Development of STK-23 - gripper machine with a mechanism for vertical movement and right-angle rotation

Entwicklung STK-23 - Greifer Maschine mit einem Mechanismus für vertikale Bewegung und Drehung im rechten Winkel – STK 23

Ing. Shtiliana Kirova
Technical University of Sofia, Faculty of German Engineering and Economics Education,
Sofia, Bulgaria, kirova.k.st@gmail.com

***Abstract* —** Since its beginning in the 1960s, robotics is still moving in a direction where these types of machines are now an indispensable part of people’s lives. As these technologies advance and develop, so do the expectations for them and the actions they perform. Based on market research, as well as the needs of industry and production, the STK-23 robot was developed - a new generation intelligent gripper with three main functions - an intelligent gripper with adjustable grip strength, as well as mechanisms for vertical movement and rotation of the object in a straight-line angle.

The developed concept for this type of machine went through the stages of creating a conceptual project, building a conceptual design of the machine. The attached project for the STK-23 was made in the form of a real mockup, with the majority of its constituent elements designed according to an individual design and made by means of three-dimensional printing. STK-23 has both a hardware and a software part for the purpose of executing commands.

***Zusammenfassung* —** Ab den 1960er Jahren entwickelt sich die Robotik immer noch in eine Richtung, in der diese Art von Maschinen heute aus dem Leben der Menschen nicht mehr wegzudenken ist. Mit dem Fortschritt und der Weiterentwicklung dieser Technologien steigen auch die Erwartungen an sie und die von ihnen durchgeführten Aktionen. Basierend auf Marktforschung sowie den Bedürfnissen von Industrie und Produktion wurde der Roboter STK-23 entwickelt – ein intelligenter Greifer der neuen Generation mit drei Hauptfunktionen – ein intelligenter Greifer mit einstellbarer Griffstärke sowie Mechanismen für vertikale Bewegung und Drehung des Objekts in einem geraden Winkel.

Das entwickelte Konzept für diesen Maschinentyp durchlief die Phasen der Erstellung eines konzeptionellen Projekts und der Erstellung eines konzeptionellen Entwurfs der Maschine. Das beigefügte Projekt für den STK-23 wurde in Form eines echten Modells erstellt, wobei die meisten seiner Bestandteile nach einem individuellen Entwurf entworfen und mittels dreidimensionalem Druck hergestellt wurden. STK-23 verfügt sowohl über einen Hardware- als auch über einen Softwareteil zur Befehlsausführung.

I. INTRODUCTION

With the advancement of science and its development in the direction of robotics and automation, the use of robots is becoming more and more popular, and the topic of automating processes in production, as well as in performing daily activities, is becoming more and more important. Based on the Industry 4.0 phenomenon, whose goals are the automation of processes through their execution by robots, as well as the advocated concept of “smart factors”, the distribution and development of new robots is increasing.

The STK-23 robot was developed and created precisely for this purpose - facilitating production processes and automating the previously used manual work on assembly lines. The main highlight of the robot is the smart gripper it has and its ability to adjust the pressure it applies to the gripped object. Thus, the robot is suitable for gripping both fragile objects and more solid ones. The remaining two functions of the robot, distributed in module 2 and module 1 respectively, allow the robot to move both in height and rotate 90 degrees and determine the application of the robot in production, when using flow lines that are parallel. The control of the robot is also innovative through remote access and Wi-Fi, which fits into the concept of smart factories and does not allow access of people near the machine.

To support the correct functioning, as well as to confirm the applicability of the robot in real conditions, a prototype of STK-23 was also made, which performs the functions of all three modules without any problems. Purchased parts are kept to a minimum as the main components used to build the robot are created by author’s design, according to the necessary requirements to meet in relation to the functionality of the robot. In order to confirm the correct performance of the functions, experiments were also carried out in laboratory conditions.

STK - 23 was developed and designed as a diploma thesis for a bachelor’s degree in the specialty Mechatronics and Information Technology in German, and for its development the technology provided by the German Faculty of the Technical University of Sofia was partially used.

II. INTELLIGENT ROBOT STK – 23 CONCEPT AND MECHANICAL PARTS DESIGN

Starting as a conceptual project, it was important for STK-23 to be, above all, a functional robot. Based on research and various types of robots developed for the needs of the industry, in the construction of the STK-23, three functions were set, which were considered important:

Function 1 - Horizontal 90-degree rotary motion

Function 2 - Vertical movement of the gripper

Function 3 - Clamping a workpiece using adjustable pressure

A. *Initial concept of the robot – Modules description*

The initial concept for the construction of the STK-23 machine is to conditionally divide it into three modules, each of which is characterized by a certain action and function, with the emphasis being on the intelligent gripper.

- **Module 1**

The first module or so-called “Module 1” and fits into the main box of the robot, which houses the first of the three motors, as well as the controller and much of the electronics that control the robot. This module also serves as the basis of the robot, and functionally it also contains the mechanism for performing the 90-degree rotation.

- **Module 2**

“Module 2” is that group of machine elements that form the structure for the vertical movement of the machine. The main part of these details is located in a cylindrical box, which, like the main box in Module 1, serves as a protective housing for the mechanism.

- **Module 3**

The main emphasis of the STK-23 robot falls on “Module 3”, which also houses the intelligent gripper of the robot, which, as I mentioned above, also performs the main function of the machine, namely the grasping of objects with regulated pressure. The pressure sensor is also located in this module, which is of particular importance.

After clearing the functional concept for the robot, the realization and construction of such a machine was considered. For this purpose, the components used in the process are divided into two groups - Standard components and Components made according to individual design.

In order to more easily and conveniently mark the details, a system for numbering the details is also used in the form of an eight-digit number divided into 4 pairs of digits, which respectively indicate the number of the product, the Module in which this part is located, whether it participates in assembly in the structure, as well as the number of the part itself.

B. *Custom designed components*

The design is personal, and the production is done on site, in the laboratory provided by the German Faculty at the Technical University of Sofia. Fabrication of the details on site allows above all the timely modification of the design and the adjustment of the dimensions according to the needs and the overall view of the construction. The steps followed in the design and engineering of these components are as follows

Step 1 - Conceptual design of the part in the form of a conditional sketch

Step 2 - Prepare a two-dimensional drawing of the part in the Solid Works program

Step 3 - making a three-dimensional model of the part using the Solid Works program

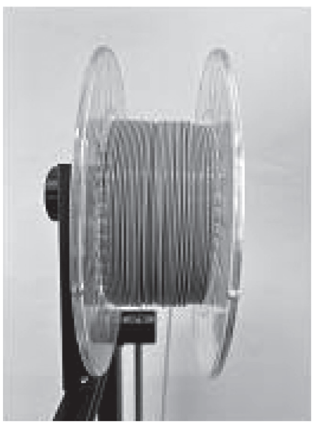
Step 4 – production of the detail in real form and its preparation for assembly/assembly in the robot Structure

B.1. list of the custom designed components

- Part Nr 01-01-00-01 - Main/base box
- Part Nr 01-01-00-02 – Top cover
- Part Nr 01-01-00-03 - spacer
- Part Nr 01-01-01-01 - side cover
- Part Nr 01-01-01-02 – hinge
- Part Nr 01-01-01-03 – Bolts
- Part Nr 01-01-01-04 - Z-shaped profiles
- Part Nr 01-01-02-01 - Gear 1
- Part Nr 01-01-02-02- Motor box
- Part Nr 01-01-02-03 - Motor stand
- Part Nr 01-02-00-01 Cylindrical box
- Part Nr 01-02-00-02 balancing box
- Part Nr 01-02-00-03 balance box cover
- Part Nr 01-02-00-04 mounting plate
- Part Nr 01-02-01-01 Hollow cylinder with spikes
- Part Nr 01-02-01-02 Gear 2
- Part Nr 01-02-01-03 lower shaft
- Part Nr 01-02-01-04 Inter bearing ring
- Part Nr 01-03-01-01 - protective case
- Part Nr 01-03-01-02 - Gear 3
- Part Nr 01-03-01-03 - Grip clip
- Part Nr 01-03-01-04 - pressure plate
- Part Nr 01-03-01-05 - pressure distributor

B.2. Materials and production of the individually designed components

For the production of the second group of details, the 3D printing method is used. In this case, fused deposition modeling is used for several main reasons. In addition to its widespread use, this method of printing helps to make the components faster, as well as reduces the financial resources needed to purchase materials. The printed parts have a level of strength and durability to meet the needs of the model being created. Among the suitable materials for making these details are ABS, PLA and their mixtures. Taking into account the strength and resistance of polylactic acid and the permissible load of these parts in the machine, the material for the parts of STK-23 is polylactic acid. Another advantage is the lower melting temperature of the material, which also leads to a reduction in the time for making the parts.



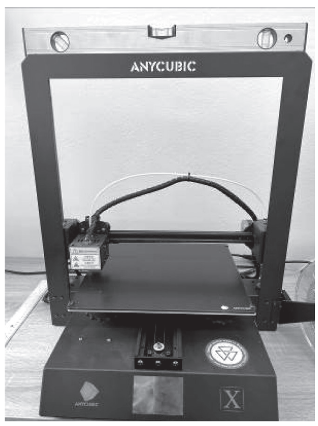


Fig 1 the PLA material used for 3D printing
Fig 2 the 3D printer

B.3. Designing and manufacturing custom detail (example)

As an example, for custom design is taken Gear 1 (*Detail 01-01-02-01*). The main function of the gear is to transfer the motion from the engine to the ring gear. Design of the part requires some calculations to be dome. The formulas that were sued are given bellow.

$$F = \tau / r \tag{1}$$

Formula (1) calculates the peripheral force

$$i = m_{construction} / F_{circumference} \tag{2}$$

Formula (2) calculates the gear ratio

$$z = d1 / m \tag{3}$$

Formula (3) calculates number of teeth

$$\text{Diametric pitch} = \pi \, . \, m \tag{4}$$

Formula (4) calculates diametrical pitch

$$H = m. \, 10 \tag{5}$$

Formula (5) calculates total height of the gear

$$h = h' + h'' = f. \, m + (f + c). \, m \tag{6}$$

Formula (6) calculates total height of the tooth

The real measurements of the gear, received from the calculations can be seen on the 2D drawing made in Solod Works. Based on the 2D drawing a 3D version of the detail is made again via Solid Works. The final step is the 3D printing of the part. The actual printed part is shown is in Fig 3,

Fig 3

C. *Standard components*

The standard components are selected based on calculations and comparison of the characteristics of the parts with those that are most suitable for the construction of the machine. An important requirement is that these details should not interfere with the overall functioning of the robot. Standard components are used primarily for the electrical part of the robot as well as for its drive.

C.1. List of the standard components

- Stepper motor 28BYJ-48
- MSW12 1-Position Stable Micro Lever Switch
- Stepper motor driver with ULN2003
- Pololu 5V, 2.5A Step Down Voltage Regulator D24V22F5
- Tapered roller bearings DIN 30202
- Seeger washer DIN 471
- Nema 17 28mm 17HS2408S Stepper Motor
- CNC Flexible Coupling 5x8
- Trapezoidal bolt - screw T8 for drive axles D8mm 400, 500mm
- Nut with trapezoidal thread 8mm T8 Z-axis
- A4988 stepper motor driver
- Voltage regulator - Step down 12
- Capacitor C0402 100nF/50V X7R
- Servo motor micro SG90-360
- Force sensitive resistor 0.5” SEN-0048
- Node MCU processor - ESP8266 Wi-Fi
- Breadboard
- Resistor R4.7/3W
- Adapter – 5 V

C.2. Standard selection of a component (example)

Because of the radial and axial loads, it makes sense to support the structure with tapered roller bearings. In this case, two bearings are used, mounted so that the tapered roller bearings form an axis O.

The calculations used, based on which the necessary bearings are selected, are described in the next paragraph.

The first step in calculating the supports required for the structure was to determine what loads the Modules 1 and 2 components would exert on the structure as a whole and what loads the supports would have to take as a result. The total weight of the elements used to build areas 1 and 2 was calculated. The weight data of the standard components was determined from their technical documentation, that of the designed components based on automatic calculations of the amount of raw material used in the 3D printing program. The data is summarized in the following table:

Total construction weight:	531
Permitted load:	69
Mass of the construction:	600

When calculating the weight of the screw, the height of the screw H=200 mm and its diameter d=8 mm, as well as the density of the steel ρ=8000 kg/m3, from which it is made, were taken into account. When calculating the required bearing, both the radial and axial load of the structure are taken into account.

After consulting the standard tables, the bearing most suitable for the structure is a roller bearing with outer diameter D=52mm, inner diameter d=25mm and mass m=150g.

To check the serviceability of the bearing at a standard time of 10,000 hours and a maximum of 6,000 revolutions, the coefficient of serviceability of the bearing is also calculated.

The bearing I have chosen has a performance factor c=350 k N. After the calculations, we can conclude that the bearing is suitable for this construction

III. SOFTWARE OF THE MACHINE STK-23

The software of the STK -23 robot is in the form of code written in Arduino. The functions as well as the general execution of the code are described and presented as block diagrams. In order to explain the algorithm of action, the algorithms of the robot's functions are presented in the next three points.

A. *Algorithm of the initial function*

The initial control function of the STK-23 robot is the function for returning it to the starting position or the so-called Initial function. The functions that this part of the code performs are described in the following order:

1. The gripper/clip opens for 1 second
2. Opening stops
3. The cylindrical box of the robot starts to rotate clockwise
4. Check of circuit breaker 1
   Case 1: The switch is pressed - the rotation stops and the clip starts to move down.
   Case 2: The switch is not pressed - rotation continues until the switch is pressed
5. The clip/Gripper starts to move downwards
6. Check of circuit breaker 2
   Case 1: Switch pressed - Downward motion stops
   Case 2: The switch is not pressed - Downward movement continues until the switch is pressed

The Initial function is necessary for the robot because it allows the robot to restore its starting position before starting work and before performing actions on its other functions. Resetting also allows for recovery after a power outage, as well as in the event of factors affecting the system.

B. *Algorithm of the Gripper function*

The main function of the Gripper (or also called the Gripper-function) is to open and close the two clamps, thus releasing or squeezing the designated part to be gripped. This happens by sending pulses from the servo motor to the drive gear and measuring from the pressure sensor and adjusting the closing of the clips. The action algorithm of this function is described in the following steps:

1. The pressure sensor measures the values
2. The gripper closes
3. Checking the values measured by the sensor
   Case 1: The value measured by the sensor is greater than or equal to the set value (the set value is established experimentally on the basis of experimental set-up) - the closing of the gripper stops
   Case 2: The measured value is not greater than or equal to the set value (the set value is established experimentally on the basis of experimental set-up) - the closing of the clamps continues until this value is reached

C. *Algorithm of the Move-up function*

The operation of this function is entirely related to the vertical movement of the robot. This happens by sending pulses from the stepper motor to the screw, which in turn causes the entire gripper structure to rotate and move. The action algorithm of this function is described in the following steps:

1. Start from zero initial number of steps
2. The structure starts moving one step up.
3. The number of steps is calculated by adding the next step to the number of the previous ones
4. The number of changed steps is checked
   Case 1: The number of steps taken is equal to the set value (the set value is established experimentally on the basis of experimental setup) - the upward movement stops
   Case 2: The measured value is different from the set value (the set value is established experimentally on the basis of experimental setup) – the movement continues until this value is reached

D. *Algorithm of the Rotation function*

The operation of this function is entirely related to the rotation of the robot. This happens by the gear being driven by the motor, which in turn causes the meshed gears to rotate and the whole structure to rotate. The action algorithm of this function is described in the following steps:

1. Start from zero initial number of steps
2. The structure rotates with 128 steps (the set value is determined experimentally on the basis of experiments)
3. The number of steps is formed by adding 128 steps to the number of previous steps.
3. Waiting for the machine
4. The number of steps taken is checked
   Case 1: The number of steps taken is greater than or equal to the maximum number of steps - rotation stops
   Case 2: The measured value is less than or not equal to the set value - the rotation continues until this value is reached

E. *Algorithm of the Web server feature*

The connection and control of the robot is done via Wi-Fi, since the processor has such a module and gives this possibility of control by remote access. The code serves to launch the robot's web page in the browser, but there are no functionalities related to the robot. Upon successful connection to the network and entering the address of the robot's web page, a page is opened that lists both the robot's control buttons and the fields for adjusting two of the main parameters - the force that is exerted when pressing, as well as for the closing speed of the clip.

"Home" button - returns the robot to the initial position, is pressed after performing the function from the "Run" button

"Run" button - starts the program by executing the commands that are responsible for gripping, lifting and shifting the workpiece, both up and 90 degrees

"Release" button - this button releases the gripper

"Force" field - in this field, the value of the force with which the clamp will press the workpiece that it grips is set

"Speed" field - in this field, the value of the speed with which the clamp closes when gripping the workpiece is

F. *Algorithm of the entire program code of STK-23*

Some of the functions discussed in the general scheme are explained in the previous points. The action algorithm of this function is described in the following steps:

1. The robot is turned on and has power
2. The robot controller connects to the machine through the web server (The algorithm of connection is explained in point
3. Execution of received command

Command 1: "Home" command
   Case 1: If this command is received and the robot is not in the "Home" position, then goes to the "Run" command
   Case 2: If the robot has received the "Home" command, but is already in this position, it the command was honored.

Command 2: "Run" Command
   Case 1: If the robot has fired this command and is in "Home" position, it is executed sequentially the following functions "Close the gripper" (the detailed algorithm is discussed in

point B), “Move up” “(the detailed algorithm is discussed in point C), “Rotation” “(the detailed algorithm is discussed in point D)

Case 2: If the robot has received this command but is not in the “Home” position, it the command is deleted.

Command 3: Command “Release”

Case 1: If this command is given, “Open Gripper” is executed and then the command is deleted

Case 2: When this command is not issued, the robot remains connected to the server and waiting for a new command to be submitted

4. If none of the three commands are entered, the robot remains connected to the server and waits
submitting a command

IV. ASSEMBLING THE MACHINE - STK-23

The assembly of the STK-23 robot takes place in three big steps The parts are connected either by assembling the nodes provided in the design, or by using standard screws.

A. *Assembling Module 1*

The following steps were followed to assemble Module 1:

Step 1 Install the side cover hinges
Step 2 Install the side cover
Step 3 Installing the Side Cover Lock Mechanism Step 4 Assembling the Structure and 28BYJ-48 Stepper Motor (Motor 1)
Step 5 Assembling gear 1
Step 6 Install the limit switch 1
Step 7 Motor assembly 1 driver
Step 8 Assembly of processor STK-23
Step 9 Assembling the STK-23 board and electrical components

The photos below (Fig 4 and Fig 5) show the Module 1 before and after assembling process.

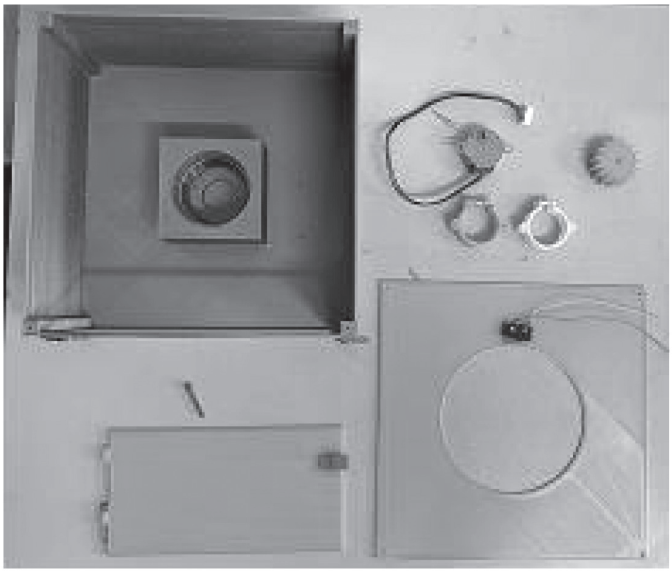


Fig 4

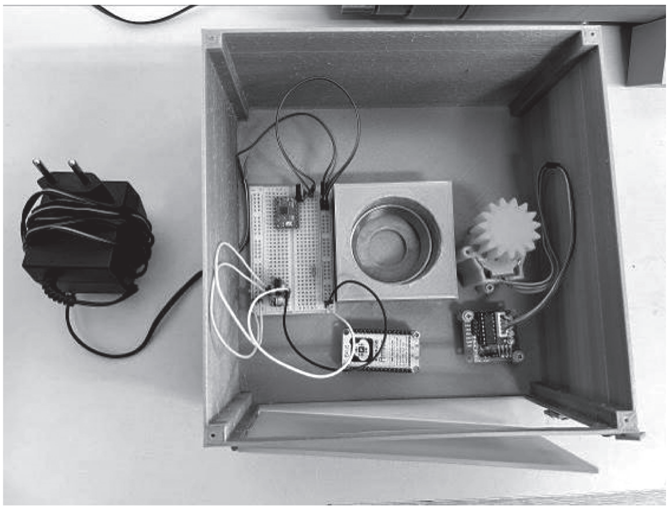


Fig 5

B. *Assembling Module 3*

The following steps were followed to assemble Module 3

Step 10 Assembling the pressure device
Step 11 Installation of the pressure sensor with treadle
Step 12 Mounting the pressure device on the clamping bracket
Step 13 Installation of the nut
Step 14 Micro SG90-360 Servo Motor Assembly (Motor 3)
Step 15 Installation of the clamping brackets
Step 16 Assembly and attachment of gear 3

The photos below (Fig 6 and Fig 7) show the Module 3 before and after assembling process.

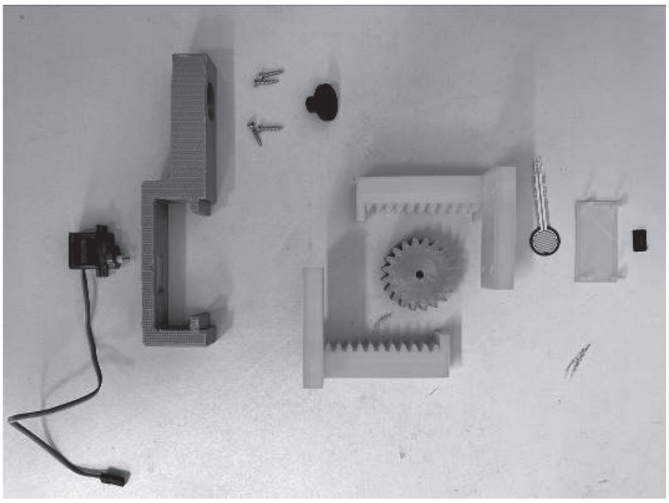


Fig 6

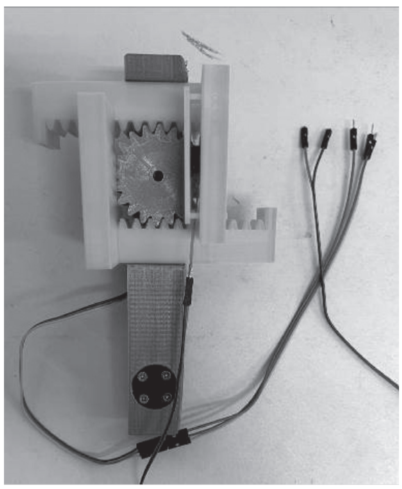


Fig 7

C. *Assembling Module 2*

The following steps were followed in assembling Module 2:

step 17 Installation of tapered roller bearings

Step 18 Nema 17HS2408S Stepper Motor Assembly (Motor 2)

step 19 Installation of the vertical movement mechanism

Step 20 Installation of the limit switch

step 21 Assembling the module housing 2

step 22 Assembly and installation of the compensatory part

step 23 Assembling gear 2

step 24 Connecting the assembled components of Module 2

The photos below (Fig 8 and Fig 9) show the Module 2 before and after assembling process.

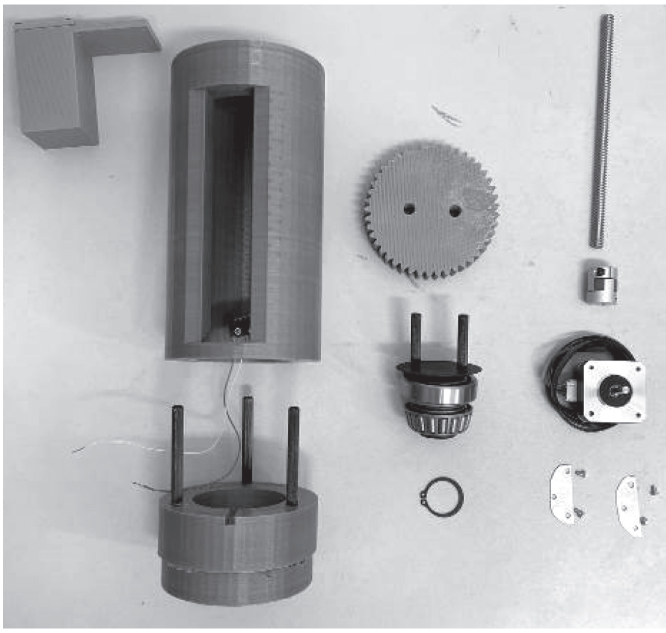


Fig 8

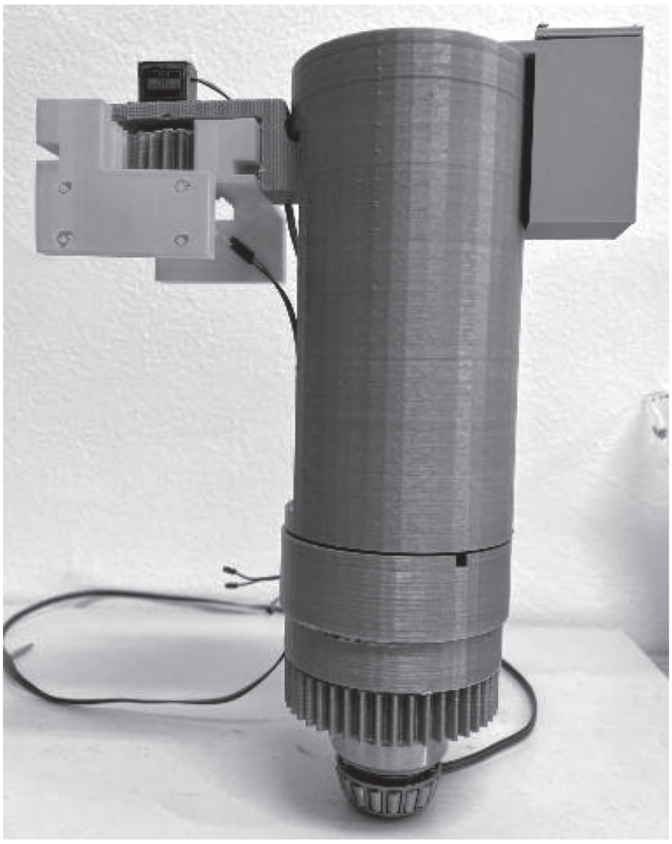


Fig 9

D. *Assembling the complete machine STK -23*

The complete assembly of the machine is done when the following steps are performed:

step 25 Assemble the shaft assembly and pinion 2 into the main box

step 26 Installation of the top cover

step 27 Connecting module 2 structural parts. Complete the installation of the STK-23

On the picture below (Fig 10) there is the completely assembled machine.

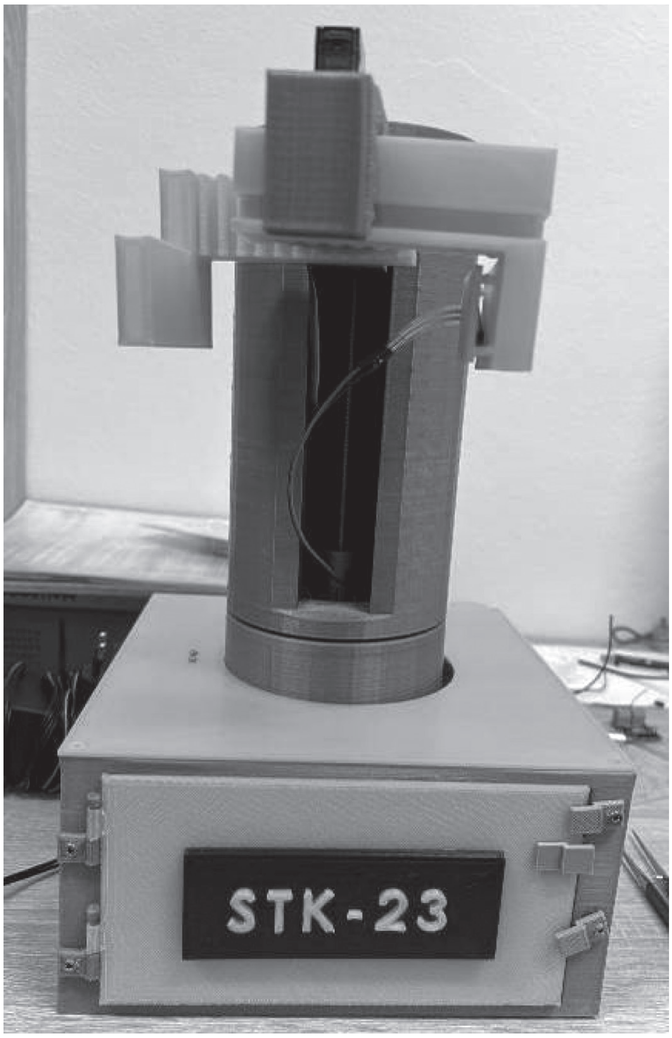


Fig 10

V. FUNCTIONAL TESTING OF STK -23

To test and prove the functionality of the constructed machine, some experiments and test were performed with the STK-23. The purpose of the tests as well as their results are described in the paragraphs below.

A. *Experiment 1 - Calibration of the robot - determination of permissible loads and parameters*

The purpose of the functional tests that are performed during the first part of the experiments is to determine the values of the main parameters that are important for the robot STK -23 to work properly.

A.1. Functional test 1 – determination of the "Force" and "Speed" parameters

The main purpose of the conducted experiment is to determine the permissible operating parameters ("Force" and "Speed") of the constructed robot. The results obtained are the robot's attempt to pick up details when providing different values for the indicated parameters.

	Results of Functionality TEST 1			
Force	1000	2000	3000	4000
Speed	2000	1800	1700	1650

Tab.A1

It is important to be mentioned that these values are dimensionless.

Based on the following results it is established a relationship between both parameters that is illustrated with the following line diagram:

A.2. Functional test 2 – determination of the maximal weight lifted by the robot

The purpose of this functional test is to determine the range of the STK-23 robot - what is the maximum permissible load, as well as for what values of the "Force" and "Speed" parameters the robot can lift the workpiece without difficulty. As the tests progressed, it was found empirically that it was necessary to introduce one more parameter for holding force. This parameter is used to keep the clamp motor running when the workpiece is gripped. This prevents the workpiece from slipping out of the clamp. It has been found experimentally that the required value for the holding force is 1630. The value is constant and does not change in the other tests.

	Results of Functionality TEST 2			
Weight of the detail m, g	90 g	80 g	70 g	60 g
Force	1000	2000	3000	4000
	2000	1800	1700	1650
Holding force	1630	1630	1630	1630
Result	Fail	Fail	Fail	Pass

Tab.A2

As a conclusion, the maximal weight is m=60 g.

B. *Experiment 2 – Establishing the dependance of the parameters on the mass of the details*

The purpose of Experiment 2 is to determine the required values of the parameters Force (force of clamping the clip) Speed (speed of closing the clip) depending on the weight of the part. In the experiment, parts of different weights were used. In this experiment, the Force and Speed values as well as the mass m of the workpiece are variable. The holding force parameter introduced in Experiment 1. Because as found in Experiment 1, the limit value for the parameter for the mass of the workpiece that the gripper can lift is 60 grams. For this reason, details with mass m1=50g, m2=40g, m3=30g were used.

First try, m = 50 g.

	Test 1	Test 2
Mass (const)	50 g	50 g
Force	1000	2000
Speed	2000	1800
Holding force	1630	1630
Result	Pass	Pass

Tab.B1.1

As a conclusion, the detail with weight is m=50 g has been moved successfully.

Second try, m = 40 g.

	Test 1	Test 2	Test 3
Mass (const)	40 g	40 g	40 g
Force	1000	2000	3000
Speed	2000	1800	1700
Holding force	1630	1630	1630
Result	Pass	Pass	Fail

Tab.B1.2

As a conclusion, the minimal values for a detail with weight m=40g have been determined.

Third try, m = 40 g.

	Test 1	Test 2	Test 3	Test 4
Mass (const)	30 g	30 g	30 g	30 g
Force	1000	2000	3000	4000
Speed	2000	1800	1700	1650
Holding force	1630	1630	1630	1630
Result	Pass	Pass	Pass	Fail

Tab.B1.3

As a conclusion, the minimal values for a detail with weight m=30g have been determined.

C. *Experiment 3 – Establishing the time for performing the "Move up" and "Move down" function*

The purpose of Experiment 3 is to determine the required time for performing different functions. The tests are divided into two types – performing the functions without detail and with detail with m=30 g.

Functional test 1 – Measurement of ascent time of the robot STK-23

The purpose of the experiment is to measure the time it takes the robot to perform the "Move up" and "Move down" functions. Since performing the "Move down" function, it is always performed without a detail, the time will be the same. The initial values as well as the results of the experiment are described in Table.

Initial values for functional test 1		
Mass (const)	Without detail	30 g
Force	1000	1000
Speed	2000	2000
Holding force	1630	1630
Results from Functional test 1		
Time for moving up, s	8.8 s	8.8 s
Time for moving down, s	8.9 s (The time is the same since there is no detail during the move down)	

Tab.C1.1

After the experiment, the following conclusion can be drawn: The time to perform the function "Move up" is the same as to perform the function "Move down". The descent time is the same because in the descent function the robot does not hold a workpiece in its clamp

Functional test 2 – Measurement of rotation time of the robot STK-23

The purpose of the experiment is to measure the rotation time of the gripper. When conducting the first part of the experiment, it is not necessary to use a detail.

Initial values for functional test 2		
Mass (const)	Without detail	40 g
Force	1000	1000
Speed	2000	2000
Holding force	1630	1630
Results from Functional test 2		
Rotation time, s	-	-
Clockwise, s	5,2 s	5,2 s
counter clockwise, s	5,4 s	5,4 s

Tab.C1.2

After the experiment, the following conclusion can be drawn: The time to execute the function "Rotate clockwise" is the same as to execute the function "Rotate counter-clockwise". These results show that stepper motors do not skip steps. This defines the choice of motors as a good one.

Functional test 3 – Measurement of gripping time of the robot STK-23

The purpose of the experiment is to measure the closing time of the gripper clip when performing the "Grip" function against different speed. The "Force" parameter and the driving force are constants. Only the "Speed" parameter is variable, as the values for it are the standard ones. When conducting the first part of the experiment, it is not necessary to use a detail.

Initial values for functional test 3 – part 1			
Force	1000		
Wight of the detail m, g	Without detail		
Holding force	1630		
Results from Functional test 3			
Test Nr	1	2	3
Speed	2000	1800	1650
Time, s	0.4 s	0.8 s	0.94 s

Tab.C1.3

The second part of the experiment is carried out under the same conditions, but this time a workpiece with a mass of m = 30 g is used. Here, in addition to changing the "Speed" parameter, the "Force" parameter is also changed.

Initial values for functional test 3 – part 1			
Wight of the detail m, g	30 g		
Holding force	1630		
Results from Functional test 3			
Test Nr	1	2	3
Force	1000	2000	4000
Speed	2000	1800	1650
Time, s	0.9 s	0.9 s	0.9 s

Tab.C1.3.2

Conclusion: In the conducted experiments, it can be concluded that when the machine is not freewheeling, but there is a workpiece to be gripped, the time to perform this operation is a constant.

D. *Conclusion – Establishing the total time of the robot STK-23 for performing all of the functions*

Based on the functional tests and experiments described in the previous paragraphs were made the following experiments to determine the total time that is required for all of the functions of STK - 23 to be performed.

Total time for performing the functions of STK-23		
Holding force	1630	
Force	1000	
Speed	2000	
Total time (t, s)	Without detail	With detail m=30 g
	29.1 s	29.2 s

Tab.D1

As a conclusion it can be said that there is a slightly difference in the time that is estimated.

VI. References

[1] Kirova Shtiliana, "Entwicklung STK-23 - Greifer Maschine mit einem Mechanismus für vertikale Bewegung und Drehung im rechten Winkel – STK 23," June 2023. (references)

[2] o.A., o.J, "5 Top Robotic Gripping Solutions Impacting The Manufacturing Industry"

[3] Fairchild, Mark, 31.08.2021 Freelance Technical Copywriter, Fairchild Copywriting, "Types of Industrial Robots and Their Different Uses"

[4] Uko, Etiido, 13.04.2022 "Fundamentals of Pneumatic Grippers for Industrial Applications "

[5] Gordon, Rachel, MIT News, 13.07.2020 "MIT creates tactile-reactive robot gripper that manipulates cables"

[6] o.A., o.J, "Robots Hall of fame: Unimate"

[7] o.A., o.J, "Slip sensor for easy and safe slip detection during gripping process "

[8] o.A., o.J, " Object Detection on Robot Grippers with Ultrasonic Sensors"

[9] o.A., 16.05.2022 "SMART GRIPPER, MUCH MORE THAN JUST A GRIPPER"

[10] o.A., o.J, " Guide to 3D Printing Materials: Types, Applications, and Properties "