

Міністерство освіти і науки України
 Національний технічний університет
 «Дніпровська політехніка»
 Інститут Електроенергетики
 (інститут)
 Електротехнічний факультет
 (факультет)
 Кафедра електропривода
 (повна назва)

ПОЯСНЮВАЛЬНА ЗАПИСКА

кваліфікаційної роботи ступеню *бакалавра*
 (бакалавра, спеціаліста, магістра)

Студента Рубана Дениса Сергійовича
 (ПІБ)
 академічної групи ЕМ-15-2
 (шифр)
 галузь знань 0507 електротехніка та електромеханіка
 (шифр і назва галузі знань)
 напрям підготовки 6.05070204 «Електромеханіка»
 (код і назва напряму підготовки)
 кваліфікація фахівець у галузі електромеханіки
 (код і назва кваліфікації)
 на тему Розробка автоматизованої системи керування виконавчим органом клепальної машини
 (назва за наказом ректора)

Керівники	Прізвище, ініціали	Оцінка за шкалою		Підпис
		рейтинговою	інституційною	
кваліфікаційної роботи	Балахонцев О.В.			
розділів: 1,2,3,4	Балахонцев О.В.			
5	Лутс І.О.			
6	Дементьєва Н.В.			

Рецензент	Рогоза М.В.			
-----------	----------------	--	--	--

Нормоконтролер	Казачковський М.М.			
----------------	-----------------------	--	--	--

Дніпро

2019

									Арк.
									1
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				

ЗАТВЕРДЖЕНО:

завідувач кафедри

електропривода

(повна назва)

_____ Казачковський М.М.

(підпис) (прізвище, ініціали)

« _____ » _____ 2019 року

ЗАВДАННЯ

на кваліфікаційну роботу

ступеня бакалавра

(бакалавра, спеціаліста, магістра)

студенту Рубану Денису Сергійовичу академічної групи ЕМ-15-2
(прізвище та ініціали) (шифр)

галузь знань 0507 електротехніка та електромеханіка
(шифр і назва галузі знань)

напрямок підготовки 6.05070204 «Електромеханіка»
(код і назва напрямку підготовки)

кваліфікація фахівець у галузі електромеханіки
(код і назва кваліфікації)

на тему Розробка автоматизованої системи керування виконавчим органом клепальної машини

затверджену наказом ректора НТУ «Дніпровська політехніка» від _____ № _____

Розділ	Зміст	Термін виконання
1	Technological part	
2	Concept design	
3	Software implementation	
4	Hardware implementation	
5	Occupational health	
6	Technical and economical evaluation	

Завдання видано _____ Балахонцев О.В.

(підпис керівника) (прізвище, ініціали)

Дата видачі 15 жовтня 2018

Дата подання до екзаменаційної комісії _____

Прийнято до виконання _____ Рубан Д.С.

(підпис студента) (прізвище, ініціали)

									Арк.
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				2

Реферат

Пояснювальна записка: 55 стор., 23 рис., 7 табл., 9 джерел, 4 листа графічної частини.

Об'єкт детальної розробки: Розробка автоматизованої системи керування виконавчим органом клепальної машини

Мета роботи: надбання необхідних навичок по технічному рішенню завдань при проектуванні системи автоматизованого керування електроприводу.

В проєкті зроблений аналіз заходів щодо модернізації та автоматизації лінії виробництва та розробка виконавчого органу клепальної машини

Виконаний розрахунок системи автоматичного регулювання і проведене дослідження динаміки електромеханічної системи.

Виконана розробка програмного забезпечення для керування клепальною машиною з трьома можливими режимами роботи.

Розроблені заходи щодо охорони праці на виробництві.

Доведена економічна ефективність впровадження технічних рішень.

КЛЕПАЛЬНА МАШИНА, ГІБРИДНИЙ ДВИГУН,
ПРОГРАМОВАНИЙ ЛОГІЧНИЙ КОМП'ЮТЕР

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
						3
Зм.	Арк.	№ докум.	Підпис	Дата		

Abstract

Explanatory note: 55 pages, 23 figures, 7 tables, 9 sources, 4 sheets of the graphic part.

The object of detailed development: Development of an automated control system of the manipulating part of riveting machine

Purpose: to acquire the necessary skills for the technical solution of tasks when designing the system of automated control of the electric drive.

The project analyzes measures for modernization and automation of the production line and development of the manipulating part of the riveting machine.

The calculation of the automatic control system was carried out and the dynamics of the electromechanical system was studied.

The development of software for controlling a riveting machine with three possible modes of work is executed.

Work on occupational safety at work is being developed.
The economic efficiency of implementation of technical solutions is proved.

CUTTING MACHINE, HYBRID ENGINE,
PROGRAMED LOGIC COMPUTER

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		4

Contents

Introduction.....	6
<u>1. Technological Part</u>	7
<u>1.1. Analysis</u>	7
<u>1.2. Requirement Determination</u>	8
<u>1.3. Power calculation</u>	9
<u>1.4. The input data for the design</u>	10
<u>2. Concept Design</u>	12
<u>2.1. General construction</u>	12
<u>2.2. Engine selection</u>	15
<u>2.3. Selection and description of the control circuit</u>	18
<u>3. Software Implementation</u>	21
<u>3.1. Concept Analysis in Simulation</u>	27
<u>4. Hardware Implementation</u>	29
<u>4.1. Mechanical Implementation</u>	29
<u>4.2. Controlling system Implementation</u>	31
<u>4.3. Test of the System</u>	34
<u>5. Occupational Health</u>	36
<u>5.1. Danger and harmful factors analysis</u>	36
<u>5.2. Engineering and technical measures for occupational safety</u>	36
<u>5.3. Fire Security</u>	40
<u>5.4. Emergency measures</u>	41
<u>6. Technical And Economic Evaluation</u>	42
<u>Introduction</u>	42
<u>6.1. Calculation of capital investments</u>	42
<u>6.2. Calculation of operating costs</u>	46
<u>6.3 Determination of annual savings from the project implementation</u>	49
<u>Conclusion</u>	52
<u>Bibliography</u>	53

Introduction

The purpose of the diploma project is to acquire the necessary skills for the technical solution of tasks when designing an automated electric drive system.

The aim of the current development is the development of automatic rivet transfer equipment using a linear motion system and a PLC controller for a riveting machine.

The objectives of this project are:

1. Choosing the method and object of programming.
2. Design of the mechanical part of the installation
3. Creation of the model of automation of the electric drive;
4. Calculation of technical and economic efficiency from the application of the developed system.

The rivet is picked by an electromagnetic picking device and punched by an air cylinder. The main objects of the equipment are to feed the rivet and transport it from the feeding station to the riveting position. To implement this system, a linear motion system, a rivet feeding unit with an appropriate sensor and a controller program for a PLC controller were developed.

						Арк.
						6
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	

1. TECHNOLOGICAL PART

1.1. Analysis

The main objects are to feed the rivet and transport it from the feeding station to the riveting position. As it is mentioned in the introduction, a linear motion system, a rivet feeding unit with an appropriate sensor and a controller program for a PLC controller were developed for the implementation of this equipment. In the future, it would be used for the process of taking a rivet from an additional production line for installation on a leather product located on the main production line. Under the condition of the course project, a task that is directly related to the electric drive control systems under industrial production conditions will be performed.

The process was organized as state machine shown on Table 1.1.

Table 1.1

No	States	Explanation
1	SInit	This state is switching on after running machine. Main motor goes to the initial position(left position) until SensorLeft will be equal to 1.
2	SReady	This state is switching on after placing motor on the initial position. The program will keep itself in this state until the start button on the control panel will be pressed.
3	SMoving1	After pressing the start button, motor will initiate the motion to the rivet pick-up position. Motor1 will operate until SensorRigth will be pressed.
4	SX1	After pressing SensorRight, Motor1 will stop and the inductive SensorRivet will check the rivet. It will keep itself in this state until SensorRivet will be TRUE, what means that there is a rivet on the right place.
5	STakeRivet	After obtaining the signal from SensorRivet, program will switch on the Magnet to pick up the rivet.
6	SMoving2	After Magnet activation, program will wait 1 second and will initiate motion to the initial position. Motor1(Inv) will operate until SensorLeft will be pressed.

									Арк.
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				7

7	SX0	After pressing SensorLeft, Motor1 will stop. As far as we can not stop motor immediately, program will wait during 1 second for motion interruption.
8	Punch	After stopping the Motor1, program activates the puncher to fix the rivet on the product(leather belt etc.)
9	MoveBelt	After rivet punching, Motor2 will be activated to change position of product for installation of the next rivet. The Magnet will be switched off. Program will be set to the state SReady.
10	STOP	Emergency stop state in which the system shuts down all engines, except Magnet. The transition to this state is possible at any moment of the cycle by pressing STOP, and the exit from it occurs after pressing the start button, which will set program to the state SInit.

The designed process and its details for the unit

1.2.Requirement Determination

The requirements for the robot-manipulator electric drives, in accordance with the requirements of modern technology, must meet the following technical requirements:

Due to the severe operating conditions in robot manipulators, as a rule, stepper motors are used. Therefore, some specific properties of the robot should be noted:

- As electric motors of the robotic arm, special electric machines should be applied, taking into account the peculiarities and the operation of this mechanism;
- The most important feature of the engines is high starting points;
- The electric motor must correspond to overloads that can occur during operation, which, if the product is jammed, can lead to an extended short circuit of the electric motor;
- In assessing the specific operating conditions of a robot, severe environmental conditions should be considered. Electric motors are often subjected to strong heat radiation from gas-flame cutting of the product;

						Арк.
						8
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	

—The electric drive must be adapted to work in the complex automation system of the entire system.[\[2\]](#)

Considering the listed features and technological requirements for controlling the robot manipulator, the electric drive must have high speed and increased overload capacity. Control discrete or analog signals of various command devices; It should provide reliable protection of equipment in emergency modes. The use of specialized robotic equipment provides:

—Improve the reliability of the cutting workshop;

—Reduction of defective items;

—Reduction of energy consumption while complying with all technological requirements[\[3\]](#)

1.3. Power calculation

According to the project condition, the acceleration of the manipulator should be 0.4 m / s^2 . The total mass of the activator, electromagnet and design is measured and is equal to 5.6 kilograms. For convenience in the calculations, it will be taken rounded up and equal to 6 kg. Based on this:

$$F = 6 \times 0,4 = 2,4 \text{ N}$$

If we take the friction coefficient of 0.15, then the resultant force will be

$$Fr = 2,4 \times 1.15 = 2,76 \approx 2.8 \text{ N}$$

The shoulder of force in this case will be the radius of the spiral shaft.

$$R = 10 \text{ mm}$$

Based on this

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		9

$$T=2,8 \cdot 0,01=0.028 \text{ Nm}$$

$$P = T \times \omega$$

$$P = 0.028 \times 300 = 8.28 \text{ W}$$

1.4. The input data for the design

Under the terms of the project, a Raspberry Pi programmable logic computer with a shield developed at Reutlingen University will be used. CODESYS 3.5 SP12, which is a development environment for programming controller applications according to IEC 61131-3, is used as the programming area on Windows 10 (64 bit). As the main realisation instrument, Structure Text programming language was chosen. Structured Text is PLC programming language defined by PLCOpen in IEC 61131-3 and it is text-based, compared to the graphics-based ladder diagram or Function Block Diagram. [7]

A stepper motor (Hybrid NEMA 23) is used for the linear motion system and the motor driver (SMCI36) controls the motor. Autodesk Inventor Professional 2019 (64 bit) is chosen as CAD software for mechanical design. Mechanical parts which needed machining are mainly made with a milling machine or a drilling machine. Table 1.2 shows all the required devices, systems and tools for the project.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		10

Table 1.2

Required devices, systems and tools

Task	Requirement
System environment construction	Windows 10 (64 bit) , CODESYS 3.5 SP12, Raspberry Pi 3
Coding	Structured Text
Software simulation	CODESYS V3.5 SP12
Sensor	Push button switch (x2), Inductive sensor
Motor	103-H7123-5040 / NEMA23
Driver	SMCI36
Mechanical design	Autodesk Inventor Professional 2019(64 bit)
Machining, Assembling	Drilling machine, Milling machine

2. CONCEPT DESIGN

2.1.General construction

The equipment consists of a linear motion system, an electromagnet, an air cylinder, a punching unit, a rivet feeding unit and a leather belt fixing as mechanical parts. The punching unit has two segments. The basement part is fixed by fixing blocks which positions can be adjusted by bolts. The linear system is mounted on an angle section and it has a slot where a leather belt can go through. The overview of the riveting machine is shown in Figure 2.1.

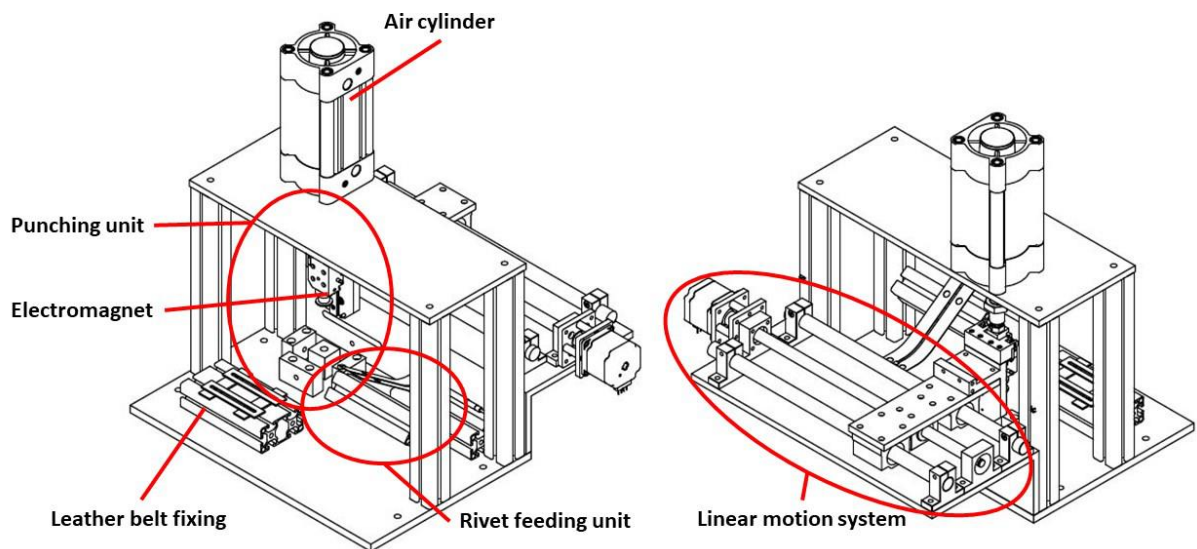


Figure 2.1: Overview of the rivet transfer equipment

The linear motion system is operated by PLC controller and two push button switches are used as sensors to detect the punching unit position and they are mounted on the right and left side on the unit. The rivet feeding unit has adjustable slopes where rivets can slip along and a inductive sensor to check the rivet at the picking up position.

Figure 2.2 shows the image of the concept design.

									Арк.	
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ					12

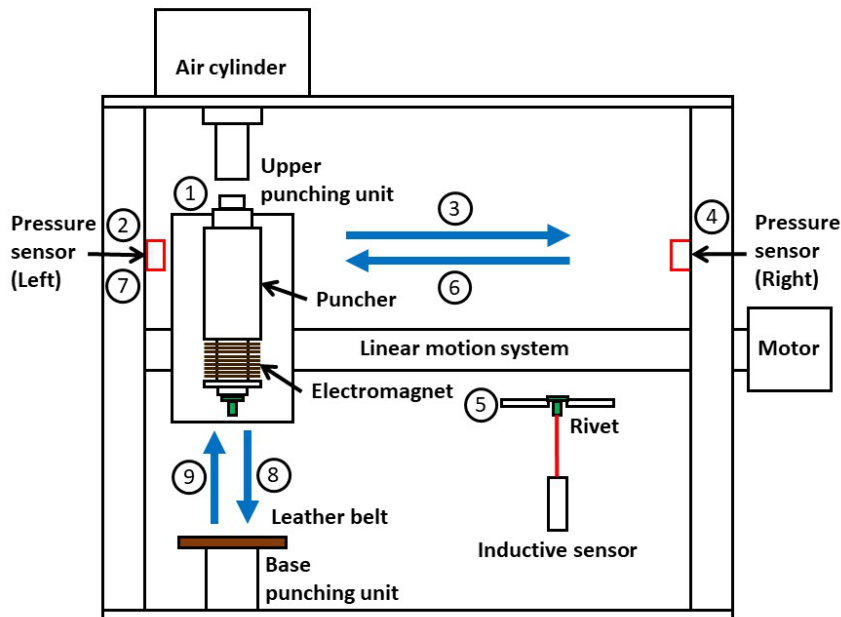


Figure 2.2: Concept Design Image

As the Table 1.1 shows the statements, firstly, the punching unit is set on using a sensor and operated with a control panel on CODESYS. The initial position is the riveting position at the same time. Once the start button was pressed, the linear motion system starts running and the upper punching unit goes to the rivet picking up position. The sensor on the right side will be pushed and its signal will stop the motor rotation. The inductive sensor detects if a rivet is at the right position to be picked up then send a signal to PLC controller. When the rivet is at the right place, the electromagnet will be turned on and pick up the rivet. After a second, the linear system will start working again then it transfers the punching unit with the rivet to the riveting position. The judgment for the riveting position is again done by the sensor on the left. If it is at the riveting position correctly, the program stops the motor and activates the puncher to fix the rivet on the product such as a leather belt. Immediately after the punching, the magnet will be switched off and the program will be settled to the first status. In addition, there is an emergency switch which can stop the system at any moment.

The unit dimensions are approximately W531 x L490 x H534 [mm] including the height of the air cylinder. The four-view drawing is shown on Figure 2.3.

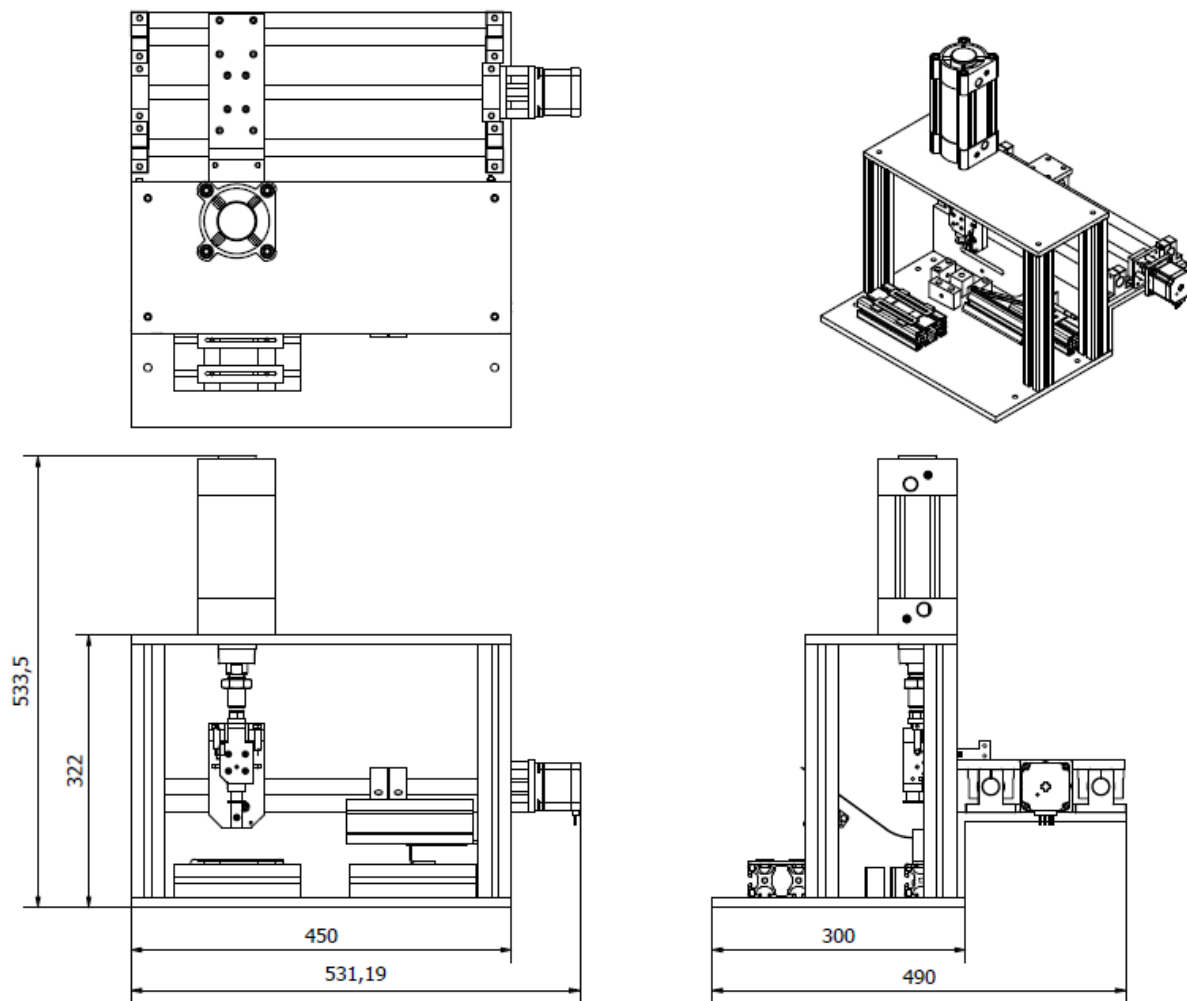
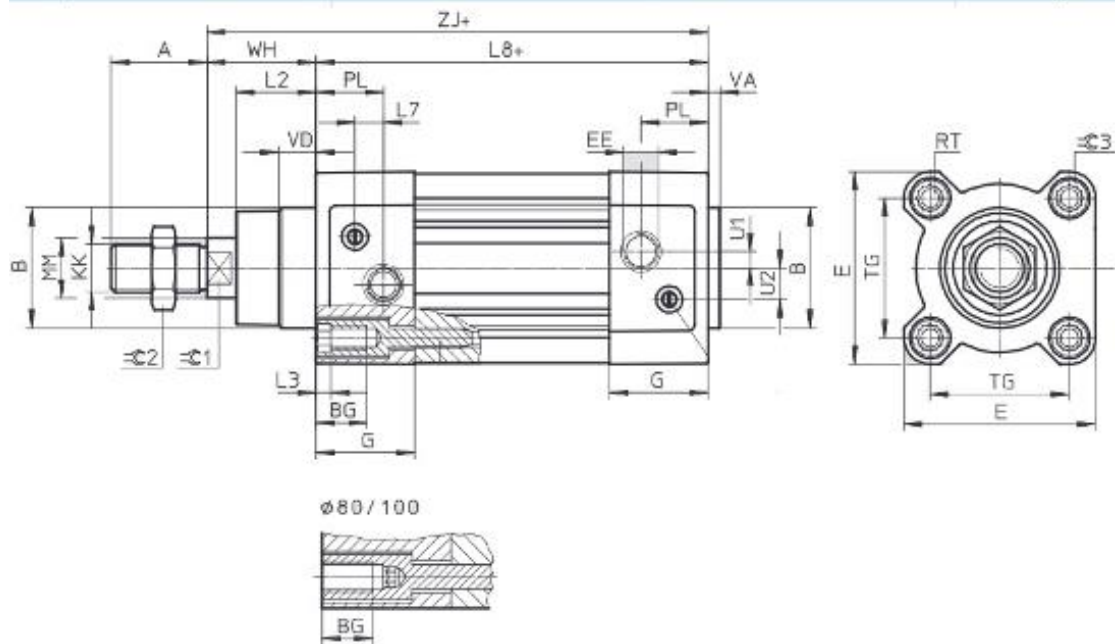


Figure 2.3: Four-view drawing with dimensions

The DSBC pneumatic cylinder series is the latest development of German pneumatic engineers. It differs from the previous series (such as DNC, DNT, DNCB) with a new aluminum profile, as well as with the design of the sealing and damping units, which will increase their service life and time between repairs. All of them are made according to the same ISO 6431 standard, therefore all sizes of the new series coincide with their predecessors.

Please note that only end position sensors of the SME / SMT-8M series (mounting from above) are suitable for DSBC cylinders.

									Арк.
									14
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				



2.4 Dimensions of FESTO dsbc-80-80-ppva-n3 pneumatic cylinder [4]

2.2. Engine selection

The project provides for a specific list of requirements set for the engine:

- high positioning accuracy
- large speed range
- low response time

Based on these conditions, it was decided to use a stepper hybrid engine, since it fully satisfies the specified conditions.

Hybrid engines are subspecies of stepper motors and are more expensive than permanent magnet motors, but they provide a smaller step size, greater torque and greater speed. The typical number of steps per revolution for hybrid engines is from 100 to 400 (the pitch angle is 3.6 - 0.9 degrees). Hybrid engines combine the best features of variable magnetic resistance and permanent magnet motors. The rotor of the hybrid engine has teeth located in the axial direction (Fig. 2.5). [8]

						Арк.
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	15

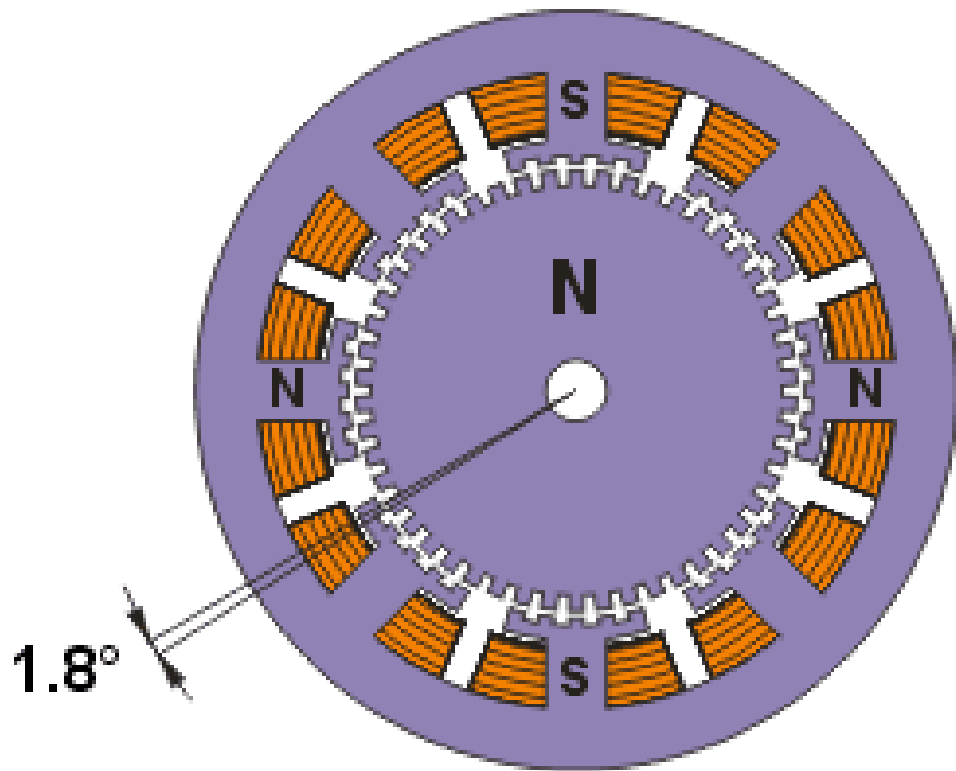


Fig. 2.5 Hybrid engine

Disadvantages of a stepper motor:

1. stepping motor inherent resonance phenomenon
2. possible loss of position control due to work without feedback
3. energy consumption does not decrease even without load
4. difficult work at high speeds
5. low power density
6. relatively complex control scheme

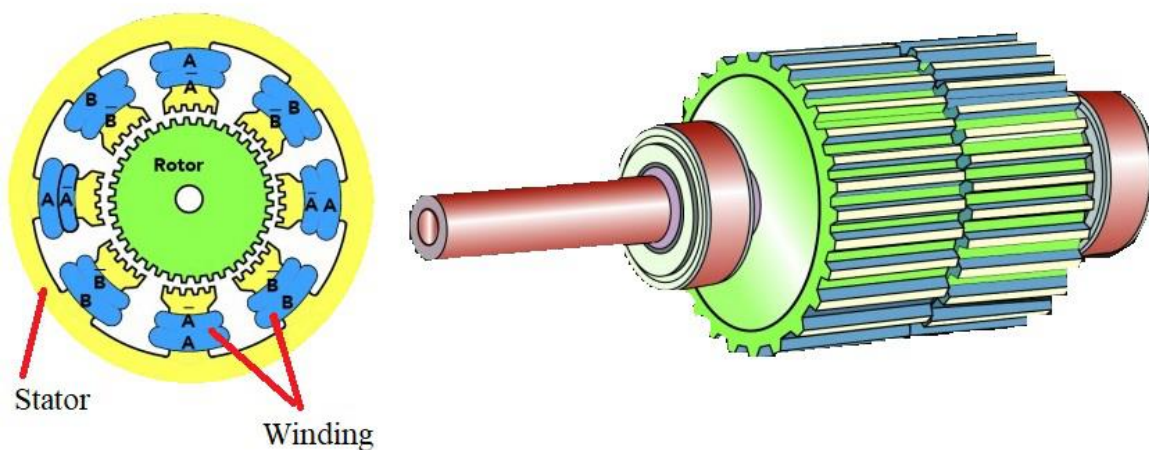
Advantages of a stepper motor:

1. the rotation angle of the rotor is determined by the number of pulses that are applied to the engine
2. motor provides full moment in stop mode (if windings are energized)

3. precision positioning and repeatability. Good stepper motors have an accuracy of 3 to 5% of the step size. This error does not accumulate from step to step.
4. possibility of quick start / stop / reversal
5. high reliability associated with the absence of brushes, the life of the stepper motor is actually determined by the life of the bearings
6. unambiguous dependence of position on input pulses provides positioning without feedback
7. the possibility of obtaining very low rotational speeds for a load attached directly to the motor shaft without an intermediate gearbox
8. a rather large speed range can be covered, the speed is proportional to the frequency of the input pulses

Hybrid stepper motors combine aspects of both permanent magnet (PM) and variable reluctance (VR) stepper motors. Like PM motors, they contain a permanent magnet in the rotor teeth. Two sets of teeth called cups ring the rotor. One ring is all south poles, and the other ring is all north poles.

Like VR motors, hybrid stepper motors have stator poles. Note that stator poles in hybrid motors are sometimes called teeth.



Stepper motor stator (with windings) and rotor (with two sets of teeth)

Fig. 2.6

To illustrate how these motors work, consider a 1.8° hybrid stepper. The teeth of one ring are offset from those on the other ring by 3.6°. The stator poles are offset by 90° and these are opposite polarity, so that every 180° the stator poles are in identical polarity. The rotor poles exist in sets of four, with two being north poles and two being south poles. The rotor poles align alternately with the rotor’s teeth and cups, so that one set of rotor poles attracts fully while the other attracts and repels $\frac{3}{4}$, $\frac{1}{2}$ or $\frac{1}{4}$ of a tooth. If there are 50 teeth, the pitch angle is 7.2° ... so at the next step, the motor rotates to the next closest step, which is $7.2^\circ \times \frac{1}{4} = 1.8^\circ$.

When the current changes, the rotor can turn a very small amount—an improvement over basic PM motors and VR motors. Newer control techniques such as half-stepping and microstepping let designers get even finer movements of rotation, which make for more exact output than that from VR stepper motors (which can’t usually be microstepped). Hybrid stepper motors also have higher torque-to-size ratios and higher output speeds than other stepper-motor types. They are also quieter than VR stepper motors.[\[9\]](#)

Based on the calculated load on the shaft, an approximate calculation of the motor speed and the size of the installation, a ready-made solution was chosen, namely the engine 103-H7123-5040 / NEMA23

2.3.Selection and description of the control circuit

There are two main ways to control stepper motors:

The first method is provided by alternating switching of phases, while they do not overlap, only one phase is switched on at a time (Fig. 2.6 A). This method is called “one phase on” full step or wave drive mode. The equilibrium points of the rotor for each step coincide with the “natural” equilibrium points of the rotor in an unpowered engine. The disadvantage of this control method is that 50% of the windings are used for the bipolar motor at the same time, and only 25% for the unipolar motor. This means that in this mode the full moment cannot be obtained.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		18

The second method is overlapping phase control: two phases are switched on at the same time. It is called “two-phase-on” full step or just full step mode. With this method of control, the rotor is fixed at intermediate positions between the stator poles (Fig. 2.6 B) and provides approximately 40% more torque than in the case of a single switched on phase. This control method provides the same pitch angle as the first method, but the position of the equilibrium points of the rotor is offset by half a step.

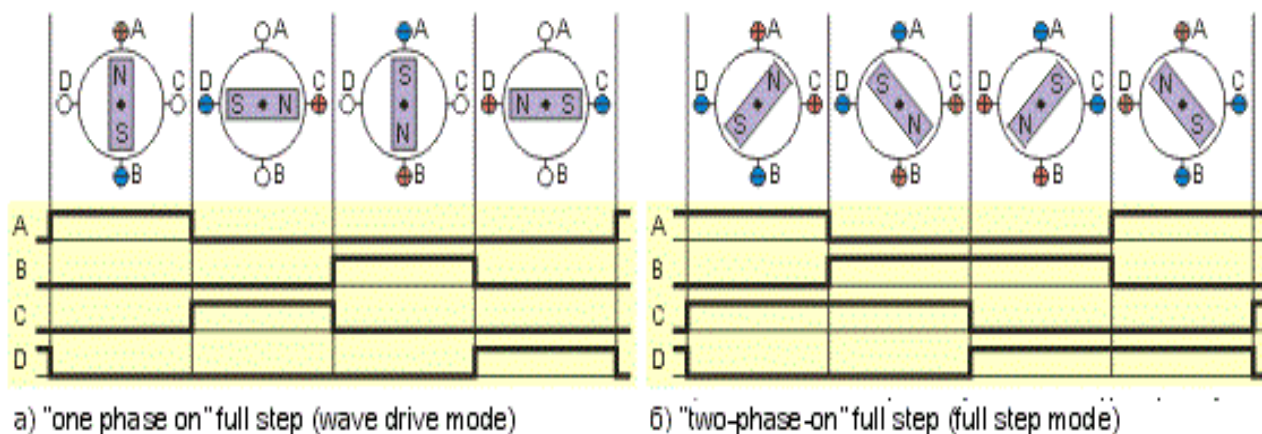


Fig. 2.7 Control modes of stepper motors

For a series of NEMA engines manufactured by Nanotec, there is a special controller SMCI36 developed by the same company. In order to avoid problems associated with the connection between the engine and the control board, a ready-made solution proposed by Nanotec was used.

Motor controller SMCI36 is an extremely compact and cost-effective constant current final output stage with integrated closed loop current control. Due to the great capacity and functions available, it offers designers and developers a rapid and simple method of resolving numerous drive requirements with less programming effort. It is used for controlling standard stepper motors (including with attached encoders) or motors with an integrated encoder. BLDC motors are also supported. The SMCI36 is ideal for device installation due to its open, economical design.

						Арк.
						19
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	

3. SOFTWARE IMPLEMENTATION

For full understanding of the processes occurring in the executed program, it is necessary to become familiar with the table of variables and their functionality. Table 3.1 shows the variables.

Table 3.1

Variables of state machine

	Name	Type	Functionality
Inputs	boStop	Button	Interrupts the cycle at any stage and sets the initial state
	boButton	Button	Starts the next cycle
	boSensorLeft	Button	Limit left position sensor
	boSensorRight	Button	Limit right position sensor
	boSensorRivet	Inductive sensor	Rivet presence sensor on the additional production line
Outputs	boDrive1	Driver SMCI36(digital)	Motion to the right side
	boDrive1Direction	Driver SMCI36(digital)	Change the direction of Drive1
	boDrive2	unknown(digital)	
	boMagnet	Digital	Magnet for taking a rivet
	boPuncher	Digital	Activator

General process was executed as a cycle with the possibility of an emergency interruption.

When starting the PLC, the program gets into the SInit state, in which the D1 Motor is powered, and the variable Drive1Direction receives a logical unit, as a result of which the motor starts moving to the left side of the stand. This state persists until pressing the left end-switch. Pressing this switch means that the motor has arrived in the extreme left position and is ready to start the cycle. After

this, the program goes into the SReady state.

In this state, all systems are disabled, but the sensors keep working. The stand will be in this state until pressing the Start button.

After pressing the Start button, the program will switch to the SMoving1 state, the Drive1 engine will receive power, and the direction variable will receive a logical zero, which will initiate movement to the rivet pickup point. Movement will continue until the right end-switch will be pressed, then the program will enter the SX1 state.

If in this state the inductive sensor send a signal that there is a rivet at the pickup point, the program will turn on the magnet and after 1 second pause , realized by the STakeRivet state, will start moving to its original position (SX0 state).

After pressing the left end-switch, the program will switch to the Punch state and in one second rivet will be hit for installation on a leather product. After the impact, the program will switch to the Move Belt state, in which power will be supplied to Motor2, to move the leather product along the conveyor line and prepare for the installation of the next rivet.

After that, the automatic transition to the SReady state will be performed, and the stand will wait of the next cycle.

At any moment during the cycle, the process can be interrupted by pressing the Stop button. When the Stop button is pressed, the program will switch to STOP state. In this state, all actuators are disabled, but the sensors and magnet keep working. To exit from this state, the START button has to be pressed. After which, the program will switch to the SInit state.

For a better understanding of the process, the state diagram and the general process are shown on Figure 3.1.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		22

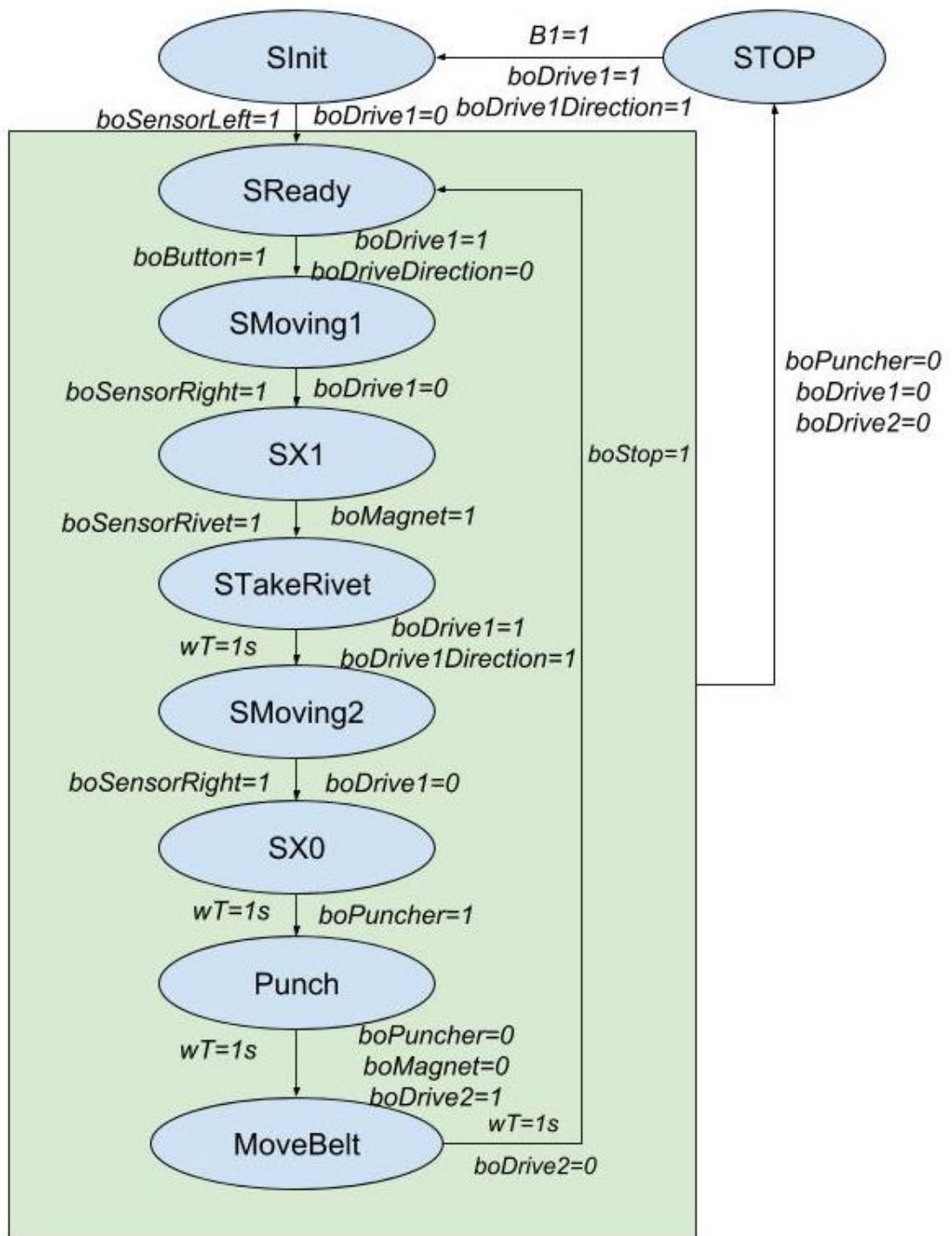


Figure 3.1: State machine of the process. From the Left/Top of transaction you can see the conditions of this transaction. On the Right/Below you can see effects of this transactions. 1 mean switched on, 0 mean switched off. wT - waiting time, using timer.

As it was written in the chapter 1, CODESYS 3.5 is used as the programming area. Main program was done using Structured' Text(ST).

									Арк.
									23
Зм.	Арк.	№ докум.	Підпис	Дата					

To debug the process, and step-by-step check the entire cycle, the signal of the Start button have to be added to the transition conditions(“If boButton = TRUE THEN” in places, marked by *).

To organize a continuous repetition of the cycle without the need to press a Start button, all lines except “intState := 2;“ must be commented out in the SReady state.

PROGRAM PLC_PRG

VAR_INPUT

boSensorLeft :BOOL;
boSensorRight :BOOL;
boSensorRivet :BOOL;
boButton :BOOL;
boSTOP :BOOL;

END_VAR

VAR_OUTPUT

boDrive1 :BOOL;
boDrive1Direction :BOOL;
boDrive2 :BOOL;
boPuncher :BOOL := TRUE; //Inverted
boMagnet :BOOL := TRUE; //Inverted

END_VAR

VAR

ton1 :TON; //Timer for taking rivet
ton2 :TON; //Timer after returning back to the initial position before punching
ton3 :TON; //Timer after punching
ton4 :TON; //Timer for moving leather product
ton5 :TON;

intState :INT;

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		24

END_VAR

boDrive1 := FALSE;

boDrive2 := FALSE;

boPuncher := TRUE;

IF boSTOP = TRUE THEN intState := 10;

END_IF

CASE intState OF

0: boDrive1Direction := 1;

boDrive1 := 1; //state SInit

boMagnet := TRUE;

*IF boSensorLeft = TRUE THEN **

intState := 1;

END_IF;

1: IF boButton = TRUE THEN

intState := 2;

END_IF;

2: boDrive1Direction := 0;

boDrive1 := 1; // state SMoving1

*IF boSensorRight = TRUE THEN **

intState := 3;

END_IF;

*3: IF boSensorRivet = TRUE THEN *// state SX1*

intState := 4;

END_IF

4: boMagnet := FALSE; //state STakeRivet

ton1(IN:=TRUE,PT:=T#1S);

*IF ton1.Q THEN **

ton1(in:=FALSE);

intState := 5;

END_IF;

									Арк.
									25
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				

```

5: boDrive1Direction := 1;
   boDrive1 := 1; //state SMoving2
   IF boSensorLeft = TRUE THEN *
       intState := 6;
   END_IF;
6: ton2(IN:=TRUE,PT:=T#1S); //state SX0
   IF ton2.Q THEN
       ton2(in:=FALSE);
       intState := 7; *
   END_IF;
7: boPuncher := FALSE; //state Punch
   ton3(IN:=TRUE,PT:=T#1S);
   IF ton3.Q THEN *
       ton3(in:=FALSE);
       boMagnet := TRUE;
       boPuncher := TRUE;
       intState := 8;
   END_IF;
8: boDrive2 := TRUE; //State MoveBelt
   ton4(IN:=TRUE,PT:=T#1S);
   IF ton4.Q THEN *
       ton4(in:=FALSE);
       boDrive2 := FALSE;
       intState := 1;
   END_IF;
ELSE
   IF boButton = TRUE THEN //state stop will set state init after pressing
button
       intState := 0;

```

										Арк.
										26
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ					

END_IF

END_CASE

3.1. Concept Analysis in Simulation

Simulation is available in the RivetingMachineSimulation file of CODESYS project and figure 3.2 shows the simulation display on CODESYS. In order to run the simulation, the operator has to go to Online>Simulation on the top tools panel, then go online and run the project.

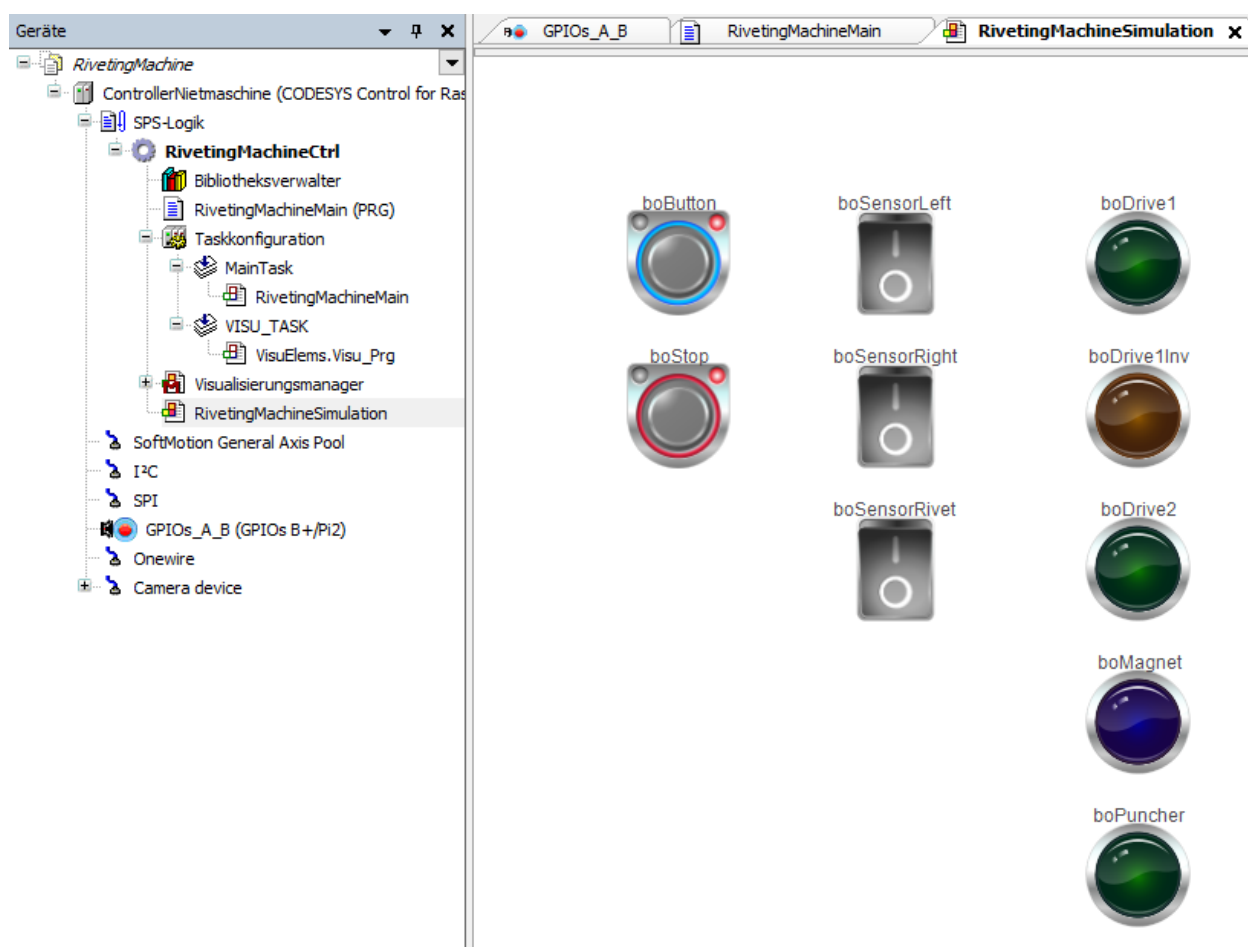


Figure 3.2: Simulation display on CODESYS

During the simulation, when a different voltage was applied, the engine showed characteristics close to those indicated in the corresponding technical documentation.

The simulation for engine testing was performed using the NanoPro

						Арк.
						27
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	

4. HARDWARE IMPLEMENTATION

4.1.Mechanical Implementation

A linear motion system, a rivet feeding unit and a leather belt fixing were designed on the basis of the air cylinder and the punching unit. The frame is composed of two metal plates for the ceiling and the basement and four aluminium profiles for the pillars. The air cylinder is mounted on the frame. Also, the base part of the punching unit is fixed with adjustable fixtures with bolts on the basement as well as the leather belt fixing unit. For the linear motion system, a stepper motor, linear shafts, a ball screw, a spindle nut block, linear bearings, bearing units and shaft holders are used and this system is mounted on an angle section, which is fixed on the profiles. The rivet feeling unit is adjustable to be used for any shapes of rivets. Table 4.1 is the list of the mechanical parts.

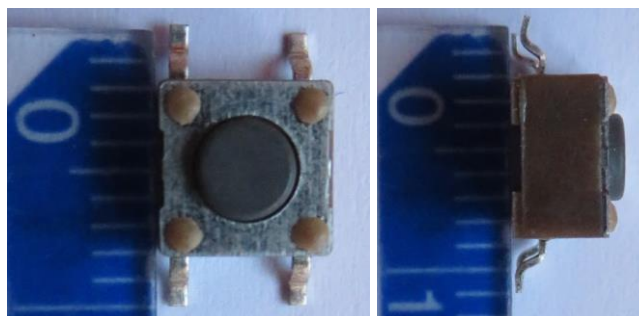
Table 4.1

Item	Size [mm]	Number	Art. No	Material
Upper plate	L450xW180xH10	1		AlMg4,5Mn
Bottom plate	L450xW300xH12	1		AlMg4,5Mn
Angle section	L450xW200xH100	1		AlMgSi0,5
Profile 8 40x40 light, natural	L=300	4	0.0.026.34	Aluminium, anodized
Profile 8 40x40 light, natural	L=150	2	0.0.026.34	Aluminium, anodized
Profile 8 80x40 light, natural	L=150	1	0.0.452.41	Aluminium, anodized
Metal block	L60xW20xH35	1		
Metal block	L45xW20xH35	2		
Sheet metal 2mm	L20xW200	2		

Sheet metal 2mm	L20xW100	2		
Sheet metal 2mm	L20xW80	2		
Stepper motor	flange 56mm	1	103-H7123-5040 / NEMA23	
Joint plate	L66xW217x10	1		
Motor support	L56xW56xH3	1		
Bearing unit		1	FLB20-3200	Aluminum, black anodized
Floating bearing unit		1	LLB20-6200	Aluminum, black anodized
Ball screw	$\phi 20$, L=452	1	SFU1605-DM	
Spindle nut block	L32xW50xH41	1	HSFU1605-DM	Steal
Linear Bearing		2	SCE20UU	
Precision Shafts 20mm h6	$\phi 20$, L= 440	2		GCr15 High carbon chromium steel
Shaft Holder		4	SH20	

Mechanical parts list

As the sensor to detect the position of the punching unit, the push button switches are chosen and it is shown on Figure 4.1.



									Арк.	
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ					30

Figure 4.3: Connection of devices

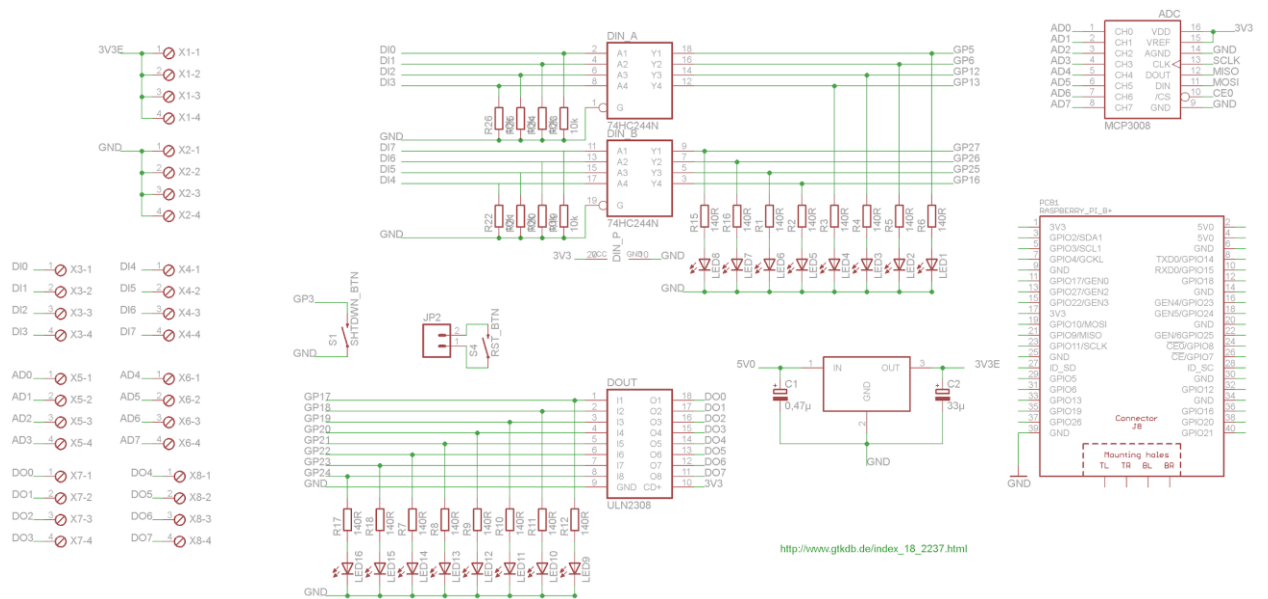


Figure 4.4: Schematic of Shield, developed by Reutlingen University

4.2.1. Inductive sensor

During operation with an inductive sensor, the main difficulty was a different voltage supply to the sensor and PLC (12 and 5 [V], respectively.). The problem was solved by using a 4n25 optocoupler. It also made it easier to work with the inductive sensor. The NPN normally opened sensor, sends an inverted signal, which is after passing through the optocoupler, is inverted again and the DI 27 input obtains a normal logical signal. Connection diagram is available in figure 4.5.

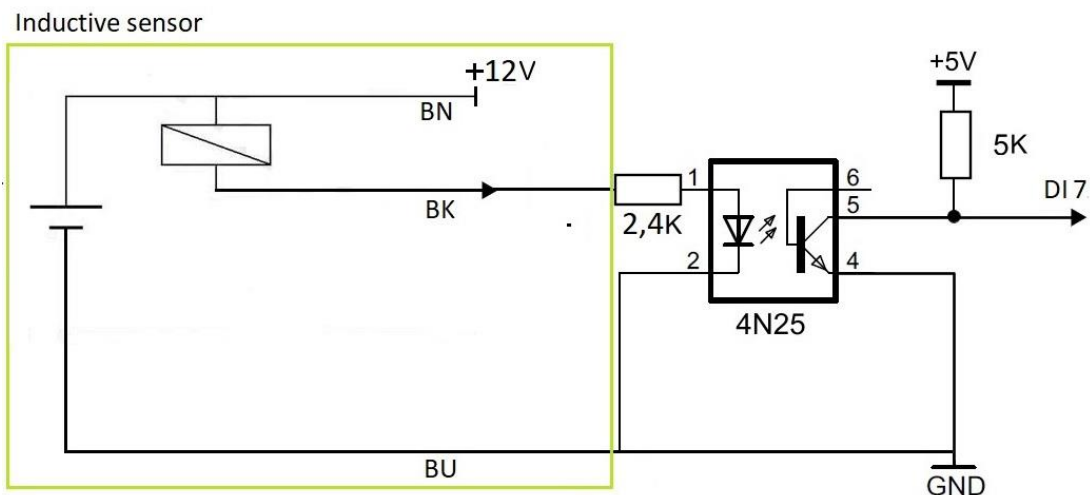


Figure 4.5: Inductive sensor connection

4.2.2. Magnet and Puncher activation

In this case, we encounter a similar problem, since both devices operate at 24 [V]. It was decided to use the Songle SRD-05VDC-SL-C dual relay with an integrated optocoupler, i.e., galvanically isolated and controlled by an inverted signal and it is shown on figure 4.6. In the process of working with the relay, difficulties arose, since the maximum output of the shield is 3.4 [V], while the relay needs 5 [V]. This problem was not solved yet, so an additional 5 [V] power supply is used to control this relay.

RELAY CONNECTIONS

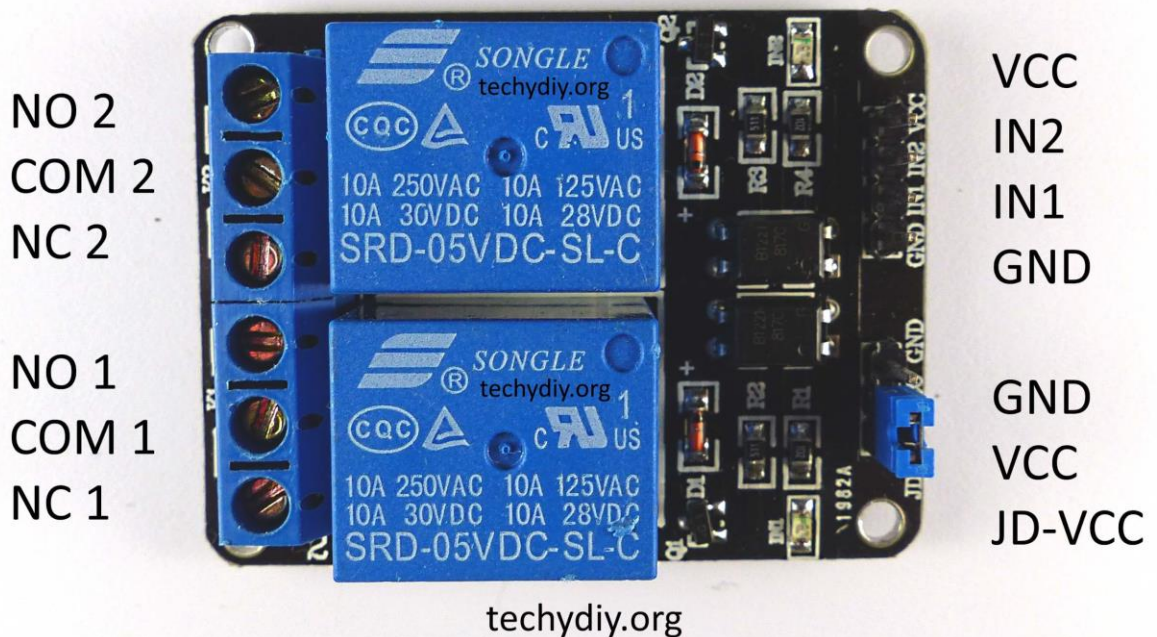


Figure 4.6: Relay Songle SRD-05VDC-SL-C

4.2.3. HEMA 23 Motor under SMCI36 driver control

Using the NanoPro software provided on the official website to configure the driver, input ports 5 and 6 were programmed to turn on the motor and change direction, respectively. Sending TRUE to the IN5, the motion of drive1 can be initialised and the activator can be moved by switching port IN6 between FALSE/TRUE to the right/left direction respectively. For successful interaction Raspberry Pi and SMCI36, their GND points have to be connected . Connection of the motor can be found in the driver manual.

4.3. Test of the System

In the test, the rivet shown on Figure 5.1(a) is punched on the leather belt, which is on Figure 5.1(b).



(a): Rivet (b): Leather belt 7

Figure 5.1: Sample materials for the test

The operation procedure is below:

1. Turn the air compressor on, wait until the air pressure level becomes 5 (2513.2[N]) or 6 (3015.8[N]) [bar]
2. Place the rivets on the rivet feeding unit
3. Switch on the power for the system
4. Press the start button on the control panel. The equipment starts transferring a rivet and punching it on the leather belt automatically

During testing of the system developed in this project, a high level of performance and accuracy of rivets placing was demonstrated. During the testing period, some errors related to the specific equipment were occurred. They were solved by changing the program code and changing the order of connecting devices to the power supply.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		35

5. OCCUPATIONAL HEALTH

5.1. Danger and harmful factors analysis

When working on a production line, the line operator may be exposed to the following dangerous and harmful production factors:

- moving machines and mechanisms, moving parts of production equipment;
- increased voltage in the electrical circuit, the closure of which can occur through the human body;
- increased air mobility (drafts);
- insufficient illumination of the working area;
- increased noise level at the workplace;
- sharp edges on the surface (glass fight).

In the process of manipulating robots, you can state: the failure of the moving parts of the production line, an unplanned gathering of products from the assembly line, a violation of the order of procedures in case of problems with power supply, which can bring to traumatic conditions.

Also in production, workers are exposed to various vibrations and noises, which can have a negative impact on the mental and physical health of the production line worker.

5.2. Engineering and technical measures for occupational safety

To prevent a malfunction on the production line, it is equipped with light and sound signals, indicating the area where the failure occurred, as well as a security system that stops this part of production.

Lines, equipped with alarm systems, warning workers about the launch. Remote start-up should be carried out after giving a warning sound or light signal and

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		36

receiving a response signal from the places of equipment maintenance about the possibility of starting. Alarm calls, sirens, lamps are protected from mechanical damage and are located so as to ensure reliable audibility and visibility of the signal in the service area of the staff.

To prevent the human being from getting into the zone of operation of the mechanisms, all retractable parts of the mechanisms and electrical equipment are firmly fixed and closed with enclosures.

In order to prevent the person from getting under pressure during the inspection and maintenance of the line, the cutter must be switched off.

The line provides a protective grounding, which is a deliberate connection to the ground of metal parts of the equipment, which are under voltage in normal conditions, but which may appear under it as a result of a violation of the electrical insulation of the installation. The protection of the main electrical circuits of the line is carried out by protective devices using automatic switching with high switching protection capability.

Tires and other non-insulated conductive parts are fenced. Also installed signal lamps, which indicate the presence of voltage on the conductive parts.

In terms of illumination, industrial buildings are projected with natural light in accordance with the rules of illumination. Artificial lighting can be of two types: work and emergency. When using electric lighting in the shop, during operation of the production line regardless of the background color and contrast of the object with the background, the illumination is equal to 14 lux (working) and 0.5 lux (emergency).

5.2.1. Measurements part

The calculation of the lighting system, the choice of the source of lighting, and the luminaire, will be performed for the operator's control cabin [6].

The total light flux of the lamp is determined by the formula:

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		37

$$F = (E_n \times S \times k \times z) / N \times \eta, \text{ lm} \quad (5.1)$$

where E_n -necessary illumination of the workplace in the norm ($E_n = 300 \text{ lux}$);

S - area of the premises, m^2 ;

k - factor of the stock, which takes into account the wear and pollution of the fixtures ($k = 1.5$);

z - coefficient which takes into account the unevenness of the illumination (range 1.1 ... 1.5, with optimal ratios of the distance between the fixtures to the design height for luminescent lamps $z = 1.1$);

The coefficient of light flow is chosen from the tables, depending on the type of lamp, the size of the room, the coefficients of reflection of the walls and ceiling of the room; N - number of lamps in the room.

Determine the size of the room if its length is $L_d = 8 \text{ m}$, width $L_s = 5 \text{ m}$, and height $H = 3 \text{ m}$:

$$S = L_d \times L_s$$

$$S = 8 \times 5 = 48 \text{ m}^2$$

Determine the design height of the suspension:

$$h = H - h_s - h_{ws}, \text{ m} \quad (5.2)$$

where H - height of the room, m ;

h_s - height of the suspension of the lamp from the ceiling, m ;

h_{ws} - height of the working surface above the floor, m .

Let's accept:

$$h_s = 0.15 \text{ m}, h_{ws} = 0.8 \text{ m}$$

Then,

$$h = 3 - 0.15 - 0.8 = 2.05 \text{ m}$$

The most suitable for our room are fluorescent lamps LB (white light) or LTB (Heat-white light), power of 20, 40 or 80 Watts.

Determine the distance between the rows of fixtures:

$$L = \lambda \times h, \text{ m} \quad (5.3)$$

Where λ is the most advantageous ratio of the distance between the fixtures to the design height (for luminescent lamps under the cosine-shaped typical curve $\lambda = 1.4$).

$$L = 1.4 \times 2.05 = 3 \text{ m}$$

									Арк.
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				38

The number of rows of fixtures in the room $N_p = 2$ rows. We determine the number of lamps in a row:

$$N_{\text{Light}} = (L_d - L_s) / L_{\text{Light}}, \text{ units} \quad (5.4)$$

where L_s is the length of the lamp (based on the size of the lamp $L_{\text{Light}} = 1325$ mm).

$$N_{\text{Light}} = (8 - 1.325) / 1.325 = 5.03 \approx 5 \text{ units.}$$

Number of fixtures:

$$N = N_p \times N_{s, M} \quad (5.5)$$

$$N = 2 \times 5 = 10 \text{ units}$$

The location of the lamps in the room is shown in Figure 6.1

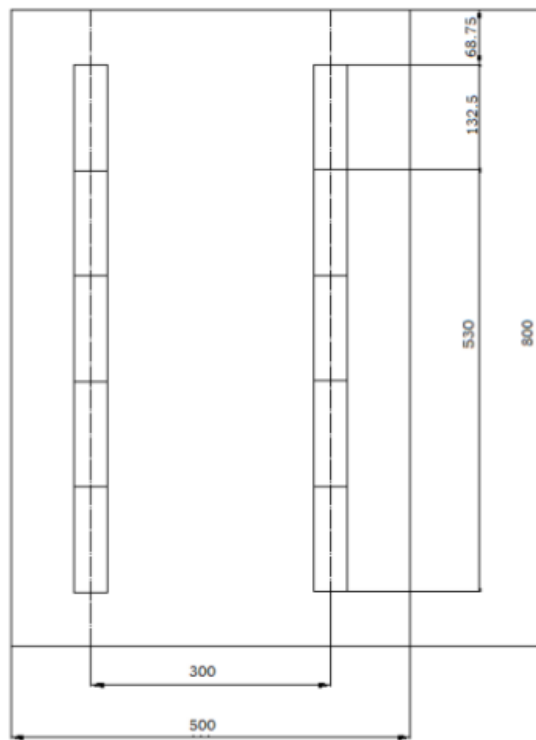


Fig.5.1: The location of the fixtures.

Determine the coefficient of light flow. For this we calculate the index of the premises i :

$$i = (L_d \times L_s) / h \times (L_d + L_s), \quad (5.6)$$

$$i = (5 \times 8) / 2.05 \times (5 + 8) = 1,5$$

Thus $i = 1.5$.

Determine the coefficients of reflection of the surfaces of the premises - ceilings, walls and working surface: $\rho_{\text{Ceilings}} = 70\%$, $\rho_{\text{Stan}} = 50\%$, $\rho_{\text{Pn}} = 30\%$

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		39

Based on the values obtained and p , we determine the value of the coefficient of use of the light flux for the selected $i = 0.48$

Determine the total luminous flux:

$$F = (300 \times 40 \times 1.5 \times 1.1) / 10 \times 0.48 \approx 4125 \text{ lm}$$

Proceeding from the fact that the total light flux is $F = 4125 \text{ lm}$, choose the lamp LTB40, whose light flow is $F1 = 2100 \text{ lm}$, thus it is necessary to install 2 lamps LTB40 in the lamp. Deviation of actual illumination from the calculated composition:

$$\Delta = (F - F1) / F \quad (6.7)$$

$$\Delta = (4125 - 2 \times 2100) / 4125 = -0.018$$

At calculations of illumination the allowable value of deviations from the normalized is $-10\% \dots + 20\%$, therefore, artificial lighting is enough. As a result of the correct calculation of lighting, the workforce reduces the risk of occupational diseases (mainly loss of vision), tiredness and as a consequence - increases productivity.

5.3. Fire Security

Dangerous factors of fire affecting people are: open fire, sparks, elevated ambient temperature, objects, toxic products of combustion, smoke, reduced oxygen concentration.

For the production line, the following measures are used to ensure fire safety: all control equipment is located in a sealed container, the motors of all mechanisms have a degree of protection from the external environment.

In order to provide fire safety, the workplace provides a fire extinguisher, which is used for the purpose of extinguishing the wiring and electrical equipment.

Employees of at least 18 years old who have the necessary theoretical and practical training, have undergone a medical examination and have no contraindications for health reasons, have undergone introductory and primary on-the-job training on labor protection, training, testing knowledge of labor protection

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		40

requirements, certified by the qualification commission and received admission to independent work are allowed to work with manipulators

5.4. Emergency measures

Of the ES. Proceeding from the predicted possibility of accidents, catastrophes or natural disasters that may result in human casualties, harm human health, disrupt the conditions of their life, outlined the following measures and temporary evacuation parameters:

- Defines the type of evacuation (scheduled or emergency);

Calculation of workers and employees required for evacuation; Emergency situations (ES) in the enterprise, which are related to the production and economic activity of man at the facilities of technosphere, are classified as technical ES. As a rule, technical ES arise as a result of crashes accompanied by involuntary release into the surrounding space of matter and (or) energy. One of the main methods of protection is the timely and prompt removal of people from the danger zone, ie evacuation. The type of evacuation is determined by the type, nature and conditions of the ES.

- Among the measures to protect the personnel of the enterprise are indicated actions to evacuate the working change, as in the case of a threat, and in case of emergence
- Measures are being established for the emergency stop of production;
- Schedules of evacuees from the zone of emergency to the points of temporary placement are planned;

Taking into account the analysis and assessment of the situation, the head of the Object Committee of the ES can take one of the decisions:

- Conduct an evacuation inside the object;
- Remove personnel outside the object;

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		41

6. TECHNICAL AND ECONOMIC EVALUATION

Introduction

The purpose of this section of the diploma project is to calculate the economic indicators of a technical solution for the development of an automatic rifle transfer device using a linear displacement system and a PLC controller. The essence of the technical solution is to automate the process of taking riveting and installed on a leather product.

Automation of this process allows:

- increase reliability of equipment and systems;
- save resources and energy;
- to reduce operating time.

The process of production automation is effectively used in most industries over the last decades. Replacing living workers with machines has a number of undeniable advantages, since when using robots in production, the processing speed of materials increases, the marriage due to the human factor is reduced to a minimum, and the cost of the work of the robot is indisputably less than the cost of employees.

To substantiate the economic feasibility of the equipment offered in the diploma project, the following tasks must be solved:

1. Calculation of capital expenditures
2. Calculation of operating costs
3. Recording and analysis of indicators of economic efficiency

6.1. Calculation of capital investments

The section is written taking into account the exchange rate of 07.06.2019 by MinFin of Ukraine as:

$$1\text{€} = 30.187353 \text{ UAH}$$

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		42

To determine capital expenditure, you can use the formula

$$K_{gen} = K_{purch} + K_{trans} + K_{inst} \quad (6.1)$$

K_{gen} - general costs of the project; K_{purch} - purchase costs of the equipment and construction elements; K_{trans} - transportation costs and corresponding wastes; K_{inst} - installation and adjustment costs of the equipment

A calculation of parts and components costs is listed in Table 6.1.

Table 6.1

Parts and components costs

Item	Size [mm]	Number	Cost, €
Upper plate	L450xW180xH10	1	32.90
Bottom plate	L450xW300xH12	1	28.79
Angle section	L450xW200xH100	1	34.40
Profile 8 40x40 light, natural	L=300	4	29.60
Profile 8 40x40 light, natural	L=150	2	7.40
Profile 8 80x40 light, natural	L=150	1	3.70
Metal block	L60xW20xH35	1	5.35
Metal block	L45xW20xH35	2	4.90
Sheet metal 2mm	L20xW200	2	13.40
Sheet metal 2mm	L20xW100	2	12.00
Sheet metal 2mm	L20xW80	2	12.00
Stepper motor	flange 56mm	1	65.20
Joint plate	L66xW217x10	1	12.20
Motor support	L56xW56xH3	1	7.30
Bearing unit		1	26.32
Floating bearing unit		1	15.68

Ball screw	φ20, L=452	1	54.62
Spindle nut block	L32xW50xH41	1	15.97
Linear Bearing		2	13.02
Precision Shafts 20mm h6	φ20, L= 440	2	9.32
Shaft Holder		4	2.44
PLC Raspberry Pi		1	54.33
SMCI36 Driver control		1	103.56
Inductive sensor		1	20,07
		Total	564.47

Total cost of parts and components for the project - 564.47€, which is equivalent to

$$K_{purch} = 564.47 \times 30.187353 = 17039,86 \text{ UAH.}$$

The cost of transport, procurement and warehousing costs is determined on the basis of:

1. Distances of delivery of equipment from the place of purchase to the place of exploitation;
2. Quantity, weight and equipment dimensions;
3. Type of vehicles;
4. Transport tariffs;
5. Prices for loading and unloading works;
6. Expenses for warehouse processing.

In this project, transport costs are the cost of courier delivery on the trading sites and defined by trader by himself. [\[10\]](#)

Total transport costs were 68.67€, which is equal to

$$K_{trans} = 68.67 \times 30.187353 = 2072,97 \text{ UAH.}$$

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		44

The cost of assembly and debugging can be determined as follows:

$$K_{inst} = (N_i \times a_i \times t_i) \times K \quad (6.2)$$

where N_i - number of employees of the i -th category, necessary for a certain amount of installation (adjustment works), people.
 a_i - hourly tariff rate of the employee of the i -th category, UAH.
 t_i - time required to perform a certain amount of installation (adjustment works), year, h.
 K - coefficient, taking into account the amount of surcharges, the single social contribution and other expenses for implementation of installation works, units. (equal to 1 in our case)

Installation and adjustment was realized by 2 workers of mechanical workshop. They spent 23 hours for the construction work. This information is taken from the official financial statement of the company. Taking into account salary, which is equal to 17€/h (Mindestlohngesetz vom 11. August 2014 (BGBl. I S. 1348)):

$$K_{inst} = 2 \times 17 \times 23 = 782 \text{ €}$$

$$K_{inst} = 782 \times 30.187353 = 23606,51 \text{ UAH}$$

Also in this paragraph should indicate the cost of writing a program code, which were performed by a third-party developer at the piece-rate cost, which is 800€. This information is taken from the official financial statement of the company. [\[11\]](#)

Based on these data, the calculation of capital investment is:

$$K_{gen} = 564.47 + 68.67 + 782 + 800 = 2215,14 \text{ €}$$

$$K_{gen} = 2215,14 \times 30.187353 = 66869,21 \text{ UAH}$$

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		45

6.2. Calculation of operating costs

Operating costs are the current costs of operation and maintenance of the design object for a specific period (year), expressed in cash.

The main articles of the operating costs of the electrical equipment include:

1. Amortization deductions (C_a);
2. Costs for maintenance and repair of the equipment (C_r);
3. Cost of electricity consumed by the design object (C_e);
4. Other operating expenses (C_i).
5. Software upgrade (C_s)

Thus, annual operating costs for this project will be:

$$C = C_a + C_r + C_e + C_i + C_s \quad (6.3)$$

6.2.1. Calculation of amortization deductions

The annual fund depreciation is determined as a percentage of the amount of capital expenditures by type of fixed assets and intangible assets by sections of capital expenditure reduction for the project option and according to the enterprise's carrying amount of the replacement equipment for the base version.

Calculation of depreciation rates produced by the formula

$$C_a = (P_{init} - L) / T_{min} \quad (6.4)$$

where P_{init} - initial (or revalued) value of the object of fixed assets (K_{gen}), UAH;

L - estimated liquidation value of fixed assets, UAH;

T_{min} - minimal useful life (depreciation period), years.

This equipment belongs to the 4th group of fixed assets and its minimal depreciation period is 5 years

$$C_a = 2215,14 / 5 = 443,03 \text{ €}$$

$$C_a = 443,03 \times 30.187353 = 13373.90 \text{ UAH}$$

						Арк.
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ	46

6.2.2. Determination of annual maintenance and maintenance costs

The annual maintenance and maintenance costs of the electrical equipment include the costs of materials, spare parts, wages by the repair worker and may be determined by the actual data of the enterprise.

In the case of such equipment, it is more rational to complete or partial replacement of the failed component parts than to repair them, but nevertheless, the installation will need maintenance and technical processing. On this basis, the repair costs are calculated as:

$$C_r = n \times R_i \times t_i \times m \quad (6.5)$$

where n - number of automation equipment to be repaired;
 R_i - hourly rate of workers, performing repairs, 10.5 €/h. (Mindestlohngesetz vom 11. August 2014 (BGBl. I S. 1348))

t_i - complexity of one repair in the category of complexity of repair in one repair unit depending on the type of repair, h / unit: (7h average) This information is taken from the official financial statement of the company.

m_i - number of repairs per year, this sort of equipment have to be maintained twice per year;

$$C_r = 1 \times 10.5 \times 7 \times 2 = 147\text{€}$$

$$C_r = 147 \times 30.187353 = 4437.54 \text{ UAH}$$

6.2.3. Calculation of the cost of consumed electricity

The cost of electricity consumed by the design object during the year is determined based on its installed capacity and the annual working time of the design object according to the formula:

$$C_e = W_p \times E_e \quad (6.6)$$

where W_p is the amount of electricity consumed per year,

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		47

and E_e - is a tariff for electricity, (0.30 average electricity price in Germany).[\[12\]](#)

The amount of electricity consumed per year, kWh is calculated according to the formula:

$$Wp = t_d \times t_h \times t_t \times P_n$$

$$Wp = 21 \times 8 \times 12 \times 0,150 = 302,4 \text{ kWh/y (6.6)}$$

where t_d - number of working days per month, day.
 t_h - the number of working hours per day, hour.
 t_t - the number of months per year, month.
 P_n - power of the project installation, W.

$$C_e = 302,4 \times 0.3 = 90.72\text{€}$$

6.2.4. Other operating expenses

Other expenses for the operation of the design object include the cost of labor protection, overalls, and the like. In practice, these costs are determined at a rate of 4% of the annual salary fund servicing workers.

$$C_i = R_i \times t_d \times t_h \times t_t \times 0.04$$

$$R_i = 10 \text{ €/h (Mindestlohngesetz vom 11. August 2014 (BGBl. I S. 1348))}$$

$$C_i = 10 \times 8 \times 21 \times 12 \times 0.04 = 806.4\text{€}$$

6.2.5. Software upgrade

Possible changes in functionality, the addition of new programs for new products and the like changes in the program code require the work of a developer or third-party specialist with the same programming skills. Software change costs will be charged at 2% of the annual salary fund servicing workers.

$$C_i = R_i \times t_d \times t_h \times t_t \times 0.02$$

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		48

$R_i = 14,93 \text{ €/h}$ (Mindestlohngesetz vom 11. August 2014 (BGBl. I S. 1348))

$$C_i = 14,93 \times 8 \times 21 \times 12 \times 0.02 = 602\text{€}$$

$$C_i = 602 \times 30.187353 = 18172.79\text{UAH}$$

After all calculations, the annual operating costs will be:

$$C = C_a + C_r + C_e + C_i + C_s \quad (6.7)$$

$$C = 443,03 + 147 + 90.72 + 806.4 + 602 = 2089.15\text{€}$$

$$C = 2089.15 \times 30.187353 = 63065.91\text{UAH}$$

6.3.Determination of annual savings from the project implementation

In this project, the savings are realized through two indicators:

- The increase in the number of products produced per hour
- Reducing salary fund costs by reducing the position of the employee who performed the work.

Previously, the production of a single belt (not counting the preparation phase of the leather) was allotted 2.5 hours, 2 of which were spent on placing the rivets on the finished leather product, since this operation was done manually. The developed stand installs the same number of rivets in 50 minutes, thus reducing the belt production time from 4 hours to 1 hours and 20 minutes (53% of the initial value). Consequently, the number of products per hour will increase by 87%.

Before this project, 10 belts were manufactured during a day on one producing line. Such slowness caused by the complexity of the process. The rivet installation section was the slowest, and consequently, with the acceleration of its work, the overall production speed will also accelerate.

The new installation will increase the volume of production up to 18 belts

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		49

per shift. The profit from the sale of one belt is 14 €, and therefore the economy will be

$$S_{prod} = (N_{init} - N_{proj}) \times (C_{sell} - C_p) \times t_h \times t_t$$

Where S_{prod} – savings, caused by increasing producing speed, €;
 N_{init} – number of production produced during the day before implementing new technology, unit;

N_{proj} – number of production produced during the day after implementing new technology, unit;

$(C_{sell} - C_p)$ – difference between production cost and selling cost of product (equal to profit), €;

$$S_{prod} = 14 \times 8 \times 21 \times 12 = 28224€$$

$$S_{prod} = 28224 \times 30.187353 = 852007.85 \text{ UAH}$$

The second point of savings is the abolition of the position of a worker with a salary of 12€(Mindestlohngesetz vom 11. August 2014 (BGBl. I S. 1348) per hour, and therefore annual savings

$$S_{salary} = R_i \times t_d \times t_h \times t_t$$

$$S_{salary} = 12 \times 8 \times 21 \times 12 = 24192€$$

$$S_{salary} = 24192 \times 30.187353 = 730292.44 \text{ UAH}$$

Based on these calculations, the annual savings will be

$$S = \sum S - C$$

$$S = 28224 + 24192 - 2089.15 = 50326.85€$$

$$S = 50326.85 \times 30.187353 = 1519234.39 \text{ UAH}$$

									Арк.
Зм.	Арк.	№ докум.	Підпис	Дата					50

Summary:

In the calculations of this section were obtained the value of project investment, the cost of installation and adjustment work, annual operating costs, the cost of electricity consumed by the object of design throughout the year, the cost of the current repair of automation equipment and automation systems, the annual savings from the implementation of the adopted technical solution. Capital investments are equal to 2215,14€ or 66869,21 UAH

Annual maintenance costs is 2089.15€ or 63065.91UAH.

The annual savings of the offered equipment is 52416€ or 1582300.29UAH.

The annual economical effect of the offered equipment is 50326.85€ or 1519234.39 UAH.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		51

CONCLUSION

The automation of a riveting machine with an electric picker has been developed with both hardware and software parts. The mechanical design is done considering stability for the linear system and flexibility for different types of rivets and leather belts. The controlling system and simulation on CODESYS are established to operate the system.

The project was completed in deadlines and accepted by the customer without any edits or corrections.

In this report the occupational health and economic benefits of this device were calculated. Following the predicted calculations, the project costs pay off in the first few months of the device.

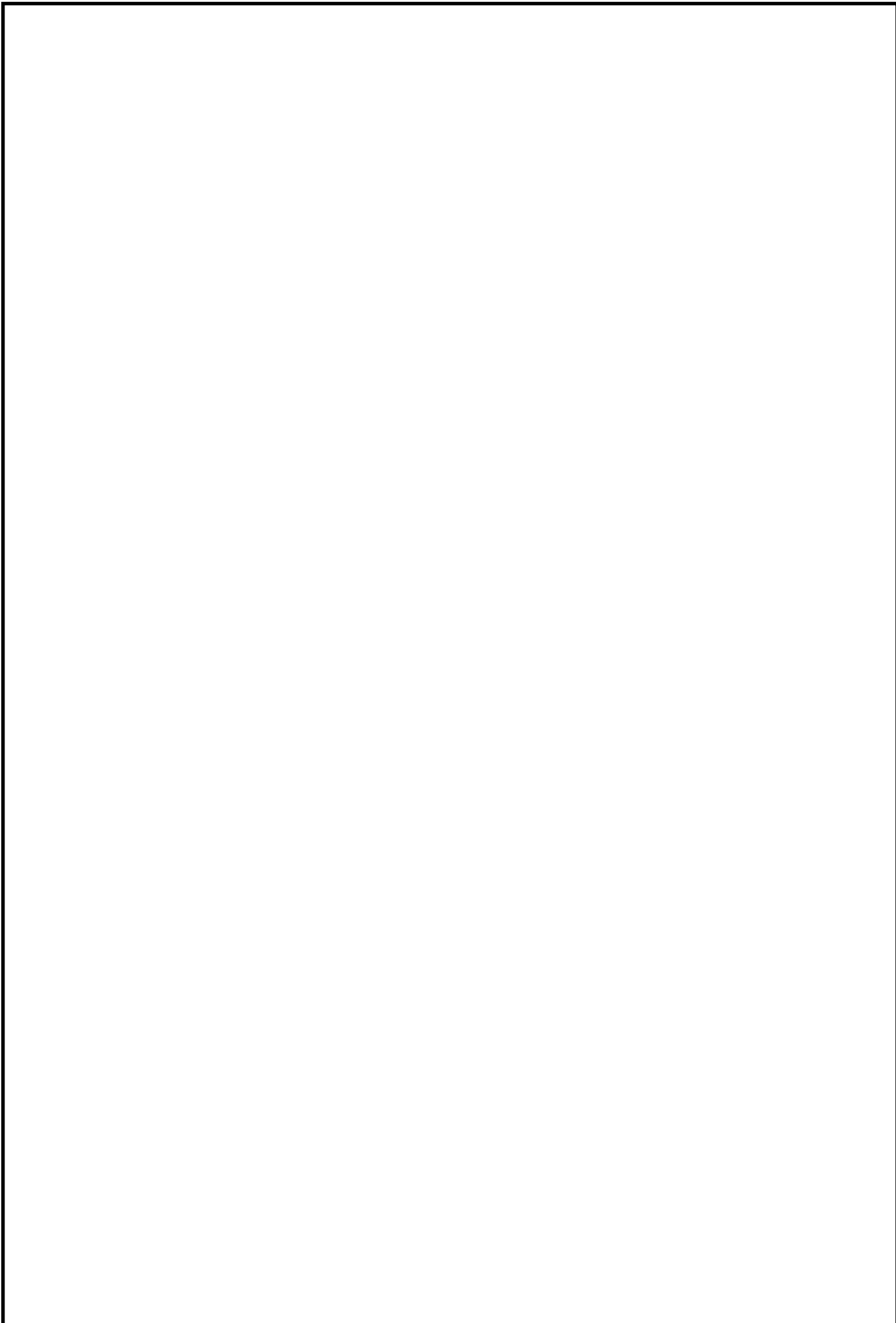
Analyzing all of the above, may be said that the diploma has proven the feasibility of using the considered automatic control system.

					ЕП.ПД. 18.14.Р.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		52

BIBLIOGRAPHY

1. http://www.eti.su/articles/elektricheskie-mashini/elektricheskie-mashini_1571.html
2. http://nwpi-fsap.narod.ru/lists/oee_matusko/asinchronn.html
3. <https://vt-tech.eu/articles/cnc/50-stepper-motors.html>
4. <http://www.servotechnica.spb.ru/calculation/ballscrew.html>
5. https://dspace.susu.ru/xmlui/bitstream/handle/0001.74/17296/2017_476_Bel_yaev.pdf?sequence=1?sequence=1
6. <https://industrialisation.ru/1383342/>
7. https://en.nanotec.com/fileadmin/files/Handbuecher/Motorsteuerungen/SMC_I36_Technical-Manual_V1.3.pdf
8. www.doe.dp.ua
9. <https://www.motioncontroltips.com/faq-what-are-hybrid-stepper-motors/>
10. https://www.ebay.com/?ef_id=Cj0KCQjwov3nBRDFARIsANgsdoEwKFTFQduoz0fw1r8WY-K480XMm0X9toSRPTkJSYXtkDRVLvz5yu0aArdoEALw_wcB:G:s
11. https://www.glassdoor.com/Job/germany-plc-controls-engineer-jobs-SRCH_IL.0,7_IN96_KO8,29.htm
12. <https://www.cleanenergywire.org/factsheets/what-german-households-pay-power>
- 13.

									Арк.
									53
Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.ПД. 18.14.Р.ПЗ				



					ЕП.ПД. 18.14.Д.ПЗ	Арк.
Зм.	Арк.	№ докум.	Підпис	Дата		54