes the appropriate pressure regulation, which changes the position of the ball in the adhesive dispenser.

The work involved the design of a pneumotronic station, which is the application of a pneumatic positioning system. The station consists of a proportional controlled axis, which allows obtaining four predefined positions and a vertical axis, which is an application of a classical electropneumatics. The vertical axis actuator is controlled by a solenoid valve. In addition, it is also possible to rotate on the vertical axis using a rotary actuator, with a range of up to 90 degrees. The stand provides the opportunity to learn about the practical application of the proportional system used in real systems existing in industry. Working at the station also allows you to familiarize yourself with the programming methods of the PLC controller, which implements the given algorithm for controlling the pneumotronic system. The concept of pneumotronics is related to electrically operated pneumatic drives that are programmable. Pneumotronics is a combination of information technology, pneumatics and electronics.

2. Development of a pneumotronic laboratory station using proportional technique

Positioning in pneumatics is a difficult issue due to the nature of the phenomenon of converting compressed air energy into mechanical work. This is a non-linear phenomenon, which makes it difficult to predict the behaviour of the actuator during positioning. Therefore, manufacturers develop and propose their own pneumatic proportional systems. In the developed laboratory stand for proportional positioning the axis of the FESTO company was used consisting of the following elements:

- SPC11-MTS-AIF axle controller,
- proportional directional valve MPYE-5-1 / 8-HF-010-B,
- rod less cylinder GPL-25-650-PPV,
- GDC-HD25-GK-D2 heavy duty guide,
- absolute MME-MTS-750-TLF-AIF digital encoder.

It is presented in Fig. 1. The number 5, in Figure 1 denotes the axis controller, with the help of which the whole drive control takes place, giving the control signal to the proportional directional valve (6). The axis is supplied with air, which should be properly prepared. By means of the air preparation unit (8), the air is filtered into particles with a maximum diameter of 5 μ m. The valve is supplied with air at a pressure of 5-7 bar. It is not recommended that the air be oiled. Controlling the position of the linear actuator (1) was carried out by a proportional valve. Information on the position of the actuator is provided by the linear encoder (2) directly to the controller. In drives of this type, the need to use limit switches and pneumatic absorbers was eliminated [5]. The current piston position of the actuator is measured by means of an encoder. The MME-MTS type encoder is a closed profile with an external guide. The position measurement is made using magnetostrictive phenomenon [6]. The distance measurement is made by the difference in the time of generating the impulse and its reflection from the encoder's sensor [7].

The position is remembered by the encoder even after disconnecting the power supply, therefore it is not required to base the axis when restarting the station.

The transfer of information between the encoder and the axis controller takes place digitally after the Controller Area Network (CAN) interface with the SPC-AIF protocol. This protocol enables fast data exchange between devices. This controller allows for quick axis movements up to four positions. The two positions are the end positions of the manipulator, while the additional two intermediate positions can be stored in the controller's memory.

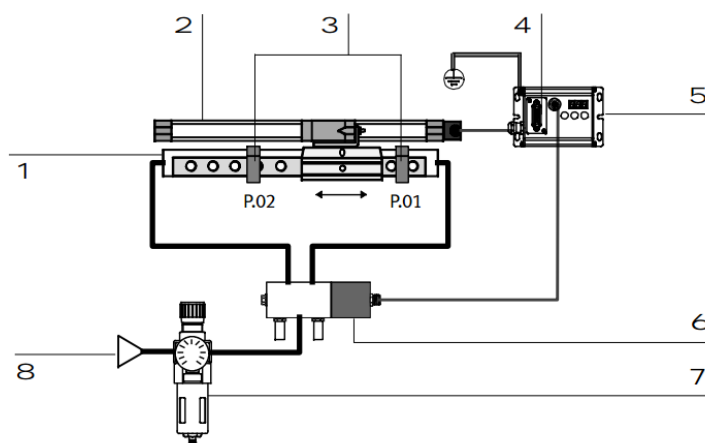


Fig. 1. The diagram of a proportional controlled pneumatic drive axle [5]

The MPYE directional proportional valve is like a simple solenoid valve, but it is equipped with a slider with its position control (2). Electronics located in the valve housing allows to control opening the valve using the analog signal. Opening the valve is directly proportional to the value of the analog signal. Valves of the MPYE series could be controlled by the voltage as well as the current signal. Flow rates are in the range of 100 - 2000 l / min. The valve used in the laboratory station is a five-way valve. The control is carried out by means of an analog voltage signal in the range of 0 - 10V. The valve hysteresis is about 0.4%. The valve operation pressure is in the range from 0 to 10 bar [8].

The axle is equipped with an additional vacuum lifter that allows lifting flat elements such as plates. The lifter consists of a double-acting cylinder with guides and a rotary actuator at the base. In addition, rubber suction cups have been installed in the base, allowing for the removal of a flat element by creating a vacuum. It is possible to perform vertical movements and rotation in the base. The entire manipulator is equipped with an adapter, which makes it possible to mount it on the actuator's cart. The cooperating axes form a system with three degrees of freedom.

The controller parameters should be configured in accordance with the axes operating conditions, which depend on the type of encoder the axis is equipped with and the mass to be moved, mounted on the bogie [5]. Parameters that can be configured in the SPC11 controller:

- gain parameter (A), responsible for acceleration of the drive,
- damping parameter (C), affects the behaviour of the drive during commuting to the final and intermediate positions,

- system option (S), is determined by two symbols. The first is the indicator of the drive measurement system, the second is the characteristic value of the drive's length ratio and its diameter,

- nominal length of the axial stroke (L). Nominal drive pitch length given in millimetres, parameter entered when the drive has an incremental encoder,

- the distance from the starting position (r), the value given in millimetres, the parameter entered in the case of the incremental encoder,

- options (o), additional options that allow assigning other actions performed on the controller's inputs and outputs.

The manufacturer provides suitable parameter configurations for different axle operating conditions. The parameters should be selected with extreme caution, because incorrect selection may cause undesirable axes or even damage. The parameters must be entered into the controller when the axis is first started or when the operating conditions of the axis have been changed [5].

In order to prepare the laboratory stand, it was necessary to prepare a frame on which the axis was mounted. The structure is made of aluminium profiles. The first step was to implement the project in the Siemens NX 10 software. Three concepts for the construction of the frame were developed. When developing the design, it was necessary to consider not only the weight of the entire axis, but also the inertial forces accompanying the dynamic movements of the actuator. After selecting the concept, details such as the place where the plate was installed with the controller and the valve were refined, and a countertop made of galvanized sheet with a thickness of 5mm was designed. A detailed executive drawing of the station is shown in Fig. 2.

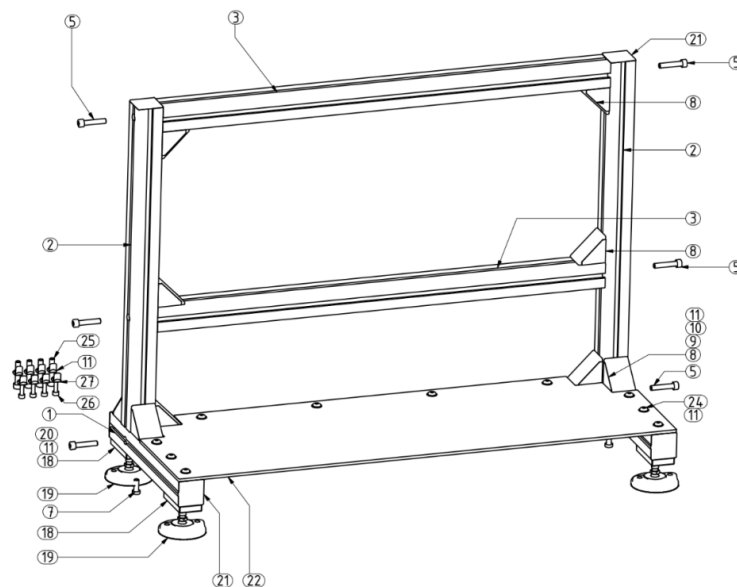


Fig. 2. The executive drawing of the laboratory station

An element supporting the encoder sensor was mounted to the axis, thanks to which the sensor moved along with the actuator. At the beginning this element was made of steel angles. In order to achieve a better presentation, the own supporting element for the encoder sensor was designed using the Siemens NX 10 system and made in 3D printing technology. It is presented in Fig. 3.

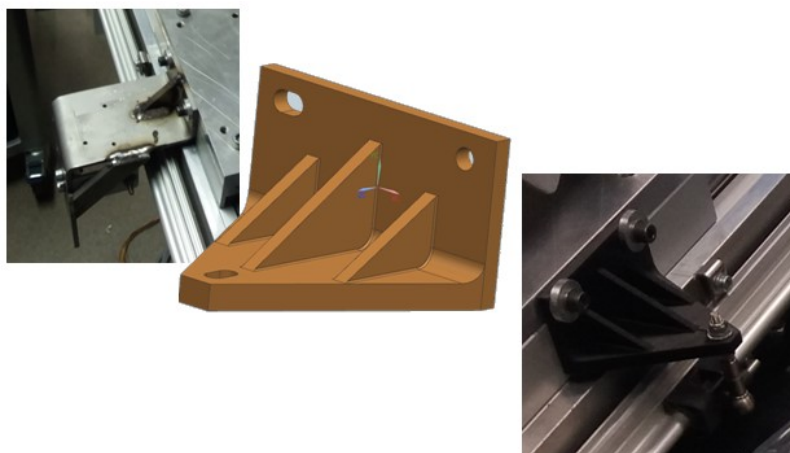


Fig. 3. Design of the element supporting the encoder's sensor

The element was made in the FDM technique on a 3D MakerBot printer. It was made of ABS material which is characterized by high hardness and impact strength compared to PLA. The print fill was 40%, the layer height was 0.75 mm. The ready to use laboratory stand is presented in Fig. 4.

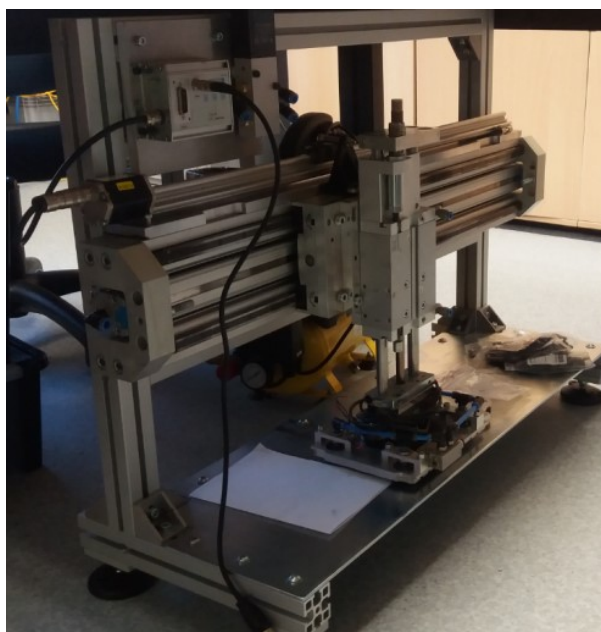


Fig. 4. The ready to use laboratory stand

The station is controlled by a Siemens S7-1200 PLC controller and the Siemens Comfort Panel 1500 operator panel. A compact controller has been used, which has built-in outputs and digital inputs. In addition, the unit has been equipped with a module that extends the number of digital outputs. The controller has two built-in PWM generators and high-speed HSC counters for counting pulses from the encoder. In addition, the unit is equipped with a PROFINET interface. Using the PROFINET interface, the controller is connected with the

HMI touch panel, by means of which the work visualization is displayed. The PROFINET interface also loads the driver program from the computer.

The S7-1200 series driver cooperates fully with the TIA Portal programming platform (Totally Integrated Automation) [9]. A program for the Siemens S7-1200 controller that supports two operating modes was written. The first mode is manual mode, in which single operations are performed by the user through the HMI panel. It is possible to move the horizontal axis to one of the predefined positions. Displacement of the vertical axis and twisting the base. The automatic mode includes four sequences of movements performed in a loop until the sequence execution is interrupted or another automatic program is selected.

Figure 5 shows the visualization made on the HMI panel. The panel has buttons for handling automatic sequences and for performing individual operations in manual mode. The drawing of the station with the indicators signaling the position of the manipulator on it is also shown.

Four programs of automatic sequences were written. Each sequence consists of elementary tasks performed by pneumatic axes. A submission of movements performs a specific task.

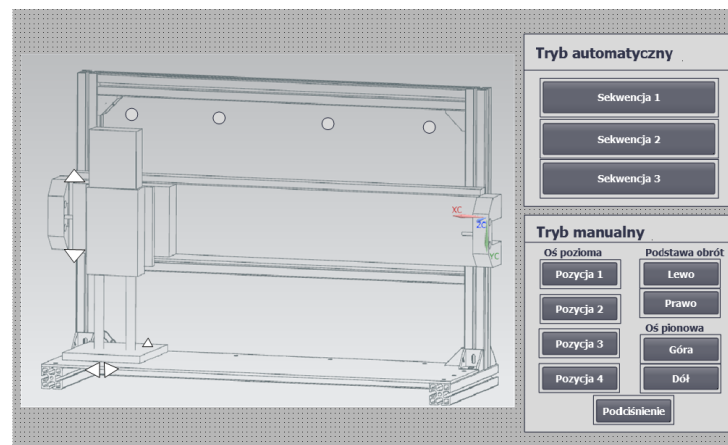


Fig. 5. The visualization made on the HMI panel

3. Conclusions

The proportional technique in pneumatics gives a wide range of applications in many industries, as well as finds its application in medicine. The biggest advantage of proportional control is the possibility of smooth flow or pressure control, which is not possible in conventional pneumatic or electropneumatic systems. The biggest obstacle in the use of proportional pneumatic systems is the high cost of control elements. Controlling proportional elements requires complex control algorithms based on m.in. genetic algorithms, fuzzy logic, neural networks. This is due to the nonlinearity problems of converting compressed air energy into mechanical energy of actuators, where the high compressibility of the air in combination with the static friction on the actuator's piston causes large problems with positioning. Proportional valves are controlled by analog signals, where at the output of the control element a direct proportional signal is obtained in the form of pressure or air flow. In electropneumatics, the control is carried out only by digital signals, which is much less flexible. The control based on Boolean logic does not give the same flexibility as in the case

of continuous control. The laboratory stand was developed to bring these issues closer in the didactic process as well as to conduct research on pneumotronic propulsion systems.

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SELECTED ENGINEERING PROBLEMS

NUMBER 8

DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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PROJECT OF A FIXTURE FOR JOINING CAR BODY PARTS

Abstract: The key step in designing a new car model to enter the market is choosing the right method to join the elements into a whole body. The known car body production technologies have been developed based on the experience gained in the use of carbon steel. Aluminium sheets stopped to rival with steel ones, when advantages of both were being used. The coexistence of different types of materials used in the same car body structure has been forced changes in the traditional methods of joining them. The random car body consists of 4,000 spot welds, 13 meters of welds, 90 meters of glue [2, 5]. The aim of the study to present various methods of joining car body parts and to compare their strength in an analytical way and using the finite element method. Particular attention has been given to the clinching, which becomes a cheaper and more flexible alternative to resistance spot welding.

1. Introduction

Considering problem concerns the integration of a new model to the produced series of cars. The existing production line is adapted to the production of one of the known models of panel vans in various length and height versions. The manufacturer also plans to introduce this model in the eleven-person minibus version. For reasons such as travel comfort and safety requirements, a few changes related to the construction of the car body should also be set. These include changes in the side walls shape (adding windows), adding next doors and changes in the shape of the roof due to the necessity to implement the emergency exit. The subject concerns the connection of roof cross members to the frame of the hatch located in the roof. It was decided to combine them using special adapters, Fig.1. The production profile should be changed in the least intrusive way to existing devices, control programs and be able to flexibly adapt to current needs [1, 3, 4].

The frame of the hatch will be connected to the intermediate parts by spot welding. The horizontal orientation of the parts and the chamfering of the pipes allow the process to be carried out automatically without major problems. Introducing this process into the existing production plan enables adaptation of the existing empty, two-story cell intended for the introduction of the future model.

The frame is taken directly from the conveyor, while the cross-member must be transported to the other end of the cell on the horizontal conveyor. Then robots equipped with grippers ensuring repeatability of the geometry position, connect elements to the rest of the body. Docked grippers ensures the accuracy of the position of the car parts at least at the level of 0.1 mm. The retooled robots equipped with welding guns perform the resistance welding process. After the process, the bodywork leaves on the skid conveyor.

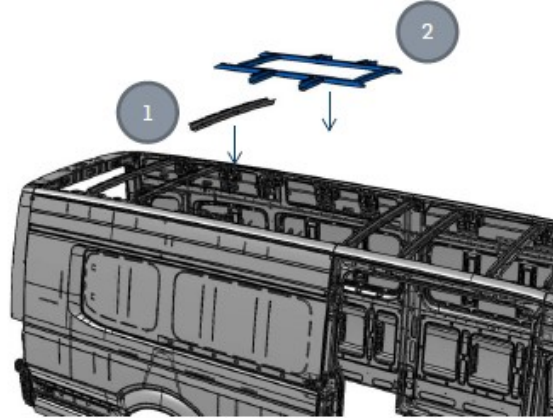


Fig. 1. Marked: 1-Cross member, 2-Frame of the hatch

On the other hand, it is problematic to connect the adapter part with the hatch frame. The Q feeder must already contain roof members assembled with adapters. The appropriate joining method should be chosen, which will meet the strength requirements and the costs of its introduction will not be high. Strength verification will be carried out using the analytical method as well as the computer finite element method. The methods considered are:

- spot welding,
- clinching,
- electric arc welding,
- riveting,
- adhesive joining.

2. Analysis of selected connection methods

This connection will work under the weight of the emergency frame. The shear force is symmetrically distributed over four elements connecting the frame with the two roof cross members. The weight of the element is 86 N. This gives a static load of 21.5 N per one adapter, Fig. 2.

All strength calculations must be based on the principle that the actual stresses must be less or at most equal to the allowable stresses. The yield strength of this material is taken as the basis for the selection of acceptable stresses for plasticity materials. In this case, it is steel with the yield strength of 275 MPa and tensile strength of 500 MPa. In order to obtain more certainty, a safety factor is introduced. The joint will work only under the weight of the manhole, so the calculations will apply to static loads. For steel with constant loads its value for shear loads is assumed to be in the range of 2.5-3. Due to the degree of responsibility, it was taken value of 3. So for steel with a yield strength of 275 MPa, for which the stress value will be calculated will be 92MPa.

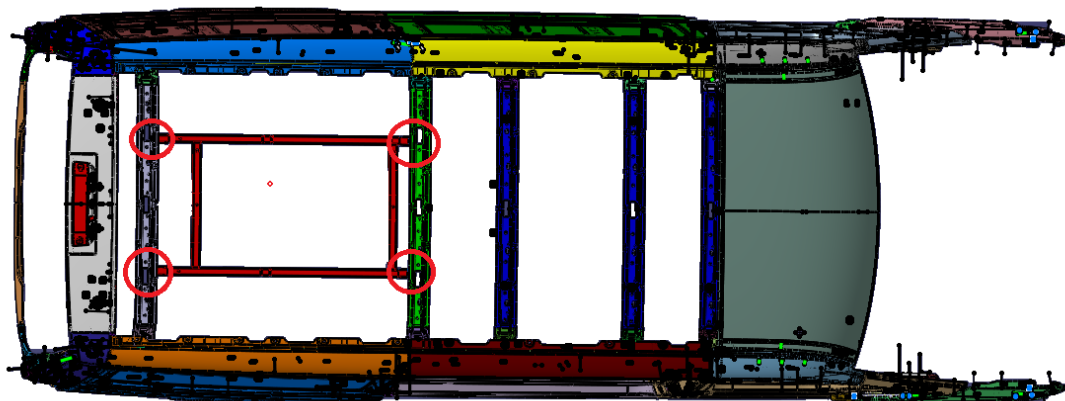


Fig. 2. Marked areas where the gravity of the manhole cuts the adaptation elements

2.1. Arc welded connection

The calculations will be carried out for welds in the areas marked below, Fig. 3. Welding in the direction perpendicular to the modeled welds would be impossible because of the size of the MIG / MAG electrode.

For the designed size of the weld Fig. 4, the size of a one active cross-section area is $A = 12.3 \text{ mm}^2$. Permissible stress for this connection is 64 MPa.

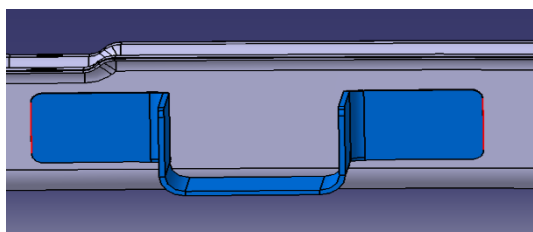


Fig.3. Marked locations of welds

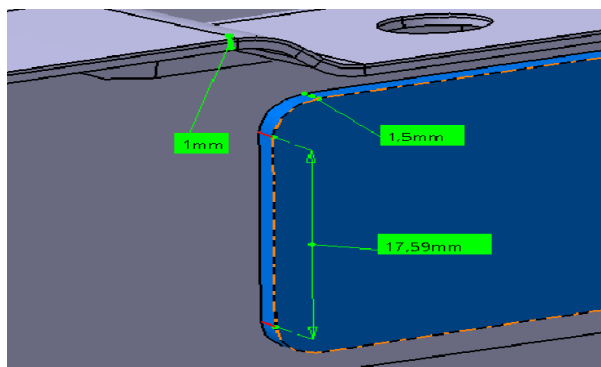


Fig.4. Determining dimensions the size of the weld

2.2. Spot welded connection

The preengineering involved welding in four points on one element, Fig. 5. The PN-EN 74-1: 2006 standard defines the parameters of spot welds in relation to the thickness of the sheets. For class A welds (electronic control welder, adjustable welding conditions, hydraulic or pneumatic clamping of electrodes) for given sheet thicknesses, their diameter is 5 mm.

According to the table contained in the standard, the breaking force of one weld is 2400 N.

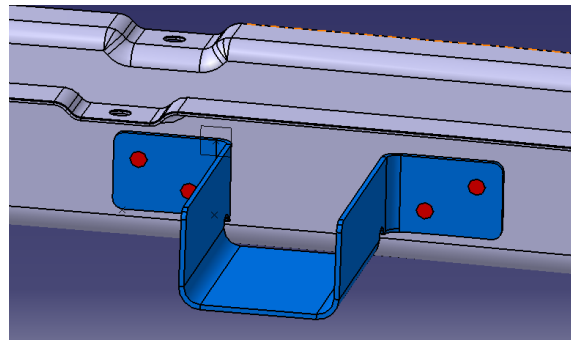


Fig. 5. Adapter welded with roof cross member

2.3. Riveted connection

The riveted connection is also designed as a four-point connection. Precisely at the same points it was planned to use blind rivets (DIN 7337) with a diameter of 5 mm. In strong joints it is use to imply the diameter of rivets as doubled sum of the joint thickness. In addition, according to the design recommendations, the minimum distance of the rivet axis from the edge of the sheet should be $e = 1.6d$. In connection with this guideline, an 8 mm gap from the edge was kept, Fig. 6. For standardized St2N rivets materials tensile strength is from 340 to 420 MPa. In the case of ordinary joints, the lower value of the allowable shear stress is $k_t = 80$ MPa. The calculation of the riveted connection requires, additionally to taking into account also a check of the strength of the surface pressure of the rivet and joining elements.

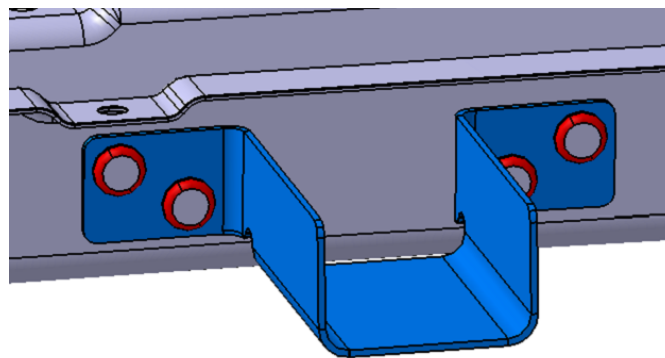


Fig.6. Riveted connection model

2.4. Adhesive connection

Usually, testing adhesive joints, connections are made in the laboratory to simulate structural joints. There are substrates of the same materials, the same adhesive and the same curing cycle are used. Then, strength and other mechanical properties are measured. In the production of presented car's body some elements are combined using a two-component

adhesive based on epoxy resin with an activator. The adhesive has a density of about 0.98 g/cm^3 . The manufacturer declares a shearing strength of $22 \pm 2 \text{ MPa}$ (according to ASTM D 3039). Temperature resistance ranges from -55° to $+120^\circ \text{ C}$. The optimum thickness of the adhesive is $0.05 - 0.2 \text{ mm}$. The thicker layer reduces the strength of the connection, because its destruction occurs through cohesive damage (shearing of the adhesive itself). Designing adhesive connections it should be remembered that the joint should be subjected to shearing forces only. The presence of a normal stresses causing tearing significantly reduces the properties of the connection.

2.5. Clinching

The calculations for the clinched connection were only analyzed using the finite element method. They were modeled according to the of clinch joints used in the production of another vehicle belonging to the same corporation, Fig. 7. The most important parameters determining the strength of the connection are:

- narrowing p : determines the strength of the shear joint; if the p value is too low, the material from the stamp side breaks in the thinnest place,
- overlap z : determines the strength of the transverse tensile joint called plucking, because in the case of normal force the joint is usually disconnected, without violating the material from the side of the punch and die.

Having the parameters p , z and an information on the geometry of the pneumatic Press, using the Generative Shape Design module, a 3D model of the joint was designed, Fig. 8.

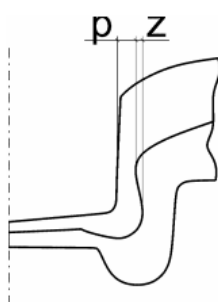


Fig.7. Basic parameters of the clinched joint.

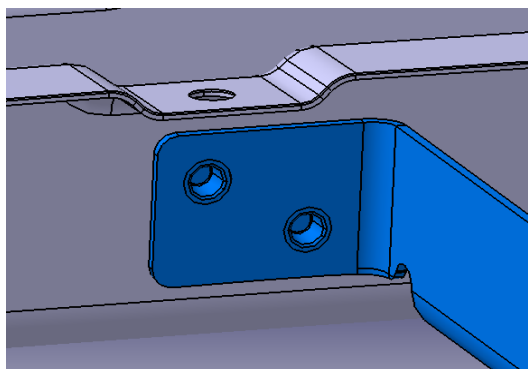


Fig.8. View of the clinched connection model from the punch side

3. Conclusions

The results of analytical calculations clearly indicate that the permanent load applied to the connection is many times lower than the joint strength. However, it can be seen that the rivet connection is several times more resistant to this type of stress. It should also be taken into account that during many years of vehicle using, various situations may arise in which the joint would be loaded with dynamic, impact and thermal loads. The percentage of joint loading for particular connection methods was:

- Arc welding: 1,35%
- Spot welding: 0,9%
- Riveting: 0,22%
- Adhesive joining: 3,95%.

Calculations by the method of finished elements show Tab. 1 and Tab. 2.

Tab. 1. Maximum displacement values under two assumed loads in millimeters

Load	Arc welding	Spot welding	Riveting	Adhesive	Clinching
21,5 N	0,48	0,188	0,223	0,17	0,118
430 N	9,6	3,22	3,39	3,4	1,41

Tab. 2. Maximum stress values under two assumed loads in MPa

Load	Arc welding	Spot welding	Riveting	Adhesive	Clinching
21,5 N	76,1	41,5	109	260	122
430 N	1562	804	166	416	237

Despite the fact that durability tests speak clearly for the use of clinching or gluing, due to the characteristics of the existing production line, it was decided to use traditional joining methods. The analysis shows that joining the considered details by riveting is the most reasonable. The shape of details, strength properties, and a relatively low cost of integration this method are the main arguments for adopting this assumption. The issue under consideration shows that not always modern methods and automation are optimal solutions, even in a modern factory.

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SELECTED ENGINEERING PROBLEMS
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DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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IDENTIFICATION OF THE OPERATIONAL STATE OF THE ROTOR MACHINE USING VIBRATION PARAMETERS MONITORING

Abstract: The article presents a method to identify the operational state of a rotating machine based on vibration symptoms. The tests were performed on the balancing and alignment laboratory stand. In the measurements, acceleration sensors and the IFM VSE100 diagnostic module were used. The measurements were made while maintaining the constant rotational speed of the motor shaft. The diagnosis was based on the vibration values measured from the bearing housings of the shaft (on which discs with the initial imbalance were placed).

1. Introduction

Over the last decades, there has been a significant increase in the functionality of technical means, and hence the complexity of their functions. Such state resulted in the emergence of a new research field, which is technical diagnostics supported by the advanced computer technology. Availability, operational safety, reliability, durability of machines and technical devices used in the production processes are of enormous importance in achieving the economic success of the company [1,3].

Large production losses can be resulted by undesirable damage of technical equipment (leading to consequent downtimes or failures). Appropriate assessment of the technical condition [8,9] of the machine allows to make decisions at particular stages of the lifecycle (the construction, manufacturing and operation phases).

A commonly used form of operational states evaluation is vibration diagnostics, which allows an assessment of the machine's condition by examining the generated vibrations parameters.

The vibrations induce cyclically variable stresses and strains in the machine components. Prolonged exposure to stresses results in exceeding the material fatigue limit and consequently in failures or damages. The described phenomena cause various types of damage [6], such as: malfunctions of impellers, bearings, seals, gears, couplings, screw connections, etc.

In the case of vibration diagnostics, the methods of operational state evaluation may take the following form: measurement of basic vibration parameters in the time domain (a displacement, a velocity or an acceleration), analysis in the frequency domain, folding of vibrations characteristics, analysis of orbit, differential spectrum, Cepstrum or envelope methods.

2. Configuration of the balancing and alignment laboratory stand

The laboratory stand has been mounted on a frame made of aluminum profiles, due to increase a stiffness and reduce a weight. The control panel and a frequency inverter have been mounted on the separate frame.

The electric drive system is based on SEW Eurodrive equipment (an AC three-phase asynchronous motor [2,4] controlled by the Movitrac B frequency inverter). The binary inputs and the external control panel have been connected to the frequency inverter via the RS485 communication interface (remote panel used to set main control commands). To parameterization the Movitools MotionStudio software was used. Figure 1 shows the basic configuration of the complete laboratory stand.

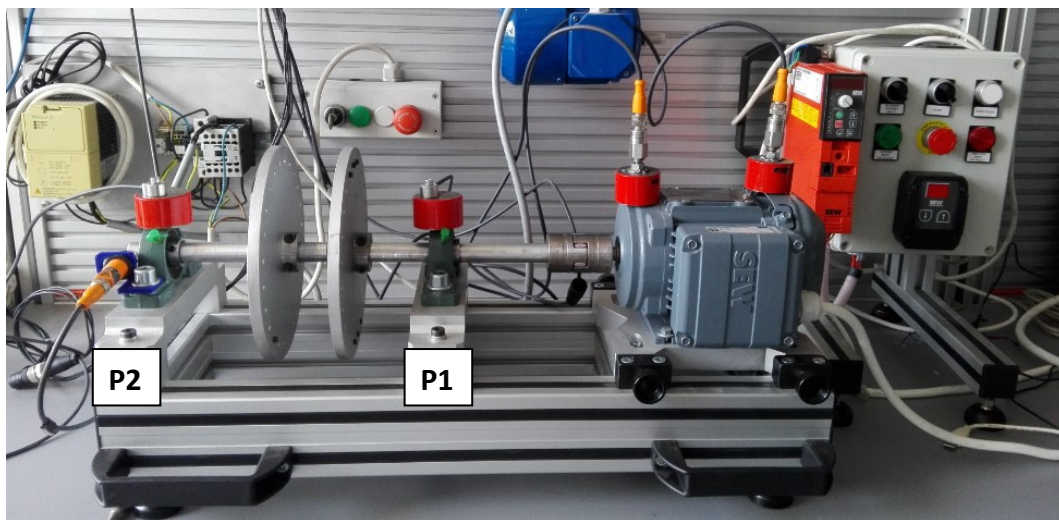


Fig.1. View of the balancing and alignment laboratory stand

The stand was extended with the VSE100 vibration diagnostics module (with VSE001 and VSE004 vibration sensors) and the IFM FR1 speed monitor. The main application of the station is vibration monitoring, resulting from [5]:

- unbalance - simulated by means of discs mounted directly on the shaft, connected with the AC motor by a jaw coupling,
- misalignment of the motor rotor and coupled shaft - regulation of the degree of inaccuracy of angular and radial position of the shafts is possible with the aid of adjustment bolts that allow changing the foundation conditions of the motor (in both horizontal and vertical planes).

3. Parametrization of the VSE100 diagnostic module

The VSE100 module is a main part of the vibration monitoring system. In addition, the module allows for monitoring the vibrations level in order to detect the unbalance of the shaft or even degree of wear of individual bearing components [1,2,6,7].

In order to configure the diagnostic electronics, the IFM VES004 software was used. Usage of high accuracy sensors allows to preserve satisfactory resolution in wide measuring ranges. It is also possible to select different filters for monitoring and machine protection. Up to 32 individual functions provide reliable and repeatable vibration characteristics, as well as performance and undisturbed flow of data (used to optimize machine functioning).

Performing the monitoring and diagnosis processes required a creation of a new project. The program options have been configured for characteristic parameters of used sensors (Fig. 2).

Sensors have been mounted on the left (P2) and right (P1) bearing housing (Fig. 1). The axes of the sensors have been oriented in the vertical direction. The next step was setting the rotational speed value. In the considered case, a fixed speed value was selected (set to 1500 rpm). Such a choice is dictated by the fact that there was no coupling between the analogue output of the vibration diagnostic module and the speed monitor input (only the function of controlling the current speed value on the front panel of the rotational speed monitor has been used).

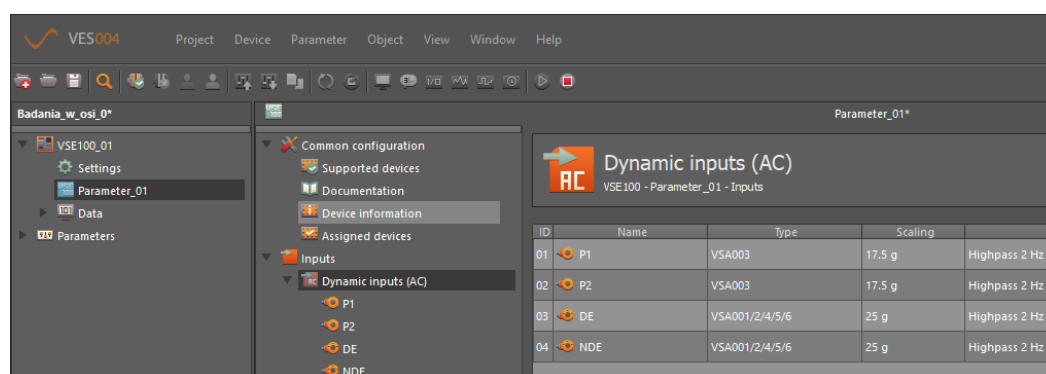


Fig.2. View of the configuration window of sensors connected to the VSE100 module

The last step of the configuration was setting the parameters gathered from the sensors (Fig. 3). In the considered case the RMS (in the frequency domain) and unbalance values (measured from sensors P1 and P2) were chosen.

iD	Name	Type	
01	P1_v_RMS_Freq	v-RMS (frequency domain)	P1 (VSA003, 17.5 g)
02	P2_v_RMS_Freq	v-RMS (frequency domain)	P2 (VSA003, 17.5 g)
03	DE_v_RMS_Freq	v-RMS (frequency domain)	DE (VSA001/2/4/5/6, 25 g)
04	NDE_v_RMS_Freq	v-RMS (frequency domain)	NDE (VSA001/2/4/5/6, 25 g)
05	P1_Unbalance	Unbalance	P1 (VSA003, 17.5 g)
06	P2_Unbalance	Unbalance	P2 (VSA003, 17.5 g)

Fig.3. View of the settings window selected for testing parameters

The tests did not take into account the signals measured from the DE (Drive End) and NDE (Non-Drive End) sensors (mounted on the motor housing).

4. An example of measurement and diagnosis of the laboratory stand

In the first stage, a preliminary analysis of the operational status of the laboratory stand was made. For this purpose, the machine under study was classified into one of the groups defined in the ISO 10816 standard (to define vibration thresholds for initial assessment). The performed measurement of the RMS value (Fig. 4) indicates that the evaluated object was in a condition that enables further work (without the need to implement additional corrective actions).

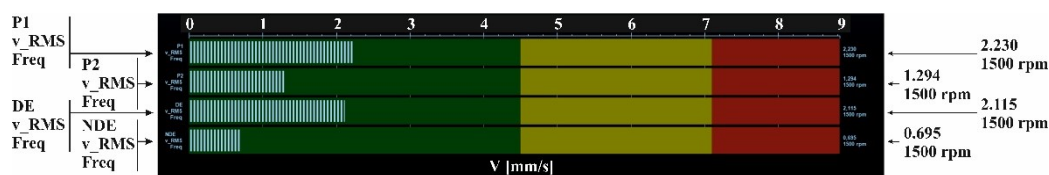


Fig. 4. View of the RMS velocity values (measured on the bearing supports of the tested system)

However, it was decided to improve the parameters determining the quality of the system's operation, which required a diagnosis based on FFT spectra (Fig. 5,6).

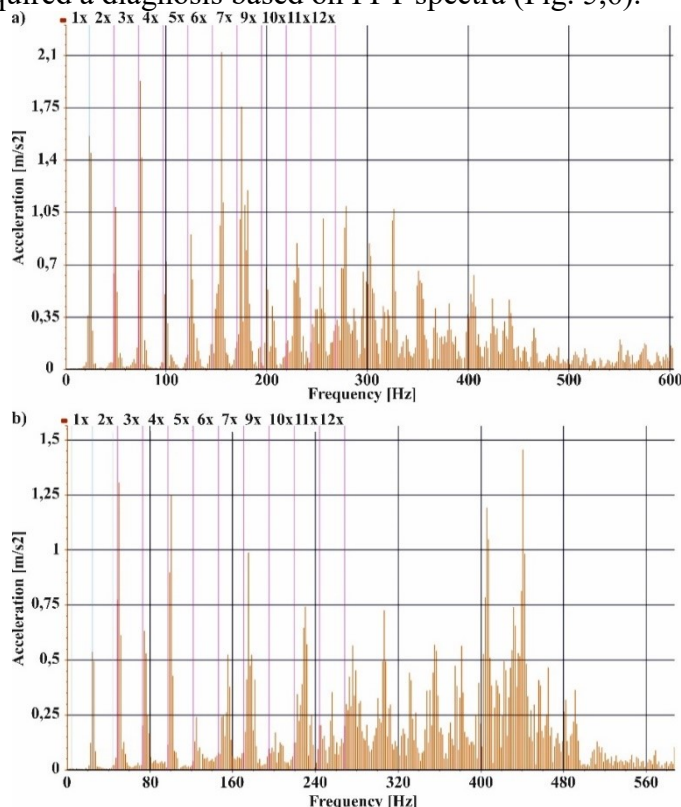


Fig.5. View of the vibration spectrum measured on the bearing support (with visible unbalance symptoms): a) location P1, b) location P2; where: 1x÷12x – harmonics

On the FFT spectra characteristic frequencies of the rotational speed and harmonics of the first frequency component were determined. In the presented case a frequency of the motor rotational speed was equal 25.18 [Hz], which gives directly the value of the rotational speed equals 1510.8 [rpm]. The first diagnosed irregularity was an existing problem with the unbalance of disks mounted on the rotor (Fig. 5).

For the purpose of further analyzes, the amplitudes of vibration accelerations measured in the vertical direction (the sensor axes) were selected. In the analyzed case, the value of acceleration vibration amplitudes were, on the support P1 - 1.558 [m/s^2], and on the support P2 - 0.519 [m/s^2]. The stage of eliminating the unbalance and determining the orientation of fixing the correction mass has been omitted. After corrections improvement (Fig. 6), values of acceleration vibration amplitudes were: on the support P1 - 0.138 [m/s^2], on the support P2 - 0.077 [m/s^2].

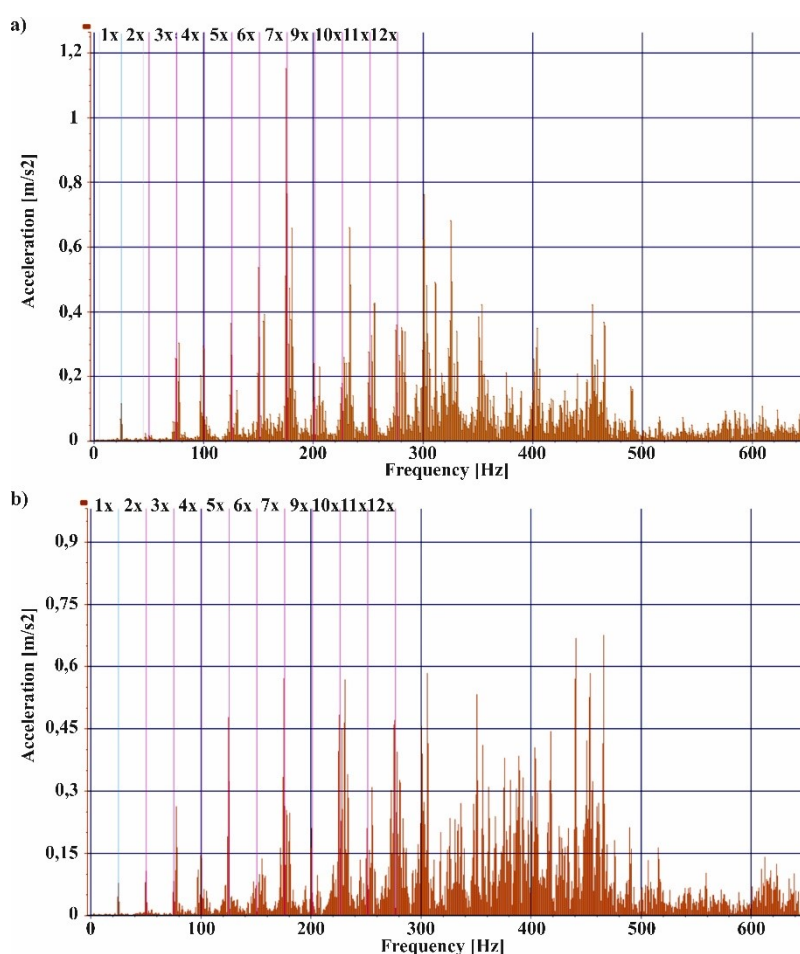


Fig. 6. View of the vibration spectrum measured on the bearing support (with removed unbalance state): a) location P1, b) location P2; where: 1x÷12x - harmonics

Such prepared laboratory stand will be used for further research including the impact of mechanical vibrations on the condition of rotating machines. The laboratory stand has been stripped of the discs burden, which resulted in elimination of large values of dynamic forces.

5. Conclusions

The FFT spectrum analysis allows to the identification of a deterioration rate of the machine's condition (with simultaneous detection based on the identification of the source of harmonic frequencies and amplitudes of vibration in the specified frequency range). The advantages of vibration parameters evaluation are achievement of the full failures selectivity and a large number of technical standards. Due to the structure of considered technical devices each analysis can be performed on different level of complexity.

Overall the vibration monitoring is performed on the basis of separate configurations of measuring systems: continuous on-line monitoring systems (large, small and medium-size machines), systems of periodic monitoring or ad-hoc methods (diagnosis in the offline mode) and diagnostic centres.

The advantages of evaluating vibration parameters are [5]: obtaining full selectivity of identifiable damages, large number of technical standards (identifying criteria for the assessment of the technical condition of machinery and measurement procedures), measurements in a wide range of rotational speeds, defined and well-described measuring procedures [1,2].

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DEPARTMENT OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

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REVIEW OF THE POSSIBILITIES OF USING UNMANNED AIRCRAFT

Abstract: This article presents the possibilities of using unmanned aircraft for transport and inspection purposes. The article is a kind of introduction to the subject of aircraft, which are developed more in the article titled "Analysis of the possibility of using autonomous aircraft to deliver parcels - route optimization".

1. Introduction

Nowadays, the popularity and interest in courier services among customers is constantly growing. This is the reason for introducing new or improving current services by courier companies to the market.

The main idea of the courier service has been the same for many years - fast picking up the parcel from the sender and delivering it to the recipient in the shortest possible time. In these days, information systems for shipment tracking are not enough, now the latest trend is the implementation of autonomous aircraft carrying out the delivery process itself.

In the last few years, the costs of electronic components and their minimization have resulted in a significant increase in the use of so-called drones. The production of more efficient batteries with shorter charging times and less mass increased the flight time and enabled the transport of more shipments.

In this article, the author will present current trends related to the use of unmanned aerial vehicles for inspection purposes and as systems supporting the delivery of goods. The main goal of current research is to optimize the operational parameters of such a system, consisting in shortening delivery time, planning a collision-free path, choosing a safe height or minimizing energy consumption are key parameters that should be subjected to detailed analysis.

2. Possibilities of using unmanned aerial vehicles

By word drone it is determined an unmanned airship, remotely controlled or operating autonomously. The first devices of this type were created and tested since the First World War in the form of maneuvering missiles. An example of such construction solutions can be maneuvering missiles with a jet propulsion marked as V-1. Currently used IT techniques and the development of engineering thought have resulted in the creation of innovative techniques for targeting and controlling the trajectory of unmanned airships.

The difference between the currently used drones and the maneuvering missiles mentioned above depended mainly on this that the latter could be used repeatedly. The controlled maneuvering missiles were often used to learn and train anti-aircraft units and were usually not reused.

In the old days, war was won mainly by parties that had a significant and larger well-equipped army. Currently, apart from the number of fighting soldiers, what counts above all is modern innovative equipment, which can undoubtedly include the unmanned airships, which are currently equipped with technical solutions, e.g. for detecting the enemy on the basis of monitoring or programs for computer identification of objects with elements of artificial intelligence.

Works concerning the identification and control of objects are carried out by numerous scientific and research units around the world. Particularly noteworthy are the work of Professor Ivan Gostev [1,2], scientist of the National Research University Higher School of Economics, Faculty of Business Informatics, from Moscow. His most important works concern:

- Pattern Recognition,
- Signal, Image and Video Processing,
- Image Segmentation,
- Image Recognition, and others.

The image can be recorded directly from monitoring using high resolution cameras, satellites or drones. Despite the fact that airships called drones were reserved exclusively for military purposes, the drones are now very often used in the civil sphere. Currently, mainly civilian applications of drones include:

- taking pictures from above,
- monitoring of hard to reach places and areas,
- specialized measurements and analyzes of particularly hazardous chemicals, including very popular measurements of air pollution. Thanks to these measurements, numerous smog maps are created in areas particularly at risk of this phenomenon,
- inspection flights, for example construction infrastructure, roads, bridges, high chimneys.

The use of drones contains a very wide spectrum of possibilities, and the only limit is the resourcefulness of constructors and designers.

Leading the review of the literature concerning the civilian applications of the drones, there have been noticed numerous innovative designs. The most interesting include the project of doctoral student Alec Momont from Delft University of Technology entitled "Flying defibrillator". Design of an unmanned, autonomously navigating flying drone that can quickly deliver a defibrillator where it is needed [5].



Fig. 1. Dron ambulanse [5]

On Fig. 1, there is shown the drone prototype that can quickly deliver a defibrillator to the place of an accident, finds the location of the patient using the caller's cell phone signal and reaches it using the GPS location. Another solution is the Iranian project Pars [2], dedicated for use in water rescue. The main purpose is to transport rescue equipment to drowning people.



Fig. 2. Pars robot developed by RTS Ideas in Iran [3]

The next type of modern drones are the drones for transporting parcels and packages at courier companies. This application was the reason to undertake scientific research on the analysis and the possibility of optimizing the trajectories of the unmanned airships. At amazon.com, an American online sales company, you can read about the ongoing research on this application.

At the largest Polish technical universities [4], there continue works and projects related to the modernization and optimization of technical parameters of the unmanned airships. The Silesian University of Technology present in this group can boast of great

achievements in this field: there was constructed, among others, a drone for search and rescue missions.



Fig. 3. Drone of the team of the Silesian University of Technology [4]

Built by the High Flyers team from the Silesian University of Technology, the drone took fifth place in the international UAV Challenge Medical Express competition. The main task of the competition was to carry out a search and rescue mission and transport the patient's blood sample. At the Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Faculty Of Mechanical Engineering, the Silesian University of Technology undertakes research related to the automation of industrial systems and intelligent systems. The Institute's researchers also cooperate in other foreign centers [1,2]. This article is part of the work carried out by the author on the study of the autonomous airships working as a parcel delivery system in an urban environment.

3. Conclusions

This article should be considered as a literature review on the current use of unmanned aerial vehicles. It is an introduction to another article, published in the International Journal of Modern Manufacturing Technologies in 2019 under the title "Analysis of the possibility of using autonomous aircraft to deliver parcels - route optimization", in which the authors discuss topics related to optimization of the flight route, minimizing energy consumption, minimizing the weight of the device.

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