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Modernization of 2D Printer Model

Bachelor's Degree Final Project

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DECLARATION OF ACADEMIC INTEGRITY

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SUMMARY

The aim of the project is to develop and construct 2D manipulator with full establishment of electrics' components, calculating acting forces on surfaces, using programming and design innovations, and calculate costs of the components. Firstly, history of printing is analysing to explain how printing evolved during the time, what influenced technology to develop and why printing is important even now - in the modern technology world. The 2D printer - manipulator assemble with assembly schemes, all components listed in table and explain. Path of assemblies are analysing and show in the schemes. Calculating stresses and moments on axes – one on main frame axis and other one on top frame axis, stresses and moments diagrams allow to fully understand the impact of forces. The electrical box is assembled with assembly scheme as well, components listed and explain. Programming drawing program, code converter process establishment and collection into cloud server. Creating real view design of the project and presentational video, calculating prices of components and comparing it in the tables, analysing economics advantages and disadvantages of the project.

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SANTRAUKA

Projekto tikslas – išvystyti ir sukonstruoti 2D spausdintuvą – manipuliatorių įtraukiant elektros dėžės surinkimą ir komponentų parinkimą, skaičiuojamos veikiančios jėgos, naudojamos programavimo kalbos ir dizaino inovacijos, apskaičiuojama komponentų kaina. Pirmiausia, spausdinimo istorija yra išanalizuojama ir paaiškinima, kaip spausdinimas vystėsi bėgant laikui, kas tai įtakojo ir kodėl spausdinimas išlieka svarbus ir šių dienų technoliginiame pasaulyje. 2D spausdintuvas – manipuliatorius yra surenkamas naudojantis surinkimo schemomis ir jų surinkimo eiliškumu, visi komponentą išdėstomi lentelėje ir paaiškinami. Skaičiuojamos veikiančios jėgos ir momentai ašyse – viena esanti pagrindiniame rėme, kita viršutiniame. Jėgų ir momentų diagramos leidžia puikiai suvokti jėgų poveikį sistemai. Elektros dėžė yra surenkama su surinkimo schemomis, visi komponentai yra išdėstyti lentelėje ir paaiškinti. Suprogramuojama piešimo programa, paaiškinamas kodų konvertavimas procesas ir debesų kompiuterijos veikimas. Sukuriamas tikras grafinis vaizdas ir prezentacinis video. Suskaičiuojama komponentų kaina ir viskas palyginima lentelėse, išanalizuojami ekonominiai produkto pranašumai ir trūkumai.

Introduction

It is hard to image the world without printing technology. Started form simple woodblock printing, nowadays we have incredible speed 2D printers, we can build objects at home with 3D printing for our projects, and 4D printing technology is coming in our daily life with polymers properties. Today printed products such as newspapers, books, magazines are used by everyone. Keeping up with new technology science investing on the new types of printing, searching for a new way to increase printing speed, make better quality of images, create less expensive equipment and etc. Therefore the project was implemented using new technologies and the best quality components. The project can be seperated into 5 parts: mechanical development and assembly using company‘s Festo parts with shear stresses, moments calculations and diagrams; electrical establisment and assembling parts with wiring and electrical scheme; advanced software programming for drawing program, data collection, G codes convertor, cloud databases computing; attractive and ergonomic design with 3D modelling presentation, economic calculation of the product‘s components costs with analyses in the technical and innovation field. All parts together creates fully working 2D manipulator by gathering all five the most important study fields – mechanics, electronics, programming, design and economics.

Aim – to develop and construct the 2D manipulator with full mechanical, electrical, programming, design establishment and economics calculations.

Objectives – Construct and assemble 2D Printer Manipulator with Electrical Box, calculating forces acting on toothed belt axes, include programming codes and software, create presentational video of the project and analyze benefit of the project with prices comparison of the components.

Requirements and technical data – Develop 2D Printer – Manipulator within Mechanical, Electrical, Programming, Design and Economical Establisment which meets safety requirements.

1. History. 2D Printers Review of Technical Use in Industry

Printing industry does not show up as a big market player, but it almost 9 times bigger than video game industry and 90 times bigger than music industry. Printing in gloval industry creates about 900 billion dollars per year, comparing with video games (100 billion) and music industries (15 billion) [1] it is clear that printing dominates in industry despite a fact that it does not look a huge market. However, how does that simple invention became so necessary for humanity and how does it developed during the ages?

History of printing started in east asia with woodblock printing (200). It is a printing technique for patterns, images or printing text with seals and stamps, used for decoration and scripting. It was primitive method and required a lot time to make stamps. Instead of big amount of labor, quality was not good enough. Anyway method was used for more than millenium until new technologies were invented [2]. Later on moveable type printing was developed (1040). It is a printing and typography method that uses movable components to reproduce the elements of a document which started in china, however it was expensive and required a high amount of labor force to manipulate the thousands of ceramic tablets or metal tablets [2]. Groundbreaking printing press technology was invented in 1454 by the Johannes Gutenberg in the holy roman empire. Printing press is a device for applying pressure to an inked surface. New generation hand mould was made for rapid and precise creation, movable type printing were used in large quantities, most importantly profitability trascended new level. That was a start of

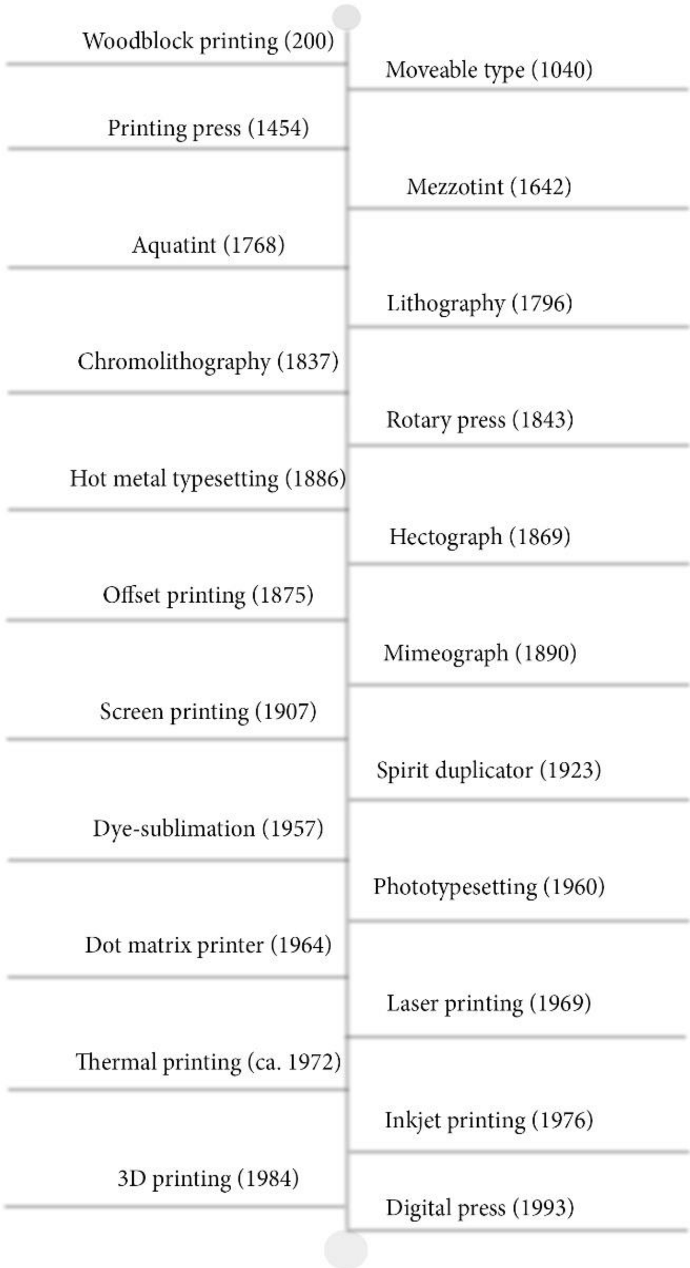


Figure 1-1. History of Printing [2]

the new era of books printing which increased number of printed books abundantly and the education level rapidly increased over the world (**fig. 1-2**). In comparison east asia movable printing type could produce about 40 pages per day, but printing presses could print more than 3600 per day. Revolution of printing reduced price of books, printing presses escalated quickly in europe, more 270 cities became centres of education, society could purchase more books and become more educated [2].

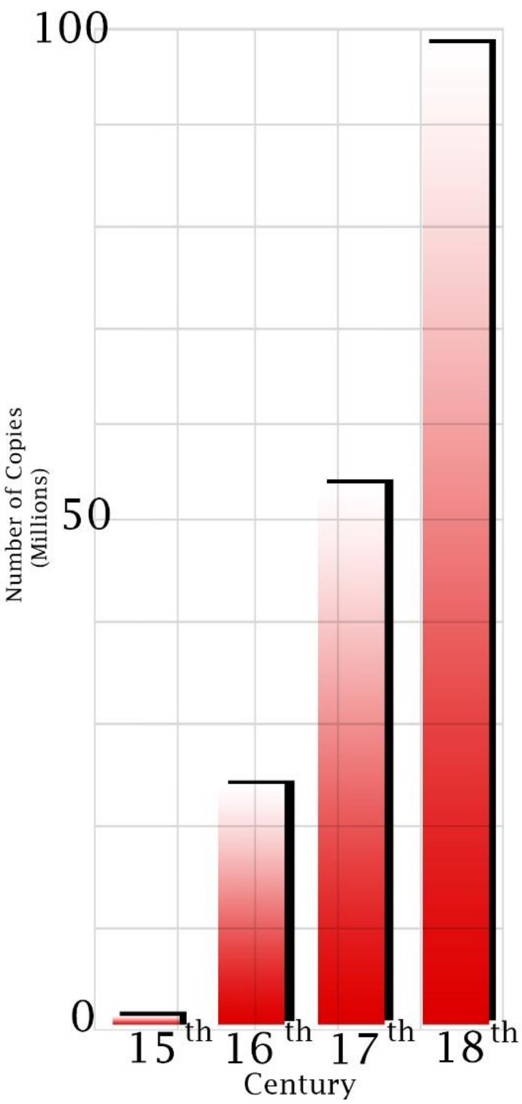


Figure 1-2. Number of Printed books [2]

After few decades was established metal treatment - etching (1500). Etching is traditionally process of using strong acid to create a design in metal plates. It was an origin of metals coating and new type of manufacturing which led to advanced technology lithography establishment for computers micro-processors printing [2]. Almost the same method but with pressing was developed - mezzotint (1642) and aquatint (1768). Those methods are using by art makers to create extraordinary craft [2]. In 1796 lithography was invented by german author and actor alois senefelde who used it as a cheap method to present publishing theatrical works. Lithography based on the immiscibility of oil and water on metal plates. Simple lithography is used for posters, books, maps, newspapers or any other graphics production [2]. Nowadays this method became advanced microlithography and nanolithography used mostly for micro-processors (photolithography) [2]. Method evolved into more complex systems such as interference lithography, interference lithography, extreme ultraviolet lithography, x-ray lithography, magnetolithography and more [2]. Lithography led to chromolithography (1837). It is method for multi-colours making, based on chemical processes by rejection of water on grease. The image can be applied on stone, zinc or aluminium to obtained and create chromolithography based art [2]. Rotary press was developed in 1843 which could print large number of cardboards, plastics and papers. There are three types of presses: offset, rotogravure, flexography. For continous and fast amount of printing sometimes this method is reffered as „web pressing“ [2]. Later on hectograph (1869) was started to be used, where special inks were used with tight pulled gelatin pad on a metal frame [2]. In 1875 offset printing was invented. Plate cylinder had water rollers and ink rollers from both sides, blanked (offset) cylinder and impression cylinder below plate cylinder are rolling by pressing paper. This method was used for newspapers, magazines, books prepress production [2]. Hot metal typesetting in 1886 started to be used as technology for typesetting letterpress printing which has many types of metal molds. Technology revolutionize printing in journalism, accounting, data collection and in many other areas [2]. After few decades mimeograph came to industry (1886) and it was low-price duplicate machine by forcing ink on the paper [2]. In 1907 photostat machine was developed. This method is origin of projection photocopier where through lens cought light is printed on drum [2]. Then spirit duplicator was invented (1923) - is the same as mimeograph but less expensive and for simplicity was mainly used by churches and schools [2]. In 1957 Dye-sublimation used heat and high pressure to transfer dye on materials, the process sometimes called dye-diffusion. This method was revolutionize technology in which by using heat and pressure dyes jumped from gas to solid without passing through the liquid phase by that could create high quality full color artwork [2]. After 3 years phototypesetting was invented (1960). Using a round metal plate with cut out symbols (mostly letters and numbers), illuminated with light on photographic paper to generate columns [2]. In 1964 dot matrix printer started to be used. It is a computer printing method which is using head that moving along one axis with moving paper in opposite direction. Striking creates dot matrix and each dot is made by tiny metal rod to produce exact shapes, lines and figures. Low cost, cheap repair expensives, easy to operate - made dot matrix printer very popular and usable. However, low resolution, slow, fading of colors pushed humanity find new ways for printing [2]. In 1969 Laser printing technology came to market. It is electrostatic digital method, with high graphics and accuracy, using laser on the mirror and lenses to obtain required shapes on the drum [2]. Thermal printing (1972) was new innovation in industry which is using heat to produce image on thermochromic paper. The coat becomes black where it is heated and mostly is used for cheques printing . Inkjet printing creates a digital image by ink through nozzle, dropping droplets on paper using pulse voltage onto piezoelectric transducer. This method is the most commonly used because of cheap production and professional quality [2]. In 1984 three dimensional printing technology started to be used. 3D printing is a method in which printer creates three dimensional object by printing layer by layer of material on plate. Sometimes it is called additive manufacturing (AM). The process model is the same as simple 2D printer but with third axis which creates three dimensional objects instead of two dimensional and therefore gives 3D name to printer [2]. Then digital press was invented in 1991. It is based by lasers printing technology on sensitive photographic paper creating continuous tone of the image. Digital printing has a higher cost of printing, however, because this printing method has no printing plates it is a cheap technology for big amount of printing [2].

Nowadays printing drives 3.8 Trillion of dollars in relative services such as books, newspapers and advertising. 8.5 Trillion letter size simplex pages are printed annualy in only North America. 96% of news reading is still in print , 87.1 billion monthly printed page views. The part of market share of print are provided in the fig. 1-3. Despite of the fact that the internet is dominating market force, but 80% of households read or browse their advertising mail and 59% of print is more engaging for users than online articles. Moreover, direct mail marketing response rates are 37% higher then mail marketing (only 0.1% of response) and 43% of print is less annoying than the internet [1]. Customers more appreciate to get printed well-design postcard or catalog than some advertising via e-mail. Here is only few reasons why printing is so important and has to get more attention for development and sponsorship to create new innovations. [1]

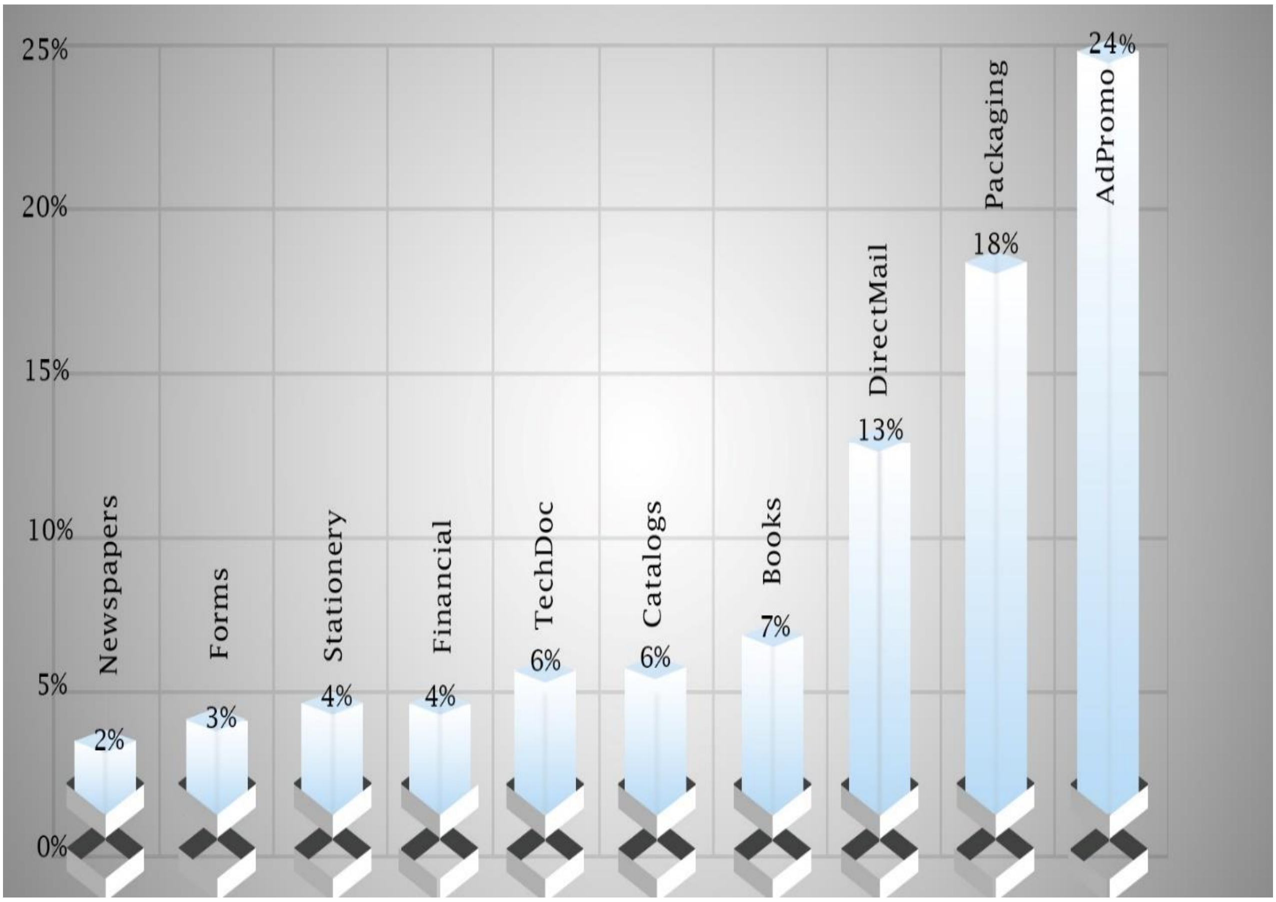


Figure 1-3. Market Share of Print Products [1]

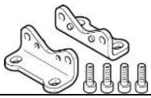
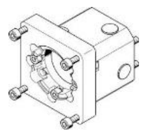
2. Mechanical Components Selection and Assembly Schemes

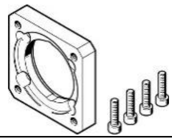
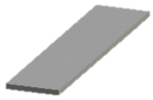
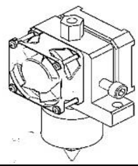
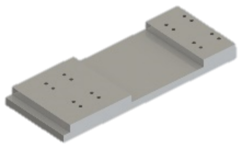
Mechanical components' importance for sustainable and effective manufacturing processes became priority for all leading companies in industry field. Produce high quality products is necessary to combine high standards corresponding mechanical parts which secure goods maintenance and durability, reliability and trustworthiness. In this project only tested and well-known components were used from best quality materials and made in advanced manufacturing companies.

The idea of the project was to create fully working 2D manipulator which was already proceed by company "Festo" one of the leader in automation technology. The aim of the project was to design into CAD system 2D Manipulator - Drawer from 3D printer using parts from "Festo" catalogue. The project was started by the company but not completed, about 70% was done, but not fully working and not started to modelling in CAD system. Company's purpose is not only to create 2D manipulator but to develop innovative product for presentational purposes in automation and up-coming technology for new the "Industry 4.0" revolution. Electrical Scheme and 3D Manipulator are shown in annex 1 and annex 2.

For assembling mechanical scheme, all parts have to be listed and numbered (table 2-1). In this project more than 36 different mechanical components were used (figure 2-1; 2-2). For every day growing industry and technology, manipulator has to have high quality components and has to be easy to access to change components for modernization or breakdown. 2D Manipulator's assembly schemes facilitate to assemble required components and strengthen stability. Two of toothed belt axes are assembled with servo motors [annex 3] and adjusted to frames. Main frame is a part of the bottom of the manipulator which holds all other parts and is a foundation of the project. Top frame is a part of the project where printing head adjusted to main axis holder and moves along axis. Belt links are adjusted to belt fixers and whole belt with ten links were made as well. Assembled all parts 2D manipulator was made, however electrical box with components and programming codes have to be included for fully functionality to print and work properly.

Mechanical Components [3] [4]

NO. of Component	Name of Component	Picture of Component
1	**HP-25** Foot mounting	
2	**MUP-18/25** Central support	
3	**QSM-M5-4-I** Push-in fitting	
4	**QSM-M5-6-I** Push-in fitting	
5	**NSTL-25** Slot nut	
6	**UC-1/8** Silencer	
7	**QS-G1/8-6-I** Push-in fitting	
8	**QS-G1/8-8-I** Push-in fitting	
9	**FDG-25-300-ZR-KF-GK** Toothed belt axis	
10	**DGE-25-300-ZR-RF-LK-RB-GK-KG** Toothed belt axis	
11	**DGE-25-300-ZR-RF-LK-RV-GK** Toothed belt axis	
12	**DGE-25-300-ZR-LV-RK-KG-KF-GK** Toothed belt axis	
13	**EAMM-A-F30-70A** Axial kit	

14	**EAMC-40-66-11-15** Coupling	
15	**EAMF-A-48A-70A** Motor flange	
16	**NPQH-BK-G18-P10** Plug screw	
17	**Profile**	
18	**Big Belt Holder’s Fix**	
19	**Main Holder**	
20	**Printer Head**	
21	**Profile Plug**	
22	**Shaft**	
23	**Main Axis Holder**	
24	**Belt**	
25	**Belt fixer**	

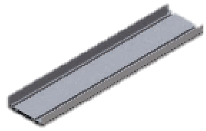
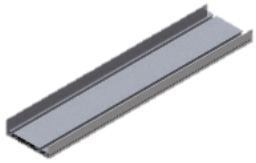
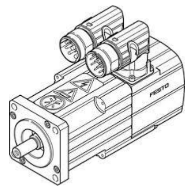
26	**Small Belt Holder I**	
27	**Big Belt Holder I**	
28	**Small Belt Holder II**	
29	**Big Belt Holder II**	
30	**EMMS-AS-70-M-LS-RR** Servo motor	
31	**Belt Link**	
32	**Head Screw ISO 1207 - M5 x 30 - 30N**	
33	**Screw DIN – 912 – M4x40**	
34	**Hex Thin Nut ISO – 4035 – M5 - N**	
35	**Plain Washer ISO 7092 - 5**	
36	**Slotted Head Screw ISO 1207 – M5 x 30 -30N**	

Table 2-1. Mechanical Components of the Manipulator

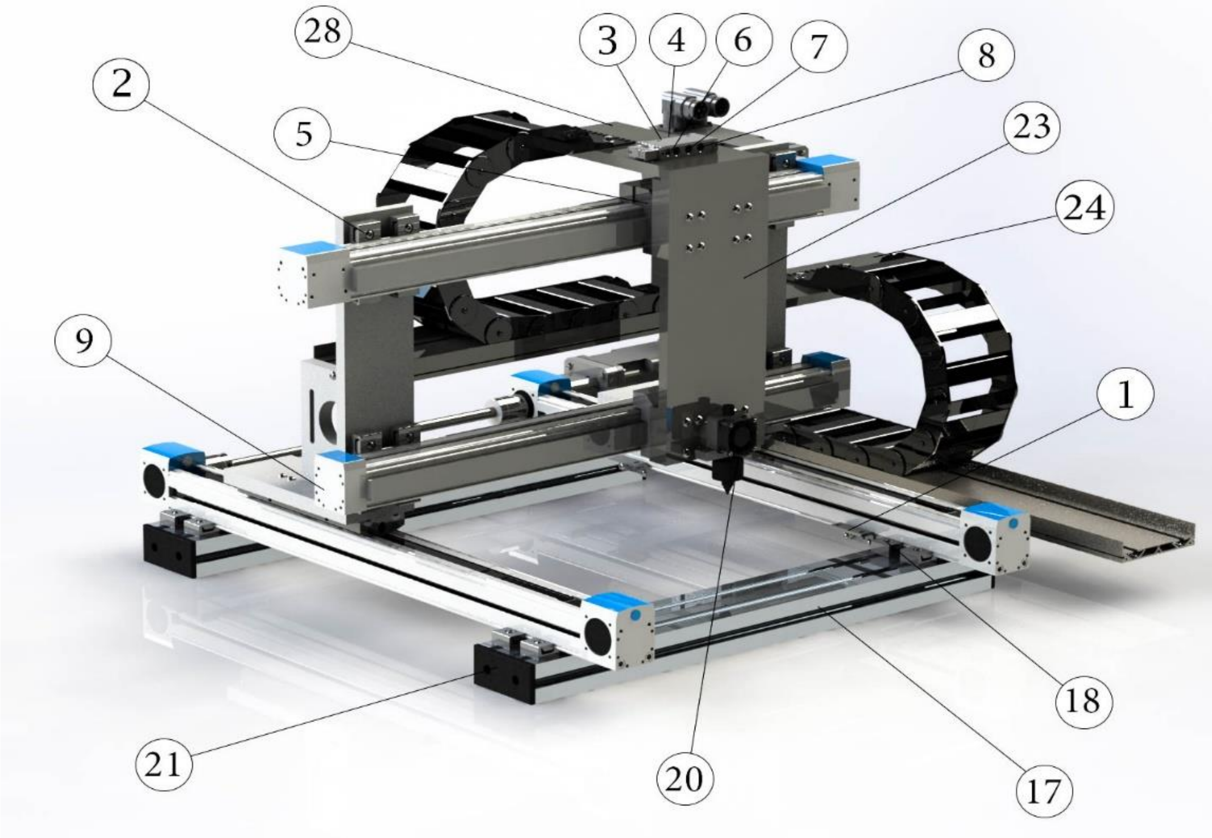


Figure 2-1. Numbered Parts of the Manipulator I

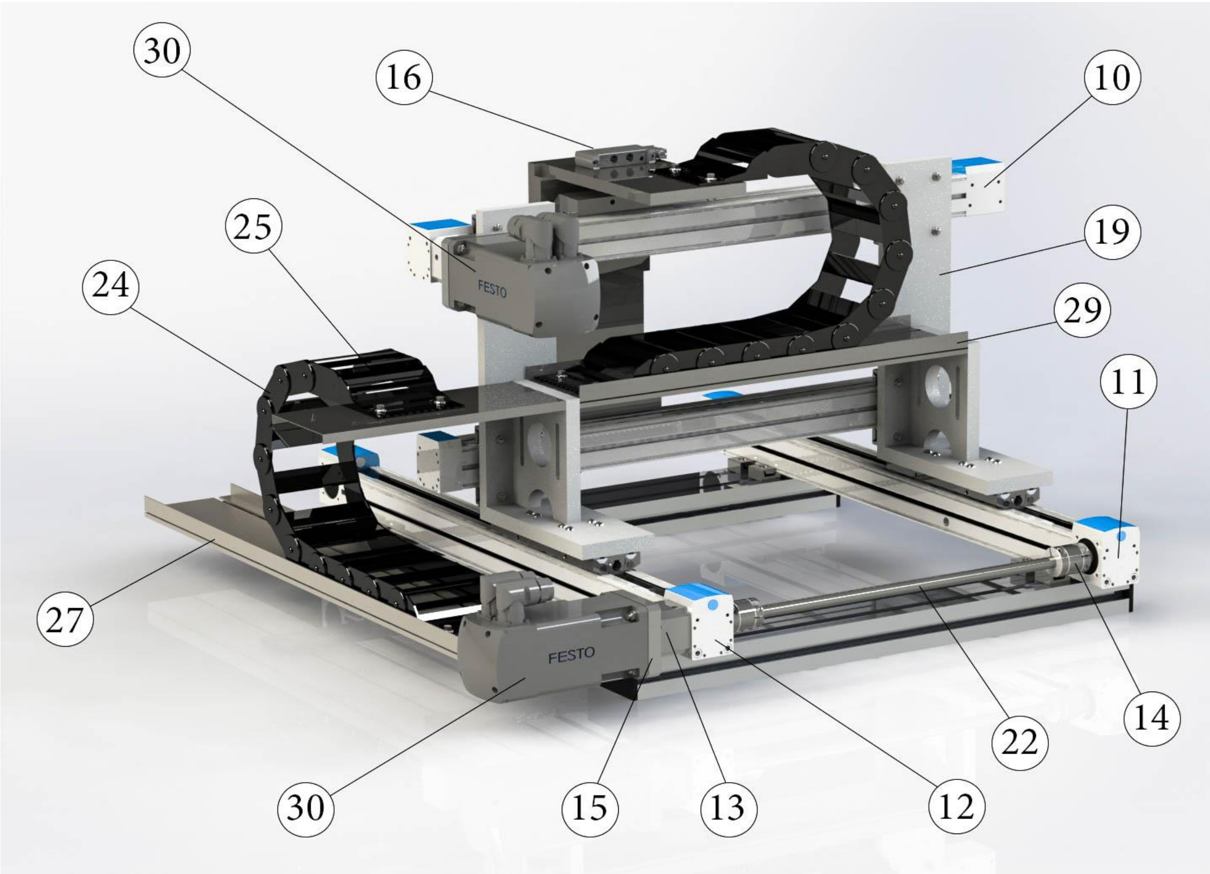


Figure 2-2. Numbered Parts of the Manipulator II

2.1. Assembly Schemes of the Manipulator

Manipulator has properties to move along X and Y axes where sensors defines limits, main frame is composed of toothed b. axis named DGE-25-300-ZR-RF-LK-RB-GK-KG (toothed Belt Axis II) which has the size of 25mm, 300mm stroke length, using ZR linear axis function with toothed belt, roller guide RF, drive shaft on the left - LK, no trunnion on left, drive shaft on the right - RB, trunnion right front/rear, slide has GK standard, coupling housing KG and another toothed b. axis named DGE-25-300-ZR-RF-LK-RV-GK which has the size of 25mm. stroke length 300m, using ZR linear axis function with toothed belt, roller guide RF, drive shaft on the left – LK, drive shaft on the right – RV with trunnion right/front, GK standard slide.

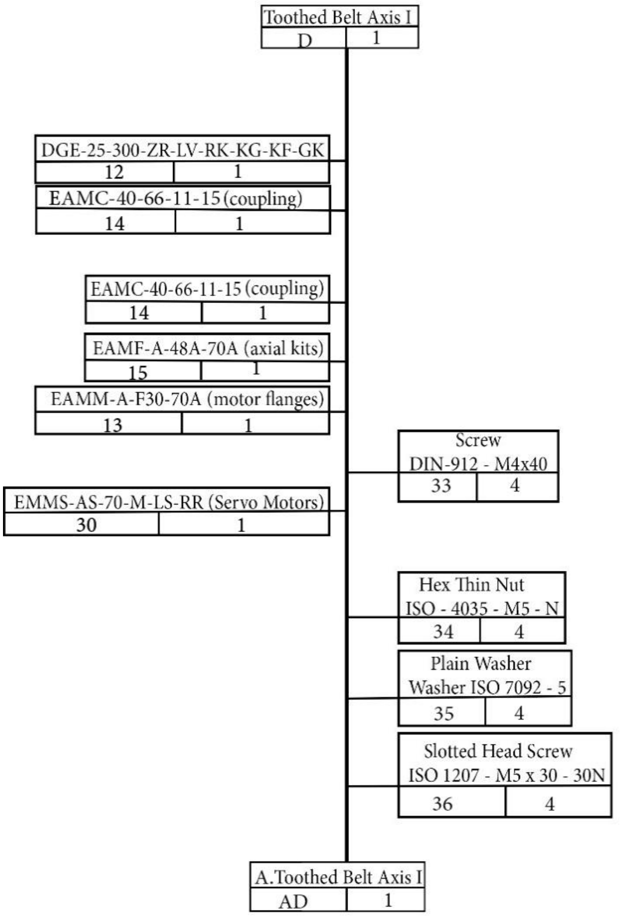


Figure 2-4. Assembly Scheme of the Toothed Belt Axis I

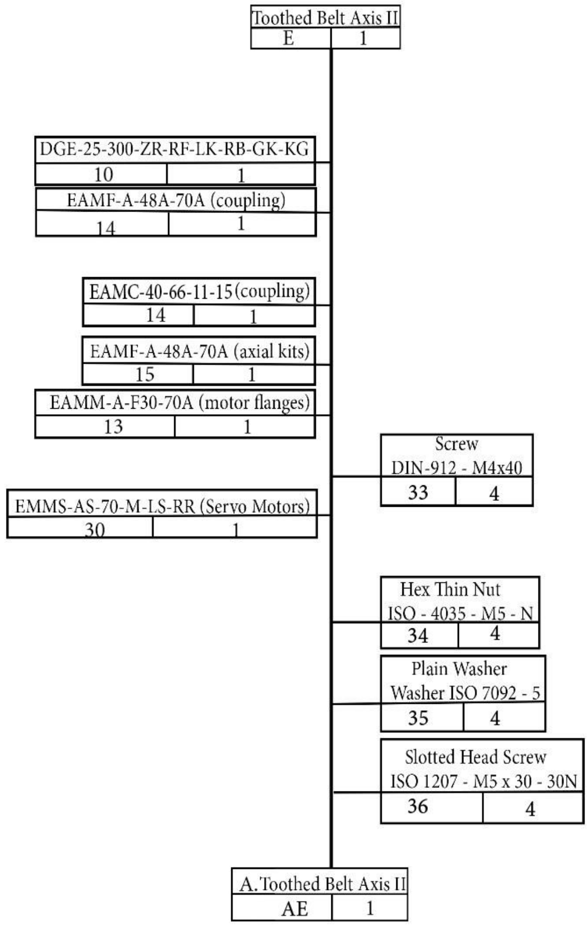


Figure 2-3. Assembly Scheme of the Toothed Belt Axis II

Both toothed belt axes (fig. 2-4) are fixed on profile (672mm x 80mm x 40mm) with NSTL-25 slot nuts inserted into profile and MUP-18/25 central supports which are screwed with head screws ISO 7380 – M5 x 30 – 30N. DGE-25-300-ZR-RF-LK-RB-GK-KG has EMMS-AS-70-M-LS-RR servo motor which is joined with EAMK-A-F37-44A_C motor flange with EAMC-30-35-6 coupling with screws DIN – 912 – M4x40., EAMF-A-44A_B-70A axial kits directly to motor and screwed with head screw ISO 1207 - M5 x 30 - 30N, washer ISO 7092 and hex nut ISO - 4035 - M5 – N.

Profile frame has two plugs each for aesthetics and ergonomics. Between belt axes shaft which is connected with two couplings.

Below toothed belt axis (DGE-25-300-ZR-RF-LK-RB-GK-KG) is fixed big belt holder’s two fixers with HP-25 foot mountings for sensors and big belt holder I. Main Holders are fixed on

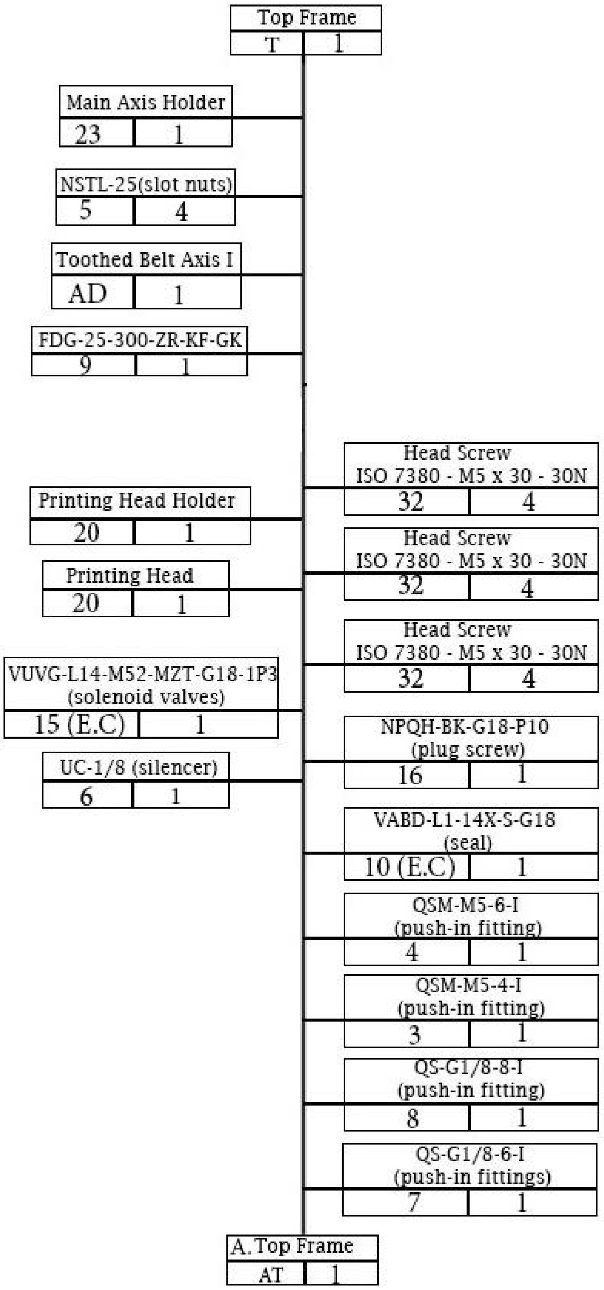


Figure 2-6. Assembly Scheme of the Top Frame

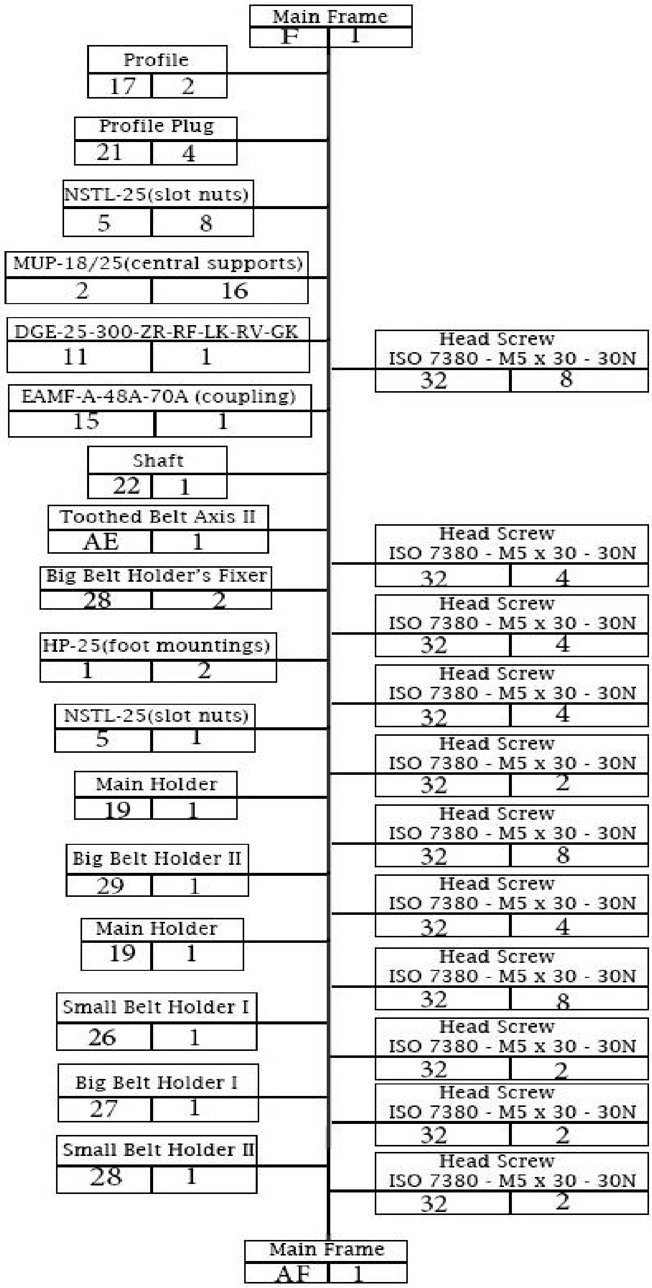


Figure 2-5. Assembly Scheme of the Main Frame

moving platform of toothed belt axes with NSTL-25 slot nuts and screwed with head screws ISO 7380 – M5 x 30 – 30N. Main holders have big belt holder II and small belt holder I fixed as well with head screws ISO 7380 – M5 x 30 – 30N (fig. 2-6).

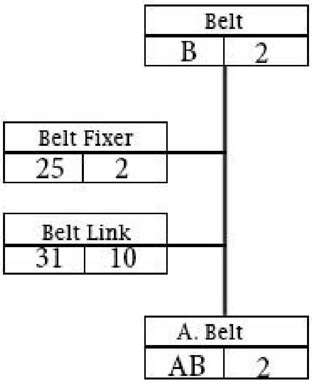


Figure 2-7. Assembly Scheme of the Belt

The top frame (fig. 2-5) is assembled with DGE-25-300-ZR-LV-RK-KG-KF-GK (fig. 2-3) which has the size of 25mm, stroke length is 300mm, linear axis function ZR, drive shaft on the left – LV, drive shaft front left, drive shaft on the right – RK, no drive shaft right, coupling housing - KG, KF recirculating ball bearing guide, GK standard slide and FDG-25-300-ZR-KF-GK is guide axis without drive with size of 25mm and 300m stroke, ZR guide axis for DGE – ZR, KF recirculating ball bearing guide, GK standard slide is used as well. Both toothed belt axes are fixed on main holders with MUP-18/25 central supports and screwed head screw ISO 1207 - M5 x 30 - 30N, washer ISO 7092 and hex nut ISO - 4035 - M5 – N. Axis DGE-25-300-ZR-LV-RK-KG-KF-GK has EMMS-AS-70-M-LS-RR servo motor which is fixed with EAMK-A-F37-44A_C motor flange, EAMC-30-35-6 coupling with screws DIN – 912 – M4x40., EAMF-A-44A_B-70A axial kits directly to motor and screwed with head screw ISO 1207 - M5 x 30 - 30N, washer ISO 7092 and hex nut ISO - 4035 - M5 – N. Main Axis holder are jointed with NSTL-25 slot nuts to both toothed belt axes and fixed with head screws ISO 7380 – M5 x 30 – 30N. On the top of the main axis holder VUVG-L14-M52-MZT-G18-1P3 solenoid valves are fixed with spare parts for valve QSM-M5-4-I (push-in fitting), QSM-M5-6-I (push-in fitting), QS-G1/8-6-I (push-in fittings), QS-G1/8-8-I (push-in fitting), NPQH-BK-G18-P10 (plug screw), UC-1/8 (silencer), VABD-L1-14X-S-G18 (seal). Printer head holder and printer head was chosen and modified for 2D purposes with ventilator (without heating wire) [5]. Head holder and printing head were screwed with head screws ISO 7380 – M5 x 30 – 30N.

Belt (fig. 2-7) are made from 10 links (92mm x 84mm x 32mm) with 2 fixers (92mm x 84mm x 32mm). Distance between links 161mm. Belt are fixed with hex flange bolt ISO 4162 - M5 x 10 x 10-N through big belt holder I The same screws, washer ISO 7092 and hex nut ISO - 4035 - M5 – N are used for fixing on small belt holder I. Second belt screwed through on small belt holder II, with head screws ISO 7380 – M5 x 30 – 30N, washer ISO 7092 and hex nut ISO - 4035 - M5 – N. Big belt holder II was fixed with NSTL-25 slot nuts and head screws ISO 7380 – M5 x 30 – 30N.

All parts were jointed and screws were used from “Solidworks Toolbox” to build manipulator’s stability. Material were selected polypropylene for belts, for other parts - wrought aluminium alloy anodized, high alloy steel (non-corrosive), stainless steel casting, polychloroprene with glass cord and nylon coating for axes, holders and etc. High quality components give possibility to create rigid and well-functionality of the machine. Manipulator matrix is large - 400mm x 500mm, servo motors provides maximum velocity, stiffness of belts, toothed belt axes establish perfect accucary, printing head has ventilator for unexpected heating and many other features which lead for advanced technology of printing which can be modified into other machines for manufacturing purposes (fig. 2-8).

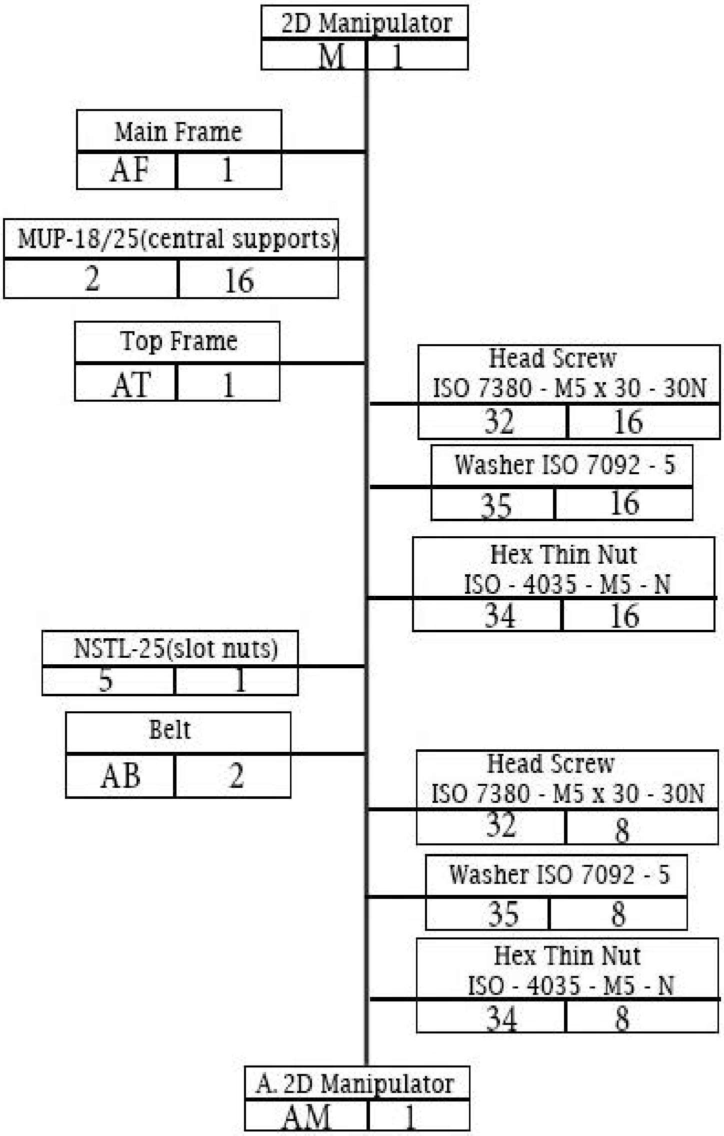


Figure 2-8. Assembly Scheme of the Manipulator

3. Calculations of Moments and Stresses on Toothed Belt Axes

Calculations of beams is important in modern buildings and mechanics for complexity of structures and safety. Using advanced software which let calculate quickly and show errors which can have impact in later development or even in buildings collapse or machines distortion. Calculations have to be accurate, all data has to be added carefully, and only then machines assembling can be started.

3.1. Features of Toothed Belt Axes

Some features of toothed belt axis (DGE-25-300-ZR-LV-RK-KG-KF-GK) is shown in the table 3-1 that will be used for calculations of stresses and moments.

Effective diameter of drive pinion	28.65 mm
Working stroke	1 ... 5,000 mm
Size	25
Stroke reserve	63 mm
Toothed-belt stretch	0.16 %
Toothed-belt pitch	3 mm
Assembly position	Any
Guide	Roller guide
Design structure	Electromechanical linear axis With toothed belt
Motor type	Servomotor
Max. speed	10 m/s
Repetition accuracy	±0,1 mm
Protection class	IP40
Ambient temperature	0 ... 60 °C
Area moment of inertia 2nd degree Ix	188E+03 mm4
Area moment of inertia 2nd degree Iy	236E+03 mm4
Max. drive torque	3.7 Nm
Max. force Fy	150 N
Max. force Fz	150 N
Max. idling displacement resistance	35 N
Max. feed force Fx	260 N
No-load driving torque	0.5 Nm
Mass moment of inertia JH per metre of stroke	0.188 kgcm2
Mass moment of inertia JL per kg of working load	2.052 kgcm2
Mass moment of inertia, JO	1.75 kgcm2
Feed constant	90 mm/U
Lubrication interval, distance dependent	10,000 km
Additional weight per 10 mm stroke	30.1 g
Basic weight for 0 mm stroke	2,610 g

Table 3-1. Features of Toothed Belt Axis [3]

Calculations are showing stresses on beams which are fixed with MUP-18/25 central supports.

$$F = mg \qquad q = \frac{F}{L} \qquad L = 0{,}716\, m \qquad m_1 = 1{,}1\, kg \qquad m_2 = 0{,}9\, kg$$

$$m_3 = 1{,}6\, kg$$

Calculated force of toothed axis (DGE-25-300-ZR-LV-RK-KG-KF-GK) with spare parts:

$$F = 1.1 * 10 = 11\ (N) \qquad q = 11\ \div 0.672 = 16\ (N)$$

Calculated force of main axis holder with printing head and other spare parts:

$$F = 0.9 * 10 = 9\ (N)$$

Calculated force of servo motor with spare parts:

$$F = 1.6 * 10 = 16\ (N)$$

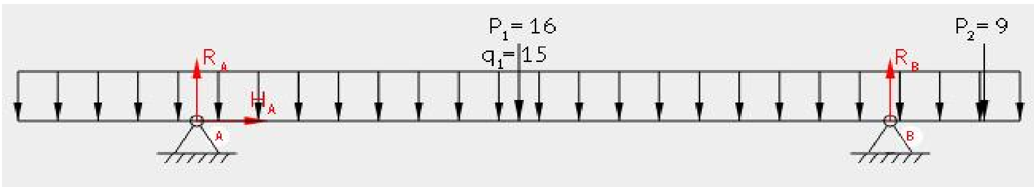


Figure 3-1. Beam Analysis of the Toothed Belt Axis I

Using "Solidworks Simulation" feature, Static motion study analyzes were obtained:

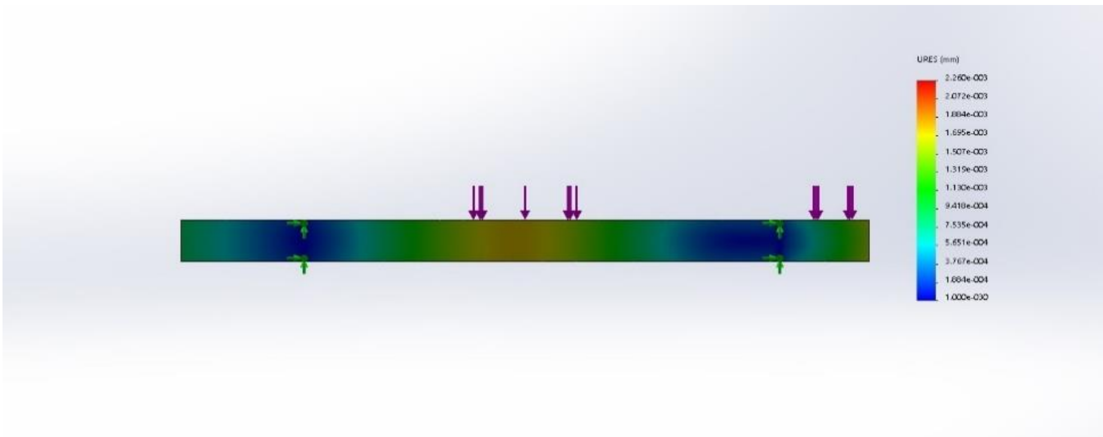


Figure 3-2. Simulation of Acting Forces on Toothed Belt Axis I

Maximum stresses act on the centre of the beam because it holds main axis holder with axis fixer. Smaller force is acting on the end of the beam where servo motor is fixed (fig. 3-2).

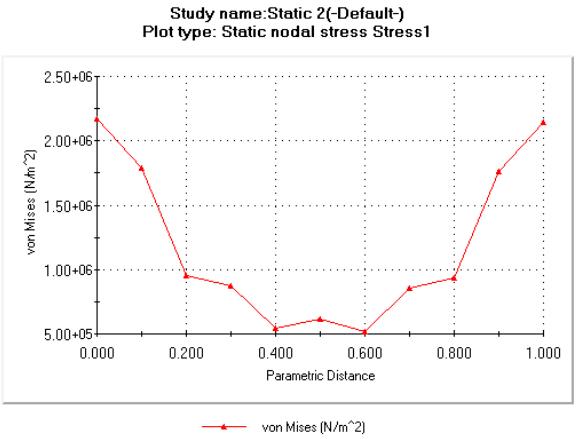


Figure 3-3. Acting Forces on Centre of the Axis

In the diagram (fig. 3-3) is shown acting forces on direct area of toothed belt axis of the main axis holder and spare parts – the maximum forces acting of the sides of area.

In the diagram (fig. 3-4) acting forces on top surface of the beam are shown. It can be concluded that toothed belt axis does not obtain stresses which can to deform axis (150N of maximum stresses).

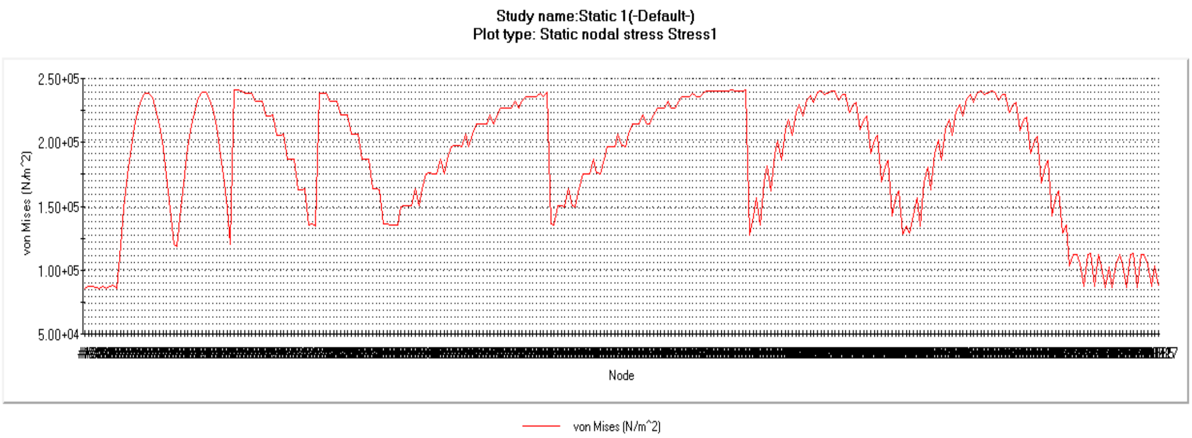


Figure 3-4. Acting Forces along the Axis

3.2. Calculation of moments and shear forces I [6]:

$$\Sigma Fx = 0$$

$\Sigma M_A = 0$ The sum of the moments about a point A is zero:

$$-q_1 * 0.672 * (-0.12 + 0.672/2) - P_1 * 0.216 + R_B * 0.465 - P_2 * 0.528 = 0$$

$\Sigma M_B = 0$ The sum of the moments about a point B is zero:

$$q_1 * 0.672 * (0.585 - 0.672/2) - R_A * 0.465 + P_1 * 0.249 - P_2 * 0.063 = 0$$

Solve this system of equations:

$$H_A = 0\ (N)$$

Calculate reaction of roller support about point B:

$$R_B = (q_1 * 0.672 * (-0.12 + 0.672/2) + P_1 * 0.216 + P_2 * 0.528) / 0.465 =$$

$$(15 * 0.672 * (-0.12 + 0.672/2) + 16 * 0.216 + 9 * 0.528) / 0.465 = 22.33\ (N)$$

Calculate reaction of pin support about point A:

$$R_A = (q_1 * 0.672 * (0.585 - 0.672/2) + P_1 * 0.249 - P_2 * 0.063) / 0.465 =$$

$$(15 * 0.672 * (0.585 - 0.672/2) + 16 * 0.249 - 9 * 0.063) / 0.465 = 12.75\ (N)$$

The sum of the forces is zero:

$$\Sigma Fy = 0: \quad - q_1 * 0.672 + R_A - P_1 + R_B - P_2 = -15 * 0.672 + 12.75 - 16 + 22.33 - 9 = 0$$

Determine the equations for the shear force (Q):

$$Q(x_1) = - q_1 * (x_1 - 0)$$

$$Q_1(0) = -15 * (0 - 0) = 0\ (N)$$

$$Q_1(0.12) = -15 * (0.12 - 0) = -1.80\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_1) = - q_1 * (x_1)2/2$$

$$M_1(0) = -15 * (0 - 0)2/2 = 0\ (N * m)$$

$$M_1(0.12) = -15 * (0.12 - 0)2/2 = -0.11\ (N * m)$$

Determine the equations for the shear force (Q):

$$Q(x_2) = -q_1 * (x_2 - 0) + R_A$$

$$Q_2(0.12) = -15 * (0.12 - 0) + 12.75 = 10.95\ (N)$$

$$Q_2(0.34) = -15 * (0.336 - 0) + 12.75 = 7.71\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_2) = -q_1 * (x_2)2/2 + R_A * (x_2 - 0.12)$$

$$M_2(0.12) = -15 * (0.12 - 0)2/2 + 12.75 * (0.12 - 0.12) = -0.11\ (N * m)$$

$$M_2(0.34) = -15 * (0.34 - 0)2/2 + 12.75 * (0.34 - 0.12) = 1.91\ (N * m)$$

Determine the equations for the shear force (Q):

$$Q(x_3) = -q_1 * (x_3 - 0) + R_A - P_1$$

$$Q_3(0.34) = -15 * (0.336 - 0) + 12.75 - 16 = -8.29\ (N)$$

$$Q_3(0.59) = -15 * (0.585 - 0) + 12.75 - 16 = -12.03\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_3) = -q_1 * (x_3)2/2 + R_A * (x_3 - 0.12) - P_1 * (x_3 - 0.336)$$

$$M_3(0.34) = -15 * (0.34 - 0)2/2 + 12.75 * (0.34 - 0.12) - 16 * (0.34 - 0.336) = 1.91\ (N * m)$$

$$M_3(0.59) = -15 * (0.59 - 0)2/2 + 12.75 * (0.59 - 0.12) - 16 * (0.59 - 0.336) = -0.62\ (N * m)$$

Determine the equations for the shear force (Q):

$$Q(x_4) = -q_1 * (x_4 - 0) + R_A - P_1 + R_B$$

$$Q_4(0.59) = -15 * (0.585 - 0) + 12.75 - 16 + 22.33 = 10.31\ (N)$$

$$Q_4(0.65) = -15 * (0.648 - 0) + 12.75 - 16 + 22.33 = 9.36\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_4) = -q_1 * (x_4)2/2 + R_A * (x_4 - 0.12)$$
$$-P_1 * (x_4 - 0.336) + R_B * (x_4 - 0.585)$$

$$M_4(0.59) = -15 * (0.59 - 0)2/2 + 12.75 * (0.59 - 0.12)$$
$$-16 * (0.59 - 0.336) + 22.33 * (0.59 - 0.585) = -0.62\ (N * m)$$

$$M_4(0.65) = -15 * (0.65 - 0)2/2 + 12.75 * (0.65 - 0.12)$$
$$-16 * (0.65 - 0.336) + 22.33 * (0.65 - 0.585) = -0.00\ (N * m)$$

Determine the equations for the shear force (Q):

$$Q(x_5) = -q_1 * (x_5 - 0) + R_A - P_1 + R_B - P_2$$
$$Q_5(0.65) = -15 * (0.648 - 0) + 12.75 - 16 + 22.33 - 9 = 0.36\ (N)$$
$$Q_5(0.67) = -15 * (0.672 - 0) + 12.75 - 16 + 22.33 - 9 = 0\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_5) = -q_1 * (x_5)2/2 + R_A * (x_5 - 0.12) - P_1 * (x_5 - 0.336)$$
$$+ R_B * (x_5 - 0.585) - P_2 * (x_5 - 0.648)$$

$$M_5(0.65) = -15 * (0.65 - 0)2/2 + 12.75 * (0.65 - 0.12) - 16 * (0.65 - 0.336)$$
$$+ 22.33 * (0.65 - 0.585) - 9 * (0.65 - 0.648) = -0.00\ (N * m)$$

$$M_5(0.67) = -15 * (0.67 - 0)2/2 + 12.75 * (0.67 - 0.12) - 16 * (0.67 - 0.336)$$
$$+ 22.33 * (0.67 - 0.585) - 9 * (0.67 - 0.648) = 0\ (N * m)$$

Calculation of shear forces and moments are shown in the diagram (fig. 3-5):

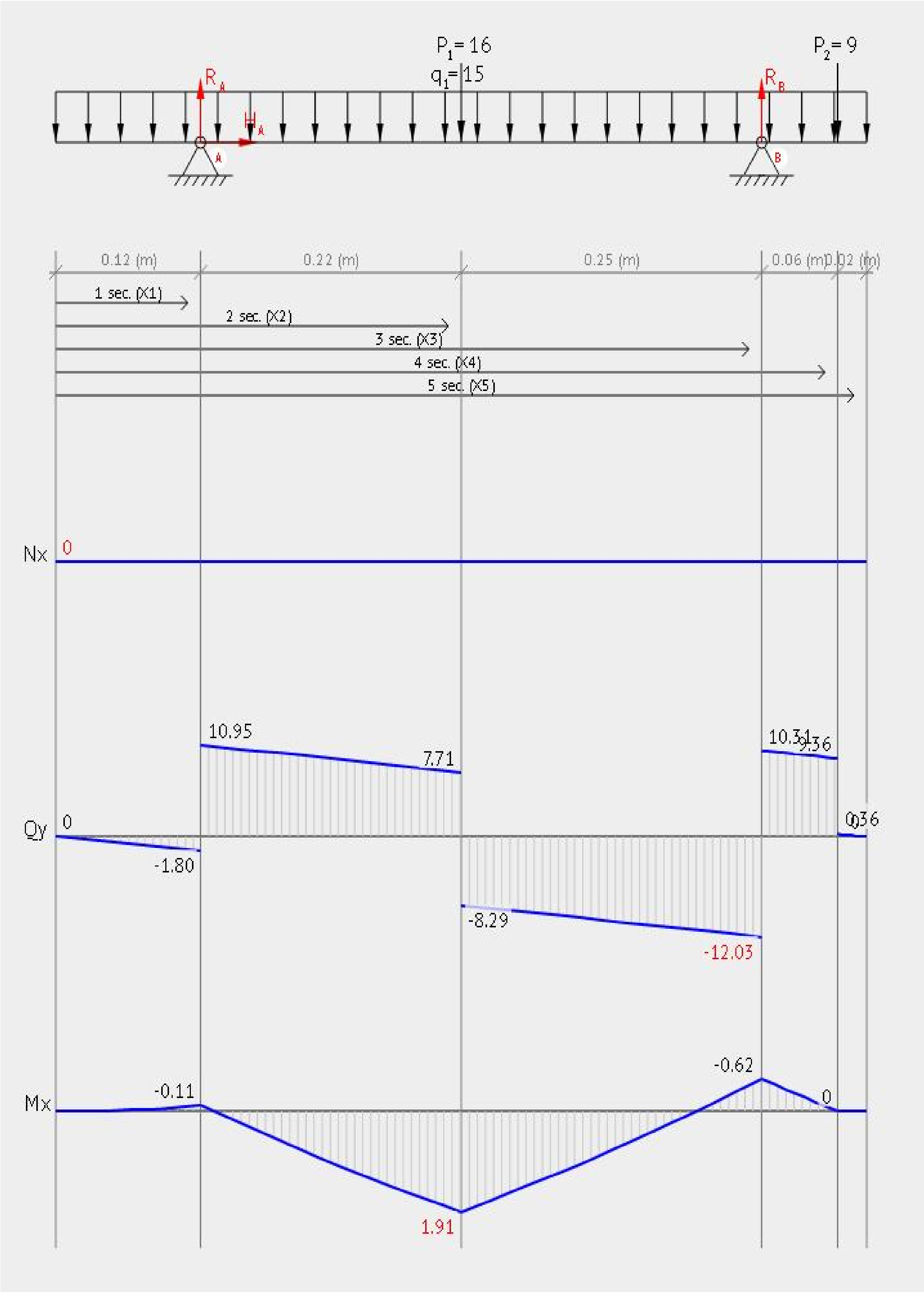


Figure 3-5. Calculation of Stresses and Moments on Toothed Belt Axis I

Calculations are showing stresses on beams which are fixed with profile supports.

$F = mg \qquad q = \frac{F}{L} \qquad L = 0{,}716\ m \qquad m_1 = 0{,}93\ kg \qquad m_2 = 3{,}3\ kg$

Calculated force of toothed axis (DGE-25-300-ZR-RF-LK-RV-GK) with spare parts:

$$F = 0{,}93 * 10 = 9{,}3\ (N) \qquad q = 9{,}3\ \div 0.716 = 13\ (N)$$

Calculated force of main axis holder with printing head and other spare parts:

$$F = 3.3 * 10 = 33\ (N)$$

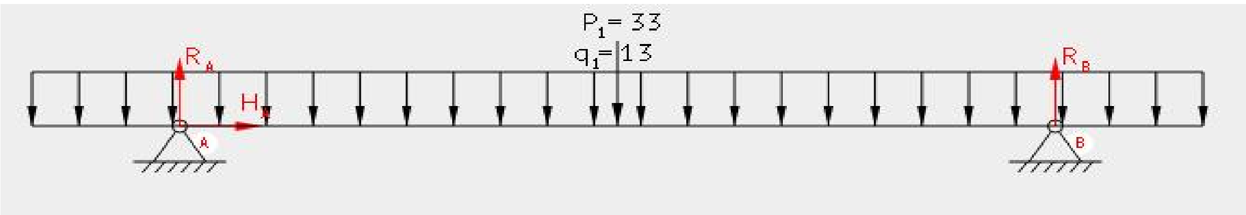


Figure 3-6. Beam Analysis of the Toothed Belt Axis II

Using “Solidworks Simulation” feature, static motion study analyzes were obtained:

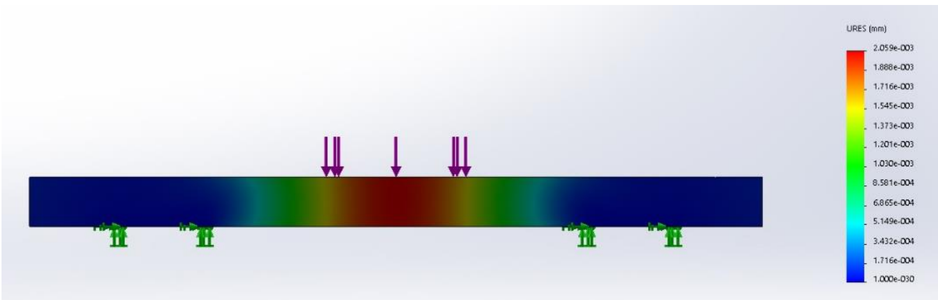


Figure 3-7. Simulation of Acting Forces on Toothed Belt Axis I

Maximum stresses act on the centre of the beam because it holds main frame which are supported by two profiles (fig. 3-7).

In the figure (fig. 3-8) acting forces on top surface of the beam are shown. It can be concluded that toothed belt axis does not obtain stresses which can to deform axis (150N of maximum stresses)

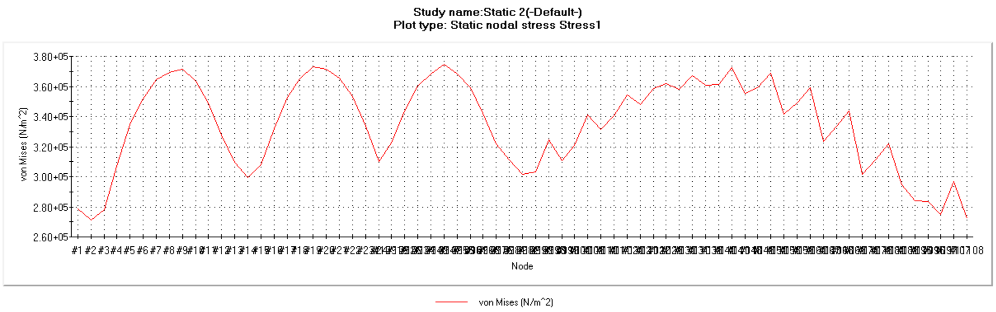


Figure 3-8. Acting Forces along the Axis

3.3. Calculation of moments and shear forces II [6]:

$$\Sigma Fx = 0: \ H_B = 0$$

$\Sigma M_A = 0$ The sum of the moments about a point A is zero:

$$-q_1 * 0.716 * (-0.05 + 0.716/2) - P_1 * 0.308 + R_B * 0.566 = 0$$

$\Sigma M_B = 0$ The sum of the moments about a point B is zero:

$$q_1 * 0.716 * (0.616 - 0.716/2) - R_A * 0.566 + P_1 * 0.258 = 0$$

Solve this system of equations:

$$H_B = 0\,(N)$$

Calculate reaction of pin support about point B:

$$R_B = (q_1 * 0.716 * (-0.05 + 0.716/2) + P_1 * 0.308) / 0.566 =$$

$$(13 * 0.716 * (-0.05 + 0.716/2) + 33 * 0.308) / 0.566 = 23.02\,(N)$$

Calculate reaction of roller support about point A:

$$R_A = (q_1 * 0.716 * (0.616 - 0.716/2) + P_1 * 0.258) / 0.566 =$$

$$(13 * 0.716 * (0.616 - 0.716/2) + 33 * 0.258) / 0.566 = 19.29\,(N)$$

3. The sum of the forces is zero: $\Sigma Fy = 0: \ - q_1 * 0.716 + R_A - P_1 + R_B = -13 * 0.716 + 19.29 - 33 + 23.02 = 0$

Determine the equations for the shear force (Q):

$$Q(x_1) = -q_1 * (x_1 - 0)$$

$$Q_1(0) = -13 * (0 - 0) = 0\ (N)$$

$$Q_1(0.05) = -13 * (0.05 - 0) = -0.65\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_1) = -q_1 * (x_1)2/2$$

$$M_1(0) = -13 * (0 - 0)2/2 = 0\ (N * m)$$

$$M_1(0.05) = -13 * (0.05 - 0)2/2 = -0.02\ (N * m)$$

Second span of the beam: $0.05 \le x_2 < 0.358$

Determine the equations for the shear force (Q):

$$Q(x_2) = -q_1 * (x_2 - 0) + R_A$$

$$Q_2(0.05) = -13 * (0.05 - 0) + 19.29 = 18.64\ (N)$$

$$Q_2(0.36) = -13 * (0.358 - 0) + 19.29 = 14.63\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_2) = -q_1 * (x_2)2/2 + R_A * (x_2 - 0.05)$$

$$M_2((0.05) = -13 * (0.05 - 0)2/2 + 19.29 * (0.05 - 0.05) = -0.02\ (N * m)$$

$$M_2(0.36) = -13 * (0.36 - 0)2/2 + 19.29 * (0.36 - 0.05) = 5.11\ (N * m)$$

Third span of the beam: $0.358 \le x_3 < 0.616$

Determine the equations for the shear force (Q):

$$Q(x_3) = -q_1 * (x_3 - 0) + R_A - P_1$$

$$Q_3(0.36) = -13 * (0.358 - 0) + 19.29 - 33 = -18.37\ (N)$$

$$Q_3(0.62) = -13 * (0.616 - 0) + 19.29 - 33 = -21.72\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_3) = -q_1 * (x_3)2/2 + R_A * (x_3 - 0.05) - P_1 * (x_3 - 0.358)$$

$$M_3(0.36) = -13 * (0.36 - 0)2/2 + 19.29 * (0.36 - 0.05) - 33 * (0.36 - 0.358) =$$

$$1.11\ (N * m)$$

$$M_3(0.62) = -13 * (0.62 - 0)2/2 + 19.29 * (0.62 - 0.05) - 33 * (0.62 - 0.358) =$$

$$-0.07\ (N * m)$$

Fourth span of the beam: $0.616 \leq x_4 < 0.716$

Determine the equations for the shear force (Q):

$$Q(x_4) = -q_1 * (x_4 - 0) + R_A - P_1 + R_B$$

$$Q_4(0.62) = -13 * (0.616 - 0) + 19.29 - 33 + 23.02 = 1.30\ (N)$$

$$Q_4(0.72) = -13 * (0.716 - 0) + 19.29 - 33 + 23.02 = 0\ (N)$$

Determine the equations for the bending moment (M):

$$M(x_4) = -q_1 * (x_4)2/2 + R_A * (x_4 - 0.05)$$

$$- P_1 * (x_4 - 0.358) + R_B * (x_4 - 0.616)$$

$$M_4(0.62) = -13 * (0.62 - 0)2/2 + 19.29 * (0.62 - 0.05)$$

$$- 33 * (0.62 - 0.358) + 23.02 * (0.62 - 0.616) = -0.07\ (N * m)$$

$$M_4(0.72) = -13 * (0.72 - 0)2/2 + 19.29 * (0.72 - 0.05)$$

$$- 33 * (0.72 - 0.358) + 23.02 * (0.72 - 0.616) = 0\ (N * m)$$

Calculation of shear forces and moments are shown in the diagram (fig. 3-9):

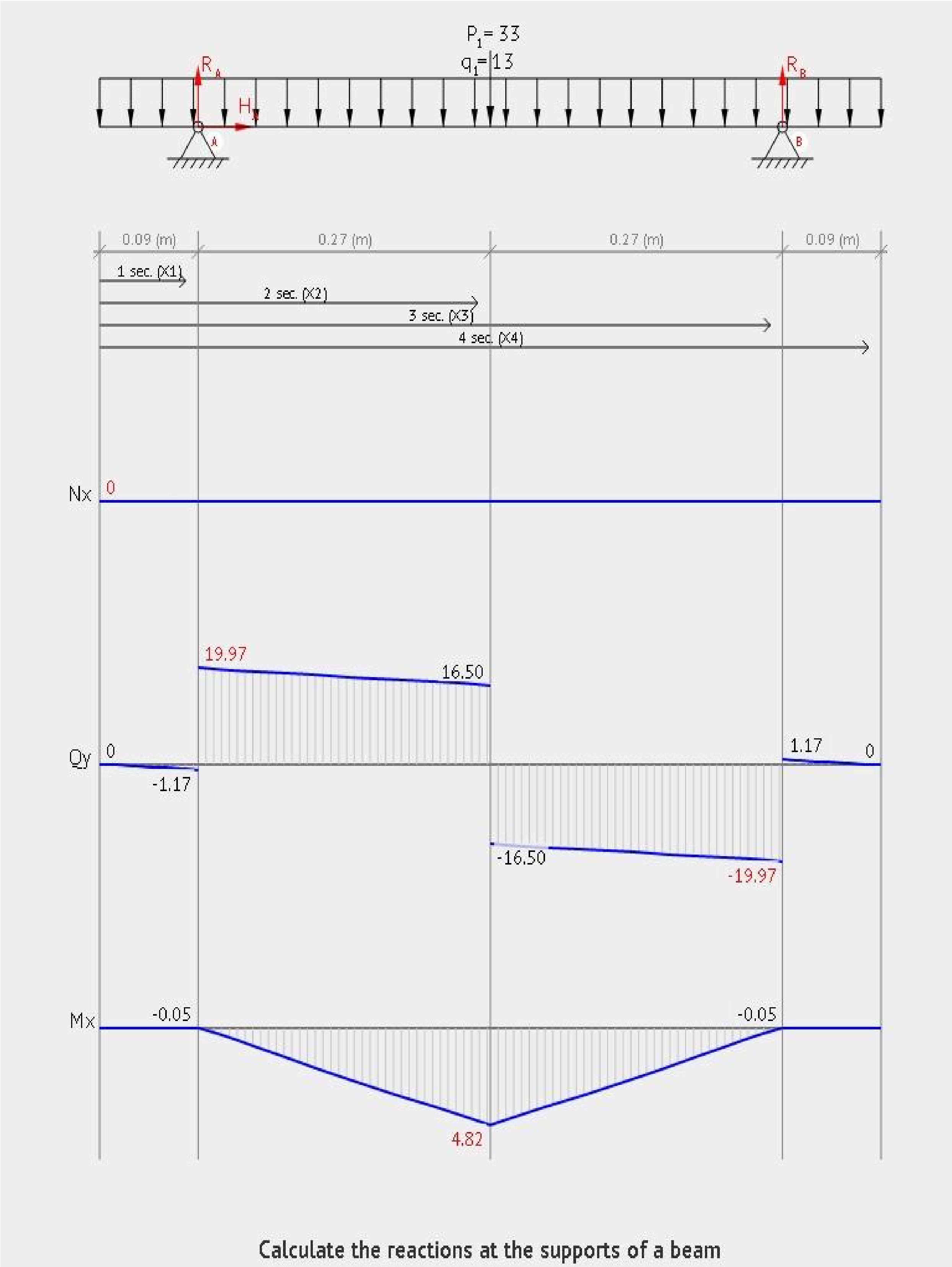


Figure 3-9. Calculation of Stresses and Moments on Toothed Belt Axis II

3.4. Stresses Simulation of Acting Forces

The 2D manipulator is well-assembled and characterize as stable machinery. Stability is obtained by structure of the printer – solid foundation is assembled with toothed belt axes and main holders, screwed with screws, slot nuts, and other spare parts to create required static motion. Applied forces are in comparison low and manipulator can load much more than it is loaded in this project. Therefore, in the fig. 3-10 of the simulation can be seen there are not overwhelmingly forces. The biggest stresses when manipulator is in action occur on belts because plastic is not strong enough element and strength of material cannot be compared with metal constructions. The lowest forces are acting on the manipulator's corners and places where any weight is added.

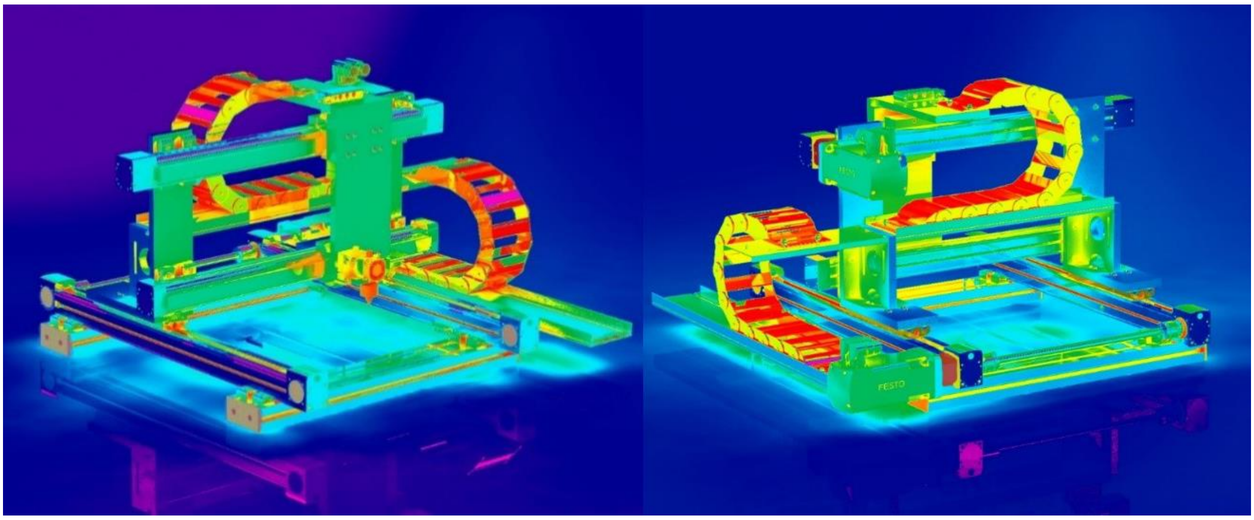


Figure 3-10. Simulation of Forces Acting on the Printing Manipulator

In conclusion of calculations, no forces appeared that could affect stable manipulator's work. Manipulator as machine which has no option for big weights transportation or holding, can be effectively used in field where velocity and accuracy is required. Despite of the fact manipulator is used for 2D printing technology, it has option to be transformed into conveyer machinery or same purpose robotic equipment. Manipulator can hold much more then it was loaded, therefore some technological waste can be seen.

4. Electrical Components Selection and Assembly Scheme

Electrics part is imported to secure reliable automation for high speed manipulator – every single detail has to be work without any interferences, power supply, wires, all components have to be highest quality, therefore expensive stuff were used.

Company's "Rittal" electrical box was selected with diameter of 500mm x 500mm [7]. Power supplier DR-75-24 was good option for controlling complex automation, conductor and screw terminal blocks were used. Power switcher, supplementary protectors and circuit breaker secures current flow and safe system from accidental errors. Ethernet router allows collect data into cloud server. All parts which properties are listed below are shown in annex 4.

Power Supplier DR-75-24 properties (fig. 4-2) [8]:

- Universal AC input / Full range
- Protections: Short circuit / Overload / Over voltage / Over temperature
- Cooling by free air convection
- Can be installed on DIN rail TS-35/7.5 or 15
- UL 508(industrial control equipment) approved
- LED indicator for power on
- 100% full load burn-in test
- Fix switching frequency at 50KHz

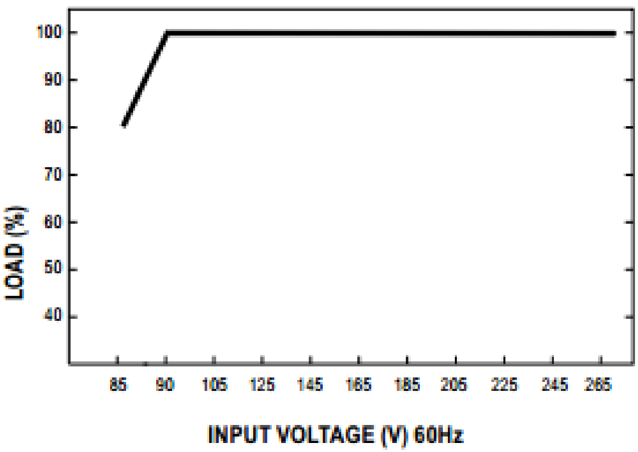


Figure 4-1. Tested Power Supply of DR-75-24 [8]

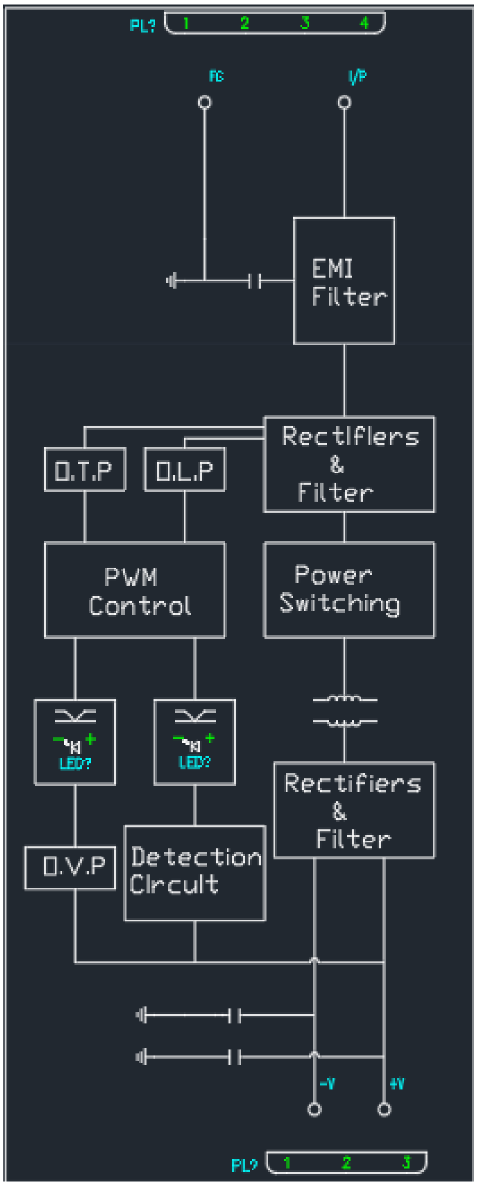


Figure 4-2. DR-75-24 E. Scheme [8]

Screw terminal block [9]:

- 24 - 12 AWG
- 115V AC measured voltage
- 300V AC/DC measured shock voltage
- 24 A Current intensity
- Front entry wiring type
- 2 connection points
- 0.31 in. (8 mm) Wire Strip Length

Conductor terminal block [10]:

- 28 - 12 AWG
- 800 V measured voltage
- 8 k V measured shock voltage
- 24 A Current intensity
- Front entry wiring type
- 2 connection points
- T S35 DIN Rail mounting

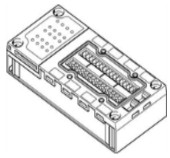
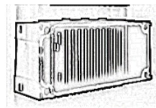
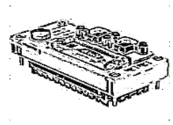
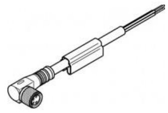
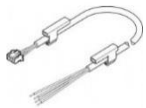
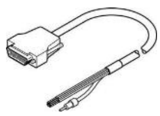
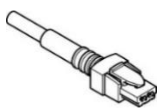
Supplementary protectors [11]:

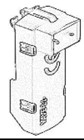
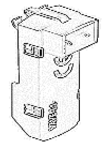
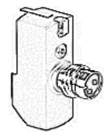
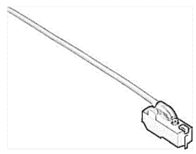
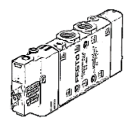
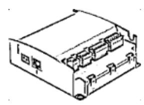
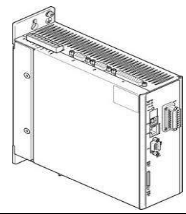
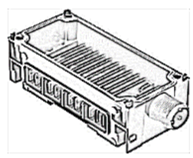
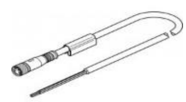
- Ul recognized
- Rated voltage 690 v ac
- No switching under load
- No-voltage changing of fuses
- For gl/gg and am cylindrical fuses

Circuit breaker [12]:

- Up to 63 A with a switching capacity up to 15 kA (depending on model)
- Up to 63 A with a switching capacity up to 25 kA in accordance with IEC/EN 60947-2 (VDE 0660-101)

Electrical Components **[3] [4]**

NO. of Component	Name of Component	Picture of Component
1	**CPX-AB-8-KL-4POL** Manifold block	
2	**CPX-GE-EV** Interlink block	
3	**CPX-GE-EV-S** Interlink block	
4	**NEBV-H1G2-KN-0.5-N-LE2** Plug s. w cable	
5	**NEBV-H1G2-KN-1-N-LE2** Plug s. w cable	
6	**NEBV-H1G2-KN-2.5-N-LE2** Plug s. w cable	
7	**NEBV-H1G2-P-0.5-N-LE2** Plug s. w cable	
8	**NEBV-H1G2-P-1-N-LE2** Plug s. w cable	
9	**NEBV-H1G2-P-2.5-N-LE2** Plug s. w cable	
10	**VABD-L1-14X-S-G18** Fixer	

11	**VAVE-L1-1VH2-LP** Sub-bases	
12	**VAVE-L1-1H2-LR** Sub-bases	
13	**VAVE-L1-1VR8-LP** Sub-bases	
14	**VAVE-L1-1VK7-LP** Sub-bases	
15	**VUVG-L14-M52-MZT-G18-1P3** Sub-base	
16	**CMMO-ST-C5-1-DIOP** Motor controller	
17	**CMMP-AS-C2-3A-M0** Motor controller	
18	**CPX-CEC-M1-V3** Control block	
19	**NEBM-M23G8-E-5-Q9N-LE8** Motor cable	
20	**NEBC-S1G25-K-3.2-N-LE25** Control cable	

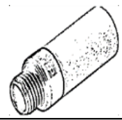
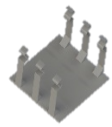
21	**UC-1/8** Silencer	
22	**Electrical Box**	
23	**Screw Terminal Blocks**	
24	**Conductor Terminal Blocks**	
25	**DR-75-24** Power supplier	
26	**Ethernet Router**	
27	**Power Switcher**	
28	**Wires Holders**	
29	**Supplementary Protector**	
30	**Circuit Breaker**	

Table 4-1. Mechanical Components of the Manipulator.

4.1. Assembly of the Electrical Box

Electrical box composed (table 4-1) of two motor controllers CMMP-AS-C2-3A-M0 and CMMO-ST-C5-1—DIOP [annex 5]. Power supplier DR-75-24, CPX-AB-8-KL-4POL (Manifold block) CPX-GE-EV (Interlink block) CPX-GE-EV-S (Interlink block) CPX-CEC-M1-V3 (Control block) [annex 6] secure manipulator's stable movement, avoidance of errors, data collection and effective printing performance. Sub-bases are used - VAVE-L1-1VK7-LP, VAVE-L1-1VR8-LP, VAVE-L1-1VH2-LP. For wiring new types cables were used: NEBV-H1G2-P-2.5-N-LE2 (Plug s. w cable) NEBV-H1G2-P-1-N-LE2 (Plug s. w cable) NEBV-H1G2-P-0.5-N-LE2 (Plug s. w cable) NEBV-H1G2-KN-2.5-N-LE2 (Plug s. w cable) NEBV-H1G2-KN-1-N-LE2 (Plug s. w cable) NEBV-H1G2-KN-0.5-N-LE2 (Plug s. w cable) NEBC-S1G25-K-3.2-N-LE25 (Control cable) and motor cable NEBM-M23G8-E-5-Q9N-LE8 which connect 30 Screw terminal blocks and 8 conductor terminal blocks with power switcher.

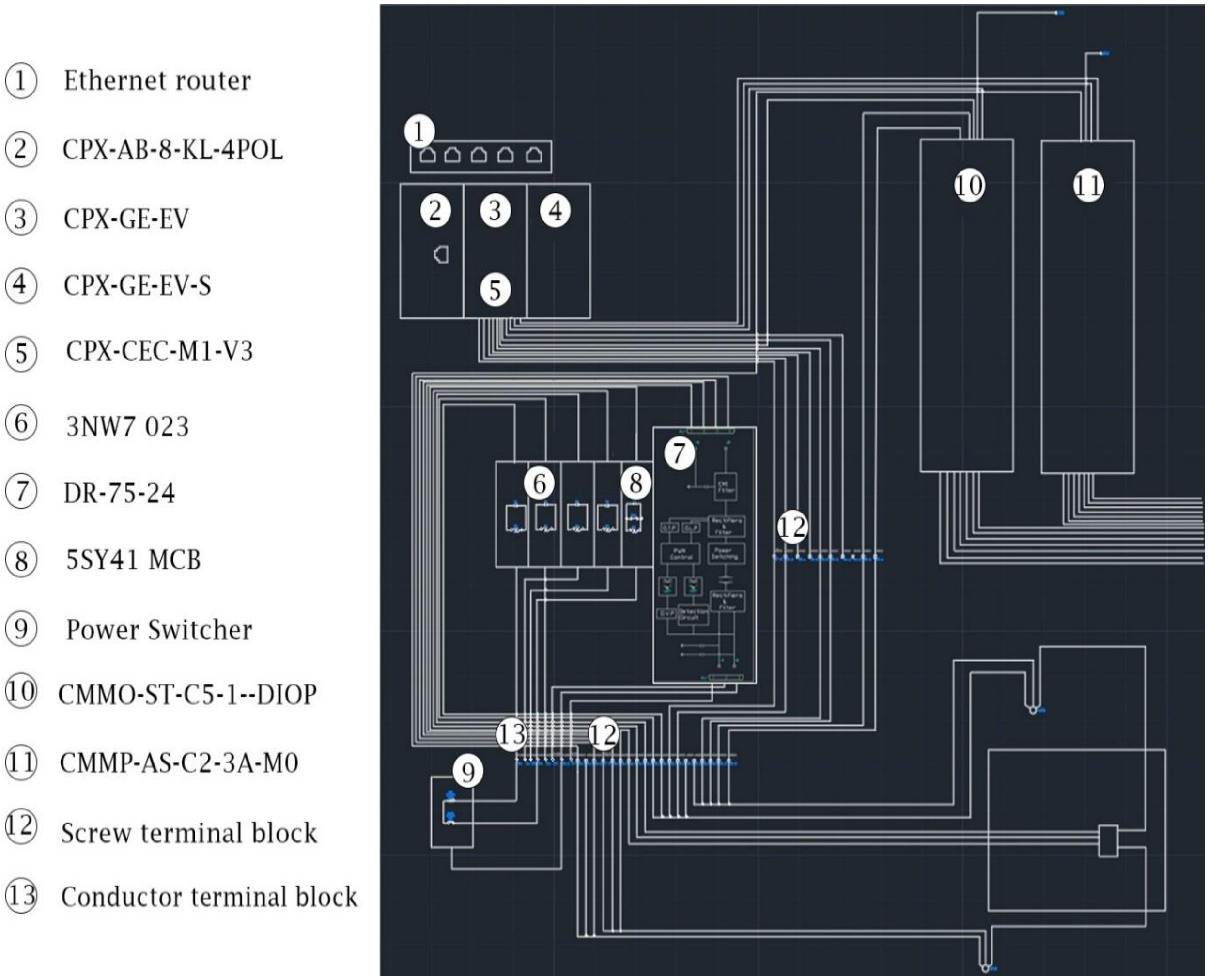


Figure 4-3. Numbered Parts of the Electric Box Scheme

The Components were selected as it should be in the internship project, other parts were chosen to meet the requirements. All 30 different parts were assembled and wired corresponding to the electric scheme (fig. 4-3). Assembly of the electrical box was created without fixing components such as holders, screws, fixers due the focus of appropriate components functionality and exact wiring to the project. Despite of the fact that manipulator has only a 2D option, complex electrical components and schemes are required. However, manipulator can be easily modified depending on requirements and most of the electrics parts will not be changed of the high capabilities of components (fig. 4-4).

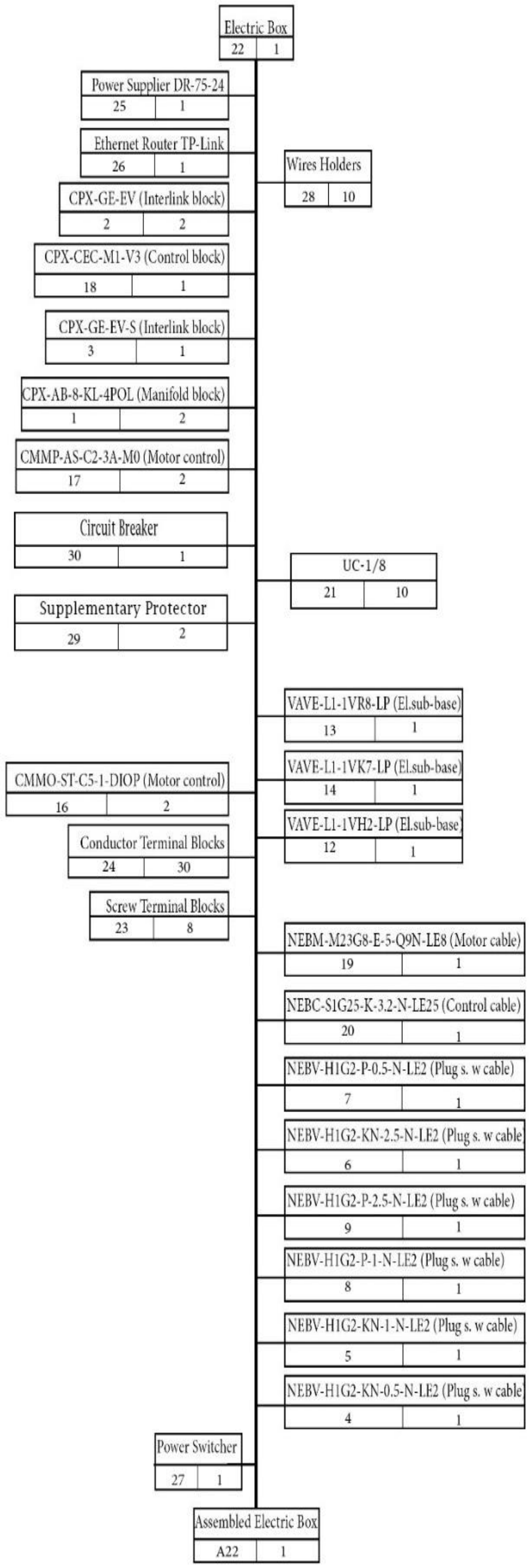


Figure 4-4. Assembly Scheme of the Electrical Box

5. Programming

Automation main purpose is make machines work automatically without any labor force. This area is inconceivable without programming and computer automation. Modern industry is using new technology in cloud computing as well to analyses data for increasing quality of products, bypass errors, analyze customers' habits, for faster company growth and etc.

The aim was to code drawing program in C# language (Microsoft Visual Studio 2015) and convert it into G codes (Inkscape 2017), collect obtained data in cloud database (Microsoft SQL Server Management Studio 2016).

5.1. Software Programming

To create simple drawing program Microsoft Visual Studio is used (fig. 5-1). Software is free to use and is the most powerful tool for ASP.NET programming. Program is composed by possibility to choose exact color and clear' button, 5 brushes sizes can be used as well. Whole code is easy to read and understand:

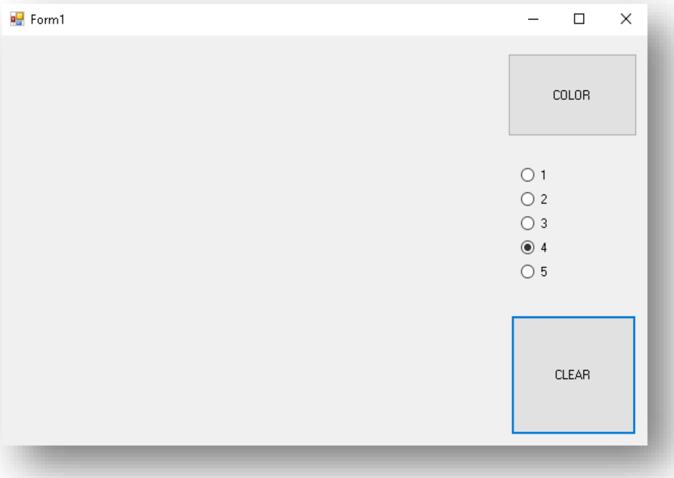


Figure 5-1. Drawing Software

- All libraries added to open source code
- Buttons are named and application code is written:
    - Size of brushes
    - Code visibility (line)
    - Colors palette
- End of the code to start software properly

Here is provided drawing program code written in C# programming language:

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
```

```
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace WindowsFormsApplication2
{
    public partial class Form1 : Form
    {
        public Point current = new Point();
        public Point old = new Point();
        public Pen p = new Pen(Color.Black, 5);
        public Graphics g;

        public Form1()
        {
            InitializeComponent();
            g = panel1.CreateGraphics();
            p.SetLineCap(System.Drawing.Drawing2D.LineCap.Round,
System.Drawing.Drawing2D.LineCap.Round,
System.Drawing.Drawing2D.DashCap.Round);

        }
        private void panel1_MouseDown(object sender, MouseEventArgs e)
        {
            old = e.Location;
            if (radioButton1.Checked)
                p.Width = 1;
            else if (radioButton2.Checked)
                p.Width = 5;
            else if (radioButton3.Checked)
                p.Width = 10;
            else if (radioButton4.Checked)
                p.Width = 15;
            else if (radioButton5.Checked)
                p.Width = 30;
        }

        private void panel1_MouseMove(object sender, MouseEventArgs e)
        {
            if(e.Button==MouseButtons.Left)
            {
                current = e.Location;
                g.DrawLine(p, old, current);
```

```
                old = current;
            }
        }

        private void button1_Click(object sender, EventArgs e)
        {
            ColorDialog cd = new ColorDialog();
            if (cd.ShowDialog() == DialogResult.OK)
                p.Color = cd.Color;
        }

        private void Form1_Load(object sender, EventArgs e)
        {

        }

        private void button2_Click(object sender, EventArgs e)
        {
            panel1.Invalidate();
        }

        private void radioButton2_CheckedChanged(object sender, EventArgs e)
        {
        }
    }
}
```

Kaunas University logo was used to present how software is generating codes (fig. 5-2).

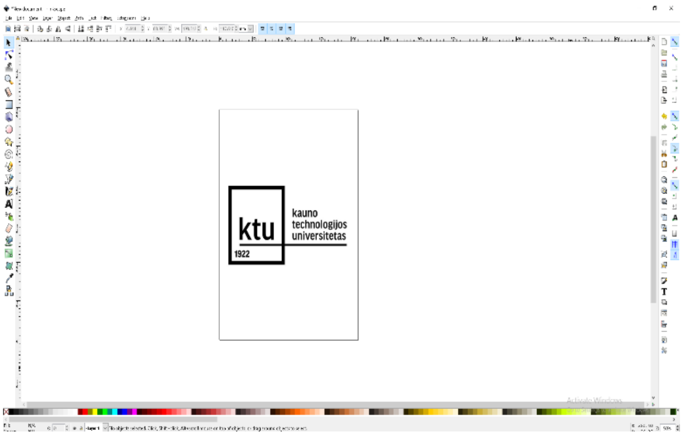


Figure 5-2. Picture Conversion into G Codes

To convert logo into G codes in which processor of manipulator will read "Inkscape" (professional quality vector graphics software) was used, which helps to convert pictures into readable G codes and text file in Windows notepad. J tech photonics laser tool in "Inkscape" is used. Tool gives possibility to track figures and colors to obtain exact G codes. G codes is mostly used numerical control (NC) controlling language for automation and machines manipulation and has big amount of variants, therefore KTU logo is quite large – 1450 rows.

Collect data is required option nowadays for further analysis in companies which are looking for establishment of their products. To work, collect data faster and without any struggles to copy it manually, converting software was created (fig. 5-3). It is simply to use just to selecting file and program converts it automatically to Microsoft Excel or Word (software can convert into many other readable files as well). Converted data can be used for SQL databases for advanced and safe data analysis. Microsoft Visual Studio 2010 software was used to create code.

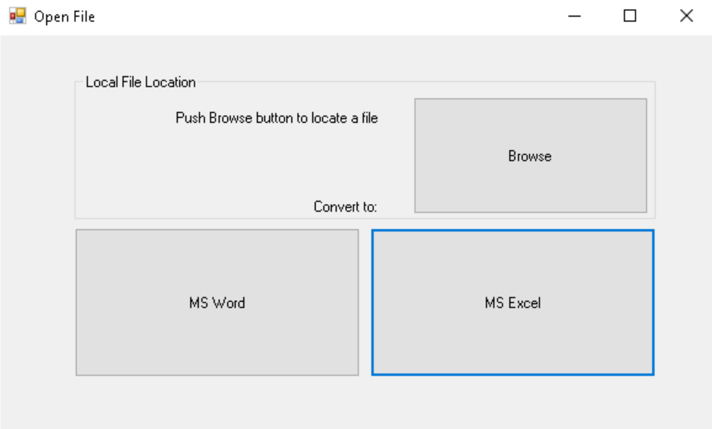


Figure 5-3. Software for Quick Data Conversion.

```
Public Class Form1
        Private Sub BrowseBtn_Click(ByVal sender As System.Object, Byval e As System.EventArgs) Handles BrowseBtn.Click

                OpenFileDialog.ShowDialog()
                FilePathLabel.Text = OpenFileDialog.FileName
        End Sub
        Private Sub WordBtn_Click(ByVal sender As System.Object, Byval e As System.EventArgs) Handles WordBtn.Click
                Process.Start("winword", FilePathLabel.Text)
        End Sub
        Private Sub ExcelBtn_Click(ByVal sender As System.Object, Byval e As System.EventArgs) Handles ExcelBtn.Click

                Process.Start("Excel", FilePathLabel.Text)
        End Sub

End Class
```

Microsoft SQL Databases Management Studio is used to convert for instance excel file to cloud server. With SQL databases information is saved in server which cannot be damaged and data analyses can be started. Data collection nowadays is huge market, forecast by 2020, it will be 1.7 megabytes created every single second for every human being on the planet, even now 4.4 zettabytes are collected, but in 2020 it will be 44 zettabytes (44 trillion gigabytes) in data servers. Companies leverage theirs margins by around 60% by powering collecting data, however only 0.5% of all data is ever analyzed.

6. Design

Design play big role in modern and every time changing world. Human beings became more fastidious for design, therefore new software and theorems have to be used. Proximity, similarity, continuance, closure, simitry and etc. are most common qualities of design which help to attract customers. Even 71% of companies are creating 10 times more assets by adding catchy design and investing into branding. Keeping up with design the newest technology has to be used to create and present attractive product for consumers.

The aim was to create 3D video in real view, exact materials, colors, shapes, dimensions, technical implementation and etc. Using “Solidworks 2017” whole project was constructed. To create animation “Solidworks Motion Study”, “Solidworks Composer” and “Solidworks Visualize” were used. “Solidwork” has features to establish real view photos or videos for product presentation with whole construction process, selection of materials and features of the product functions (fig. 6-1; 6-2; 6-3).

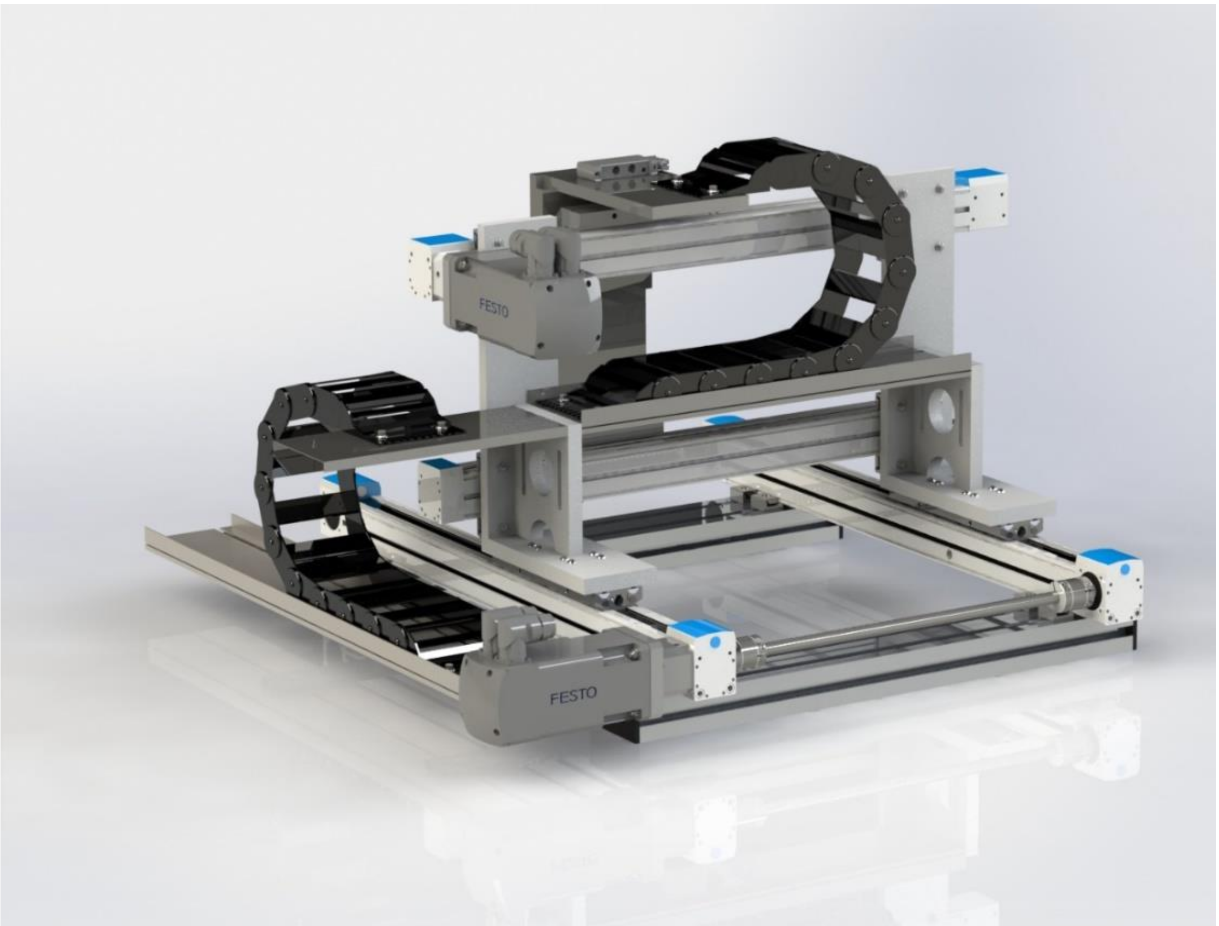


Figure 6-1. Design of the Manipulator.

Figure 6-2. Design of the Electric Box.

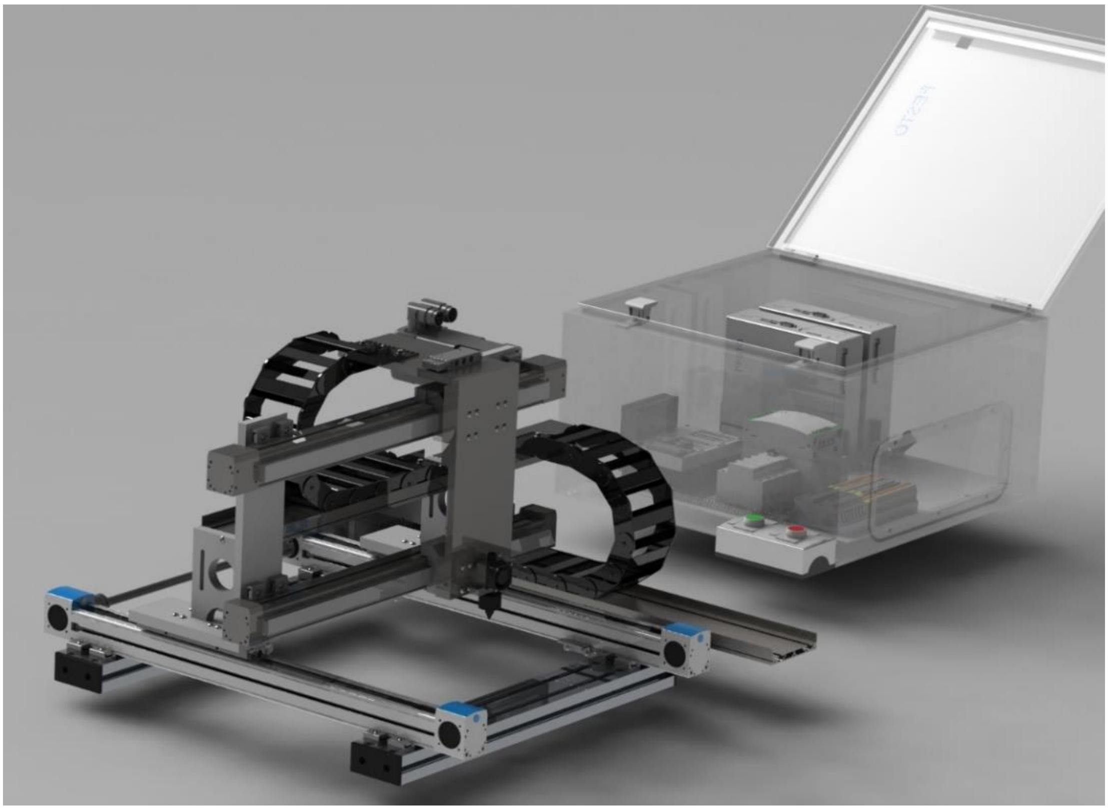


Figure 6-3. Design of 2D Manipulator and Electric Box.

7. Economical Project Establishment

Price of the product is one of the most important part which will make product accessible. Value has to be compared with other products in the market and choose wisely to minimize production cost to maximize profit. Today price has to be calculated accurate considering on materials cost, manufacturing price, labor force, logistics and etc. Using theorems, tables, diagrams for comparison of the products increasing company gains and facilitate its growth. New type datasheets are used as well which give possibility for new markets seeking. Nowadays product establishment for internal market and export has to be in the first, only visible, well prepared for market and high quality products take big part of sales margin and find customer quickly.

The highest quality standards - materials, manufacturing processes, engineering solutions set high price. Reinvestment big amount of revenue into technologies, future inventions implementation and investment to secure stable company's growth is the key for success. Only advanced staff were used in this project and as innovative product - made for engineers or students qualification. Parts price hesitating from 2,4€ to 1948€ of electrics, and 3,52€ to 1562€ of mechanical parts (table 7.1; 7.2).

7.1. Price of Products Analyses

Here is provided information about "Festo" products in my project [1]:

Name of the Part	No.	Price	Name of the Part	No.	Price
CPX-AB-8-KL-4POL	2	171.64	HP-25	2	49.8
CPX-GE-EV	2	48.4	MUP-18/25	32	41.06
CPX-GE-EV-S	1	43.12	QSM-M5-4-I	10	3.48
NEBV-H1G2-KN-0.5-N-LE2	1	2.42	QSM-M5-6-I	10	3.88
NEBV-H1G2-KN-1-N-LE2	1	3.64	NSTL-25	20	12.26
NEBV-H1G2-KN-2.5-N-LE2	1	7.28	UC-1/8	10	8.72
NEBV-H1G2-P-0.5-N-LE2	1	10.9	QS-G1/8-6-I	10	3.86
NEBV-H1G2-P-1-N-LE2	1	12.52	QS-G1/8-8-I	10	4.24
NEBV-H1G2-P-2.5-N-LE2	1	17.38	FDG-25-	1	1453.58
VABD-L1-14X-S-G18	10	26.2	DGE-25- -ZR-RF	1	1561.18
VAVE-L1-1VH2-LP	1	9.1	DGE-25- -ZR-RF	1	1561.18
VAVE-L1-1H2-LR	1	12.12	DGE-25- -ZR-RF	1	1561.18
VAVE-L1-1VR8-LP	1	20.2	EAMM-A-F30-70A	2	615.56
VAVE-L1-1VK7-LP	1	22.82	EAMC-40-66-11-15	2	251.64

VUVG-L14-M52-MZT-G18-1P3	**1**	**111.1**	**EAMF-A-48A-70A**	**2**	**215.32**
CMMO-ST-C5-1-DIOP	**2**	**1171.6**	**NPQH-BK-G18-P10**	**2**	**3.52**
EMMS-AS-70-M-LS-RR	**2**	**3894.16**			
CMMP-AS-C2-3A-M0	**2**	**4102.4**			
CPX-CEC-M1-V3	**1**	**1717**			
NEBM-M23G8-E-5-Q9N-LE8	**2**	**687.44**			
NEBC-S1G25-K-3.2-N-LE25	**2**	**72**			
UC-1/8	**10**	**87.2**			
SUM:	**47**	**12250**		**84**	**7350.46**

Table 7-1. "Festo" Products and Prices of the Project.

Figure 7-1. Price Comparison of the Components from "Festo" Catalogue.

Here is provided information of products which ones were not included:

Name Of The Part	No.	Price	Name of the Part	No.	Price
Electric Box	**1**	**250**	**Profile**	**2**	**75**
Screw Terminal Blocks	**8**	**160**	**Big Belt Holder's Fix**	**2**	**10**
Conductor Terminal Blocks	**30**	**300**	**Main Holder**	**2**	**150**

Power Supplier DR-75-24	**1**	**400**	**Printer Head**	**1**	**100**
Ethernet Router	**1**	**80**	**Profile Plug**	**4**	**20**
Power Switcher	**1**	**60**	**Shaft**	**1**	**20**
Wires Holders	**10**	**30**	**Main Axis Holder**	**1**	**40**
Supplementary Protector	**2**	**100**	**Belt**	**2**	**200**
Circuit Breaker	**1**	**50**	**Belt fixers**	**4**	**60**
			Small Belt Holder I, II	**2**	**45**
			Big Belt Holder I, II	**2**	**30**
Sum:	**55**	**1440**		**22**	**780**

Table 7-2. Components and Price of Parts from Other Catalogues.

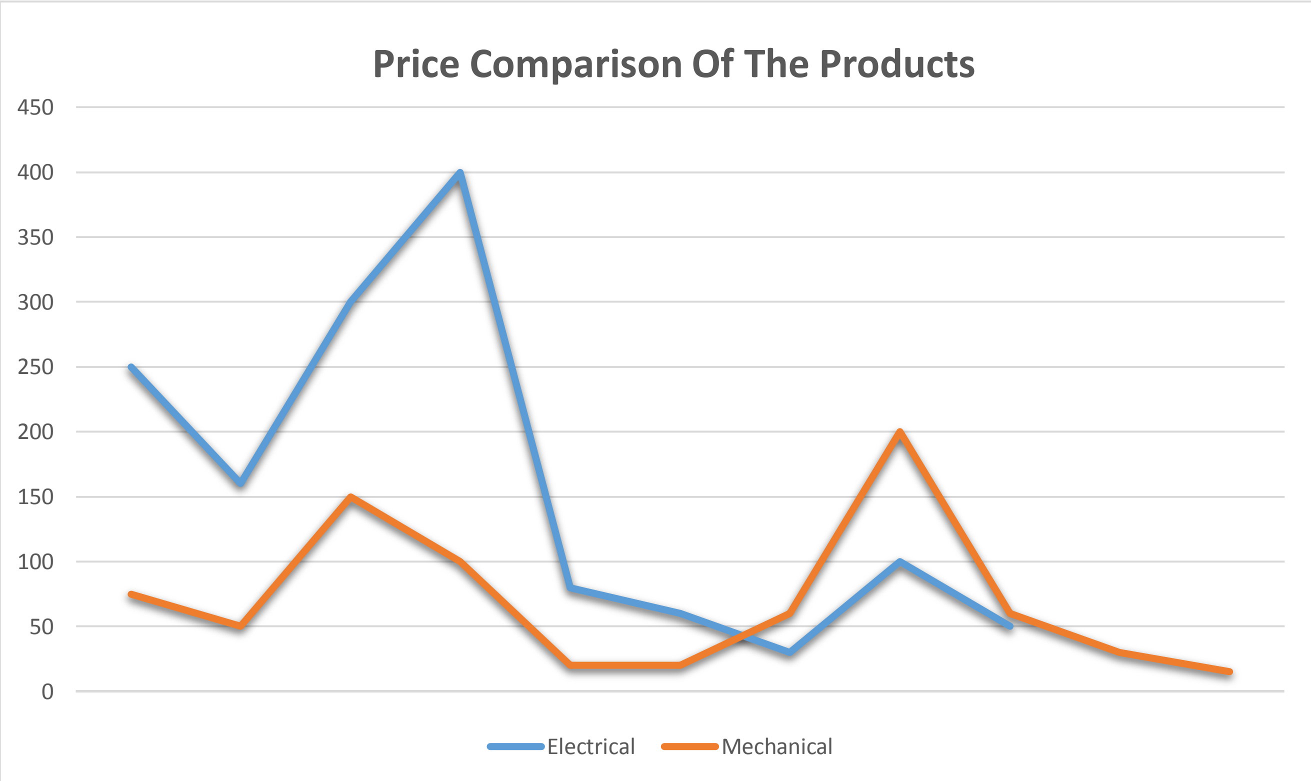


Figure 7-2. Price Comparison of the Products from Other Catalogues.

The number of some parts (for example sub. base VABD-L1-14X-S-G18) are enlarged despite of the fact only few of them will be used, because company does not to allow purchase single part of its simplicity or smallness. Other parts were bought as project demanded, however more components can be purchased, especially spare parts or electronics (despite of the supplementary protector which is protecting system), because of accidentally distortion or break. To reduce cost of experiments in mechanics and electrics fields, "AutoCAD Electrical" or "Solidworks" software is proposed for errors avoidance, checking for functionality of stable work efficiency, resource and finance saving.

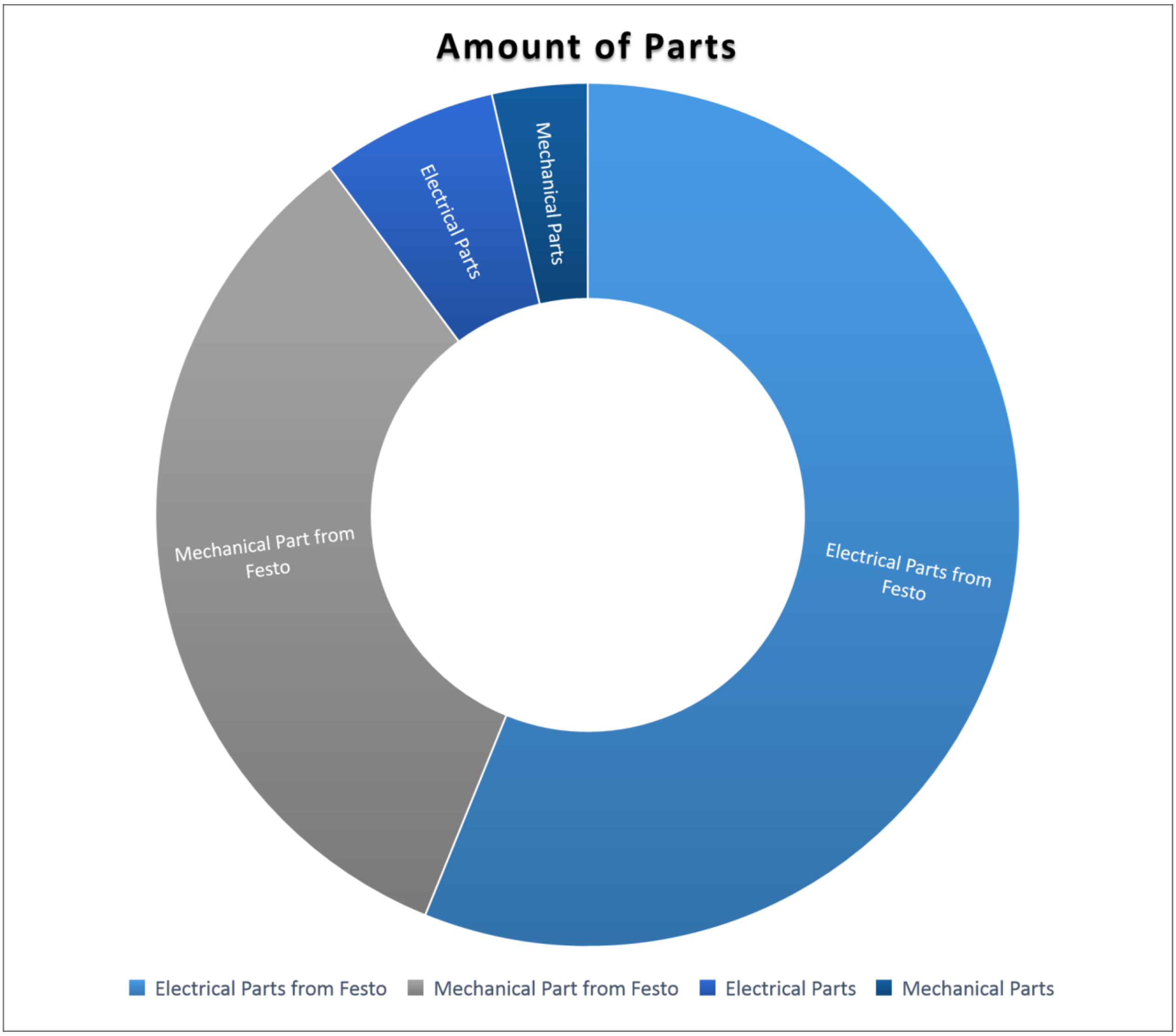


Figure 7-3. Amount Comparison of Mechanical and Electrical Components.

Name	No. of Parts	Price	No. of Parts	Price
Festo Catalogue	47	12250	84	7350.46
Others Catalogue	55	1440	22	780
Sum:	102	13690	106	8130.46

Table 7-3. Prices Comparison and Amount of Components.

Name	No. of Parts	Price
Festo Catalogue	102	13690
Others Catalogue	106	8130.46
Sum:	208	21820.46

Table 7-4. Prices Comparison and Amount of Components.

Tables and diagrams show that price of electrical parts are higher (fig. 7-1; 7-2) (about 30% - 40%), because electronics in this project is complex and it is necessity to use best quality electrical devices. Higher standards mechanical parts used as well, but manipulator compose from only few complex toothed belt axis (despite of fact big amount of spare parts), therefore it makes price lower. Calculated over 47 electrical and 84 mechanical parts from “Festo” catalogue – this is the biggest price part (near 20000€) - in total it is 90% of all price. From other catalogues needed 55 electrical parts and 22 mechanical parts (fig. 7-3 and table 7-3; 7-4). Parts were selected which have high quality, however price is not quite big. In total it is 10% of all price. The sum of all cost is 21820.46€, number of parts – 208. Another required fields for development are programming – 24 hours is required least, project assembling – 80 hours, CAD project assembling – 80 hours, electrical scheme and establishment – 40 hours, graphical implementation – 10 hours. Price can be correspondingly calculated as price per hour for engineers: programming – 40, project assembling – 30, CAD project assembling - 40, electrical scheme and establishment – 50, graphics – 160. In total 384 hours are needed for full establishment of the project and it will cost 10160 €. (table 7-5). Services prices are checked on the internet with all licenses and agreements. Value for price aspect was important for selection, quickness had no importance, however well-known companies were chosen because the project requires qualified professionals and no errors can be obtained during the process of the 2D printer – manipulator, as well as electrical box functionality.

Required Field of the Development:	Hours to Complete:	Price per Hour €	Cost €
Programming	**24**	**40**	**960**
Project Assembling	**80**	**30**	**2400**
CAD Project Assembling	**80**	**40**	**3200**
Electrical Scheme and Establishment	**40**	**50**	**2000**
Graphics	**10**	**160**	**1600**
SUM:	**384**	**170**	**10160**

Table 7-5. Price of Required Fields Development

If we look closely how much does it cost and take in total – price can be higher than 35000€ or even more than 40000€. Components price – 21820 €, system implementation - 10160 €. Price of 2D manipulator is quite high in comparison with other products in market built for 2D printing, but as innovative product which was made to increase qualification of engineers in automation, exhibit for schools or universities, is more relative to automation robots than 2D printing technology.

7.2. Manufacturing Cost of Parts

"Solidworks Costing" feature was used for new type datasheet of product which presents product in more modern way (fig. 7-4) with manufacturing operation costing (fig. 7-5) - necessary operation, operation times, material price, model visualization, dimensions, mass, times when it was made and etc. It is easy to forecast how much can part cost, how much time does it takes to make it, what operations has to be used to produce exact shape of detail.

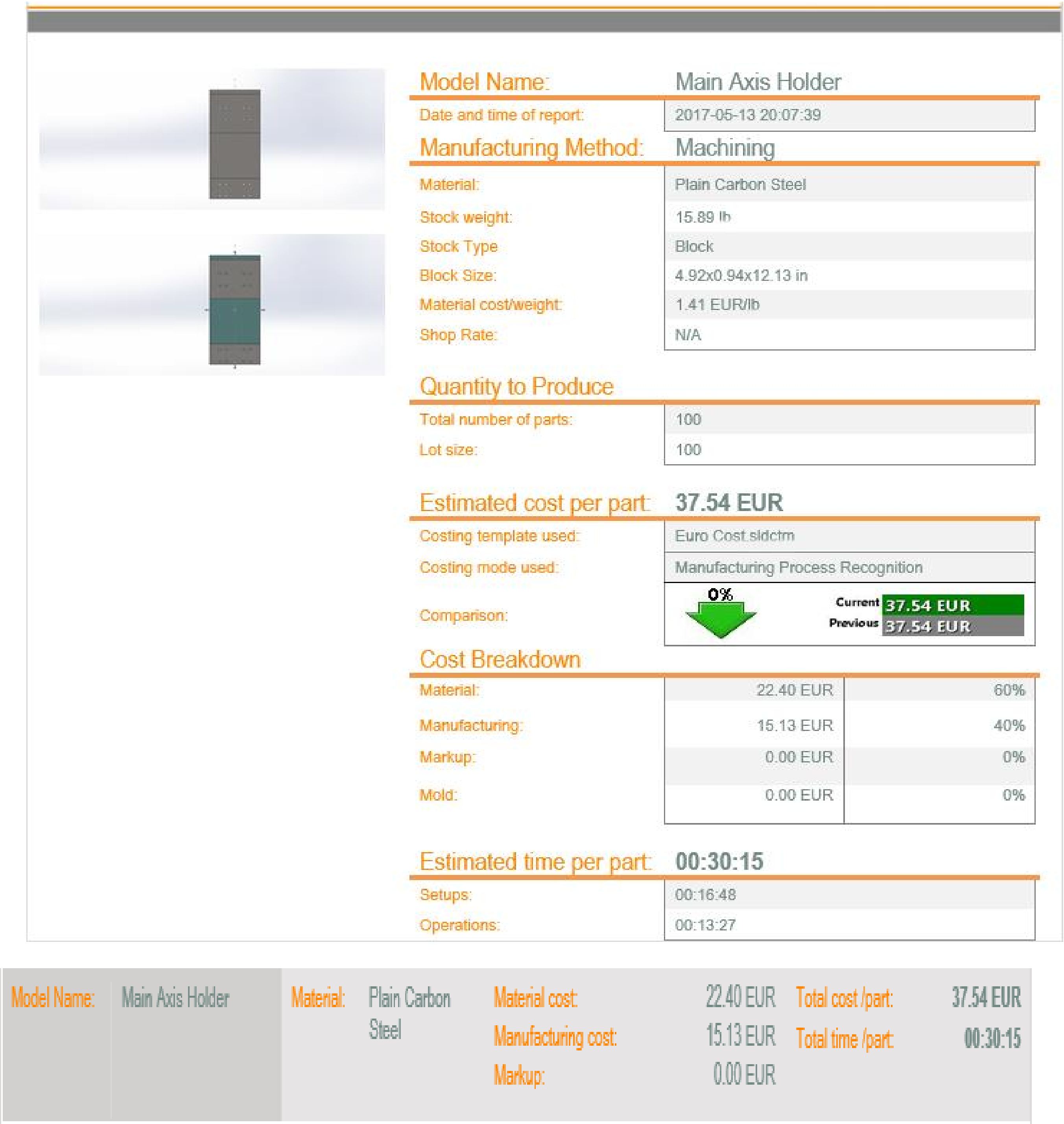


Figure 7-4. "Solidworks Costing" Feature of Main Axis Holder.

Manufacturing Cost Breakdown

Operation Setups	Time (hh:mm:ss)	Cost (EUR / Part)
Setup Operation 1	00:00:36	0.30
Setup Operation 2	00:00:36	0.30
Setup Operation 3	00:00:36	0.30
Total	**00:01:47**	**0.90**

Load and Unload Setups	Time (hh:mm:ss)	Cost (EUR / Part)
Setup Operation 1	00:05:00	2.50
Setup Operation 2	00:05:00	2.50
Setup Operation 3	00:05:00	2.50
Total	**00:15:00**	**7.50**

Operation	Surface Finish	Volume Removed (in^3)	Time (hh:mm:ss)	Cost (EUR / Part)	Tooling	Cost-per-Volume (EUR/in^3)
Slot 1	Roughing	11.72	00:04:44	2.37	Flat End Mill	N/A
Slot 2	Roughing	1.10	00:00:26	0.22	Flat End Mill	N/A
Total		**12.82**	**00:05:10**	**2.59**		

Hole Operation	Surface Finish	Volume Removed (in^3)	Time (hh:mm:ss)	Cost (EUR / Part)	Tooling	Cost-per-Volume (EUR/in^3)
Hole 1	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 2	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 3	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 4	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 5	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 6	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 7	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 8	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 9	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 10	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 11	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 12	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 13	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 14	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 15	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Hole 16	Drill	0.03	00:00:31	0.26	HSS Drill	N/A
Total		**0.56**	**00:08:17**	**4.14**		

Figure 7-5. "Solidworks Costing" Feature to Calculate Operation Times.

7.3. SWOT and PESTEL

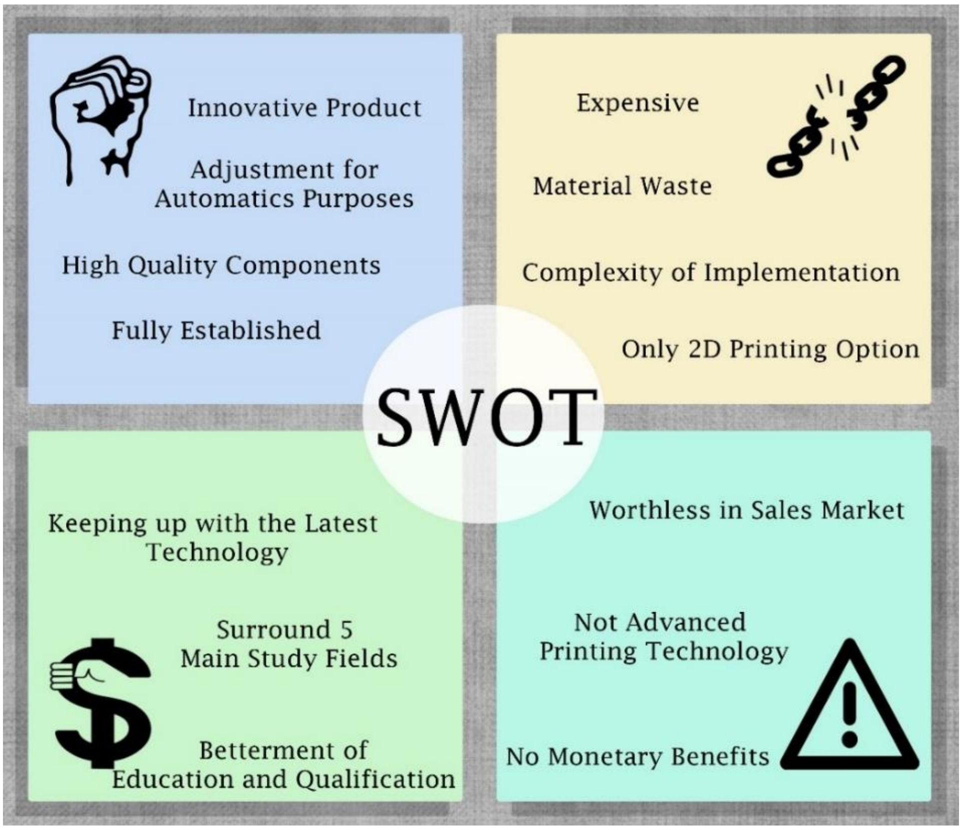


Figure 7-6. SWOT Analysis of the Project.

Figure 7-7. PESTEL Analysis of the Project.

SWOT and PESTEL analyses are showing that product has pros and cons. Strength of the product can be seen as possibility to establish or change working purposes of manipulator. As innovation it may be sponsorship by government, because product meets the highest standards and has high quality components. Fully establishment allows to open new markets or exhibitions without any of costs for paying to improve the product. Keeping up with the latest technology product surround 5 main study fields (mechanics, electrics, programming, design and economics) and helps to present innovation for students or engineers which will increase their qualification. However, the manipulator is quite expensive, it is really complex project where all parts have to be manufactured and jointed accurate with fully working efficiency despite of the fact it has only 2D printing option. Definitely it is low possibility to enter new markets, price is considerable too high for 2D printing and monetary benefits cannot be obtained.

7.4. Conclusions of Economics

In conclusion, the 2D manipulator is well developed product which meets the highest standards, has attractive design and programmed without any errors, however, manipulator exceed all price limits comparing with other similar products in market and has no possibilities to be produce for massive production. 2D option does not make any usability for business and for betterment of production or sales growth. Prices of product parts are particularly analyzed, all data is shown in diagrams and tables and all price differences can be seen. Most of the parts are from company "Festo", however, it can be replaced with other similar products which do not change functionality of manipulator or electrical box. Other parts can be chosen from another supplier. Average price can be checked with "Solidworks Costing" feature with full operation times. All Parts price is 21820.46€ and 10160€ for system implementation, in total 32000€, where screws, washers, nuts and etc. not included. Nevertheless, analyses are showing that manipulator can be used for education purposes – qualification of engineers and students, as exhibit in schools, universities or exhibitions.

Conclusions

All mechanical parts of the 2D manipulator were fully assembled with 5 assembly schemes. No errors were obtained and the printer moves properly along X and Y axes. Calculation of acting forces has shown that materials and components were selected suitably and by using stresses and moments diagrams, maximum forces could not impact deformation or do other harm for toothed belt axes which can hold 150N (comparing with 12.03 N, 19.97 N stresses and 1.91 N*m, 4.83 N*m moments respectively) of power and effective and stable operations of manipulator can be obtained. The biggest stresses were acting on the belts, because of plastic's low strength capabilities. Electrics components were assembled without any errors as well as the mechanical part of the project – 1 assembly scheme was enough to joint all the parts. In order to make clear view how does the project wiring should look like electrical scheme was created. Programmed drawing software and used G codes converter, gave possibility every single code be collected into cloud databases by using SQL server. 3D video presentation of the project allowed better understand functionality of the printer – manipulator.

However, the price 2D printer – manipulator transcend all price limits comparing with machines which have the same option in market and it is too complex. takes to much labor force for fully implementation and only can be used for educational purposes.

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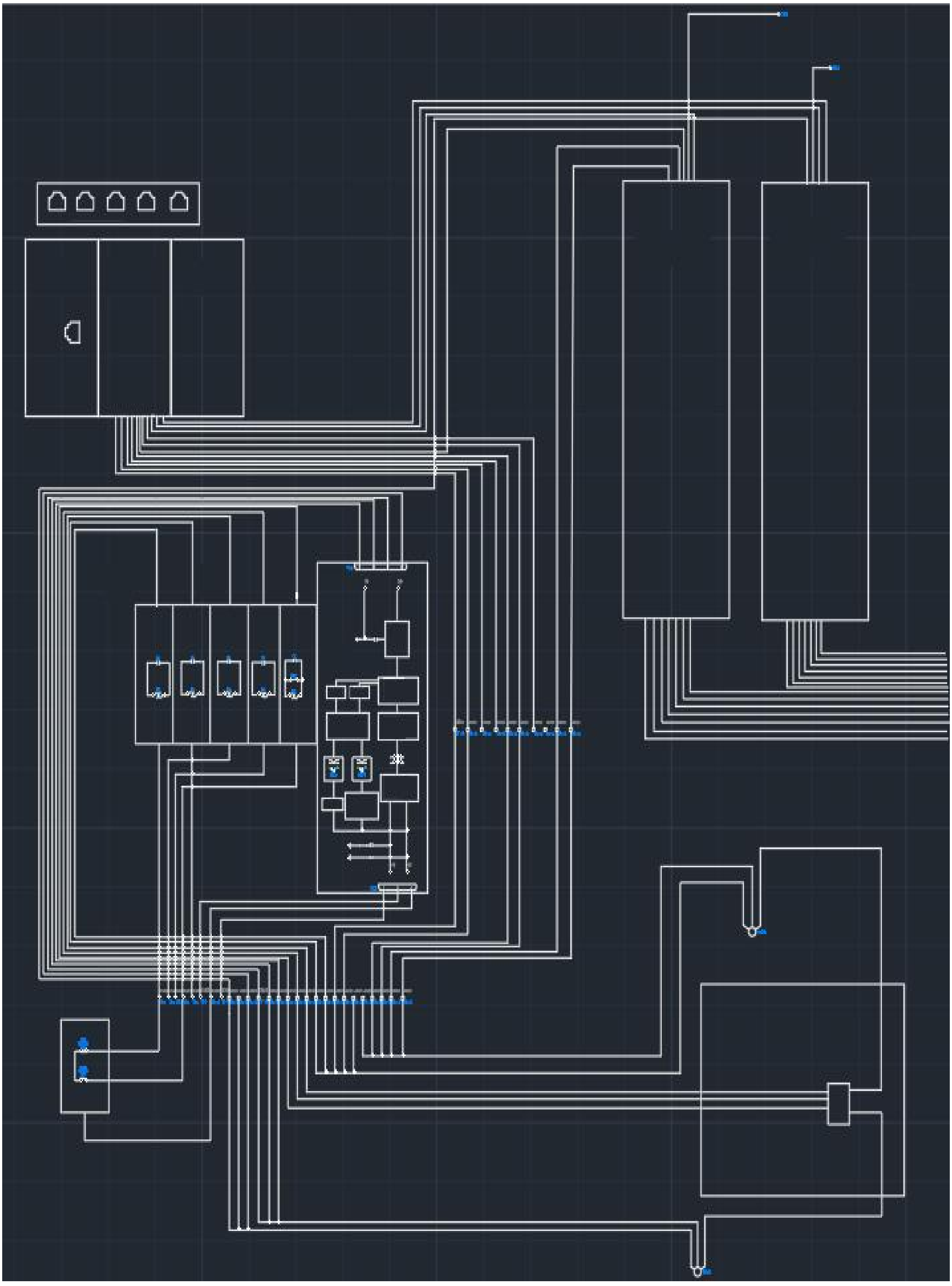
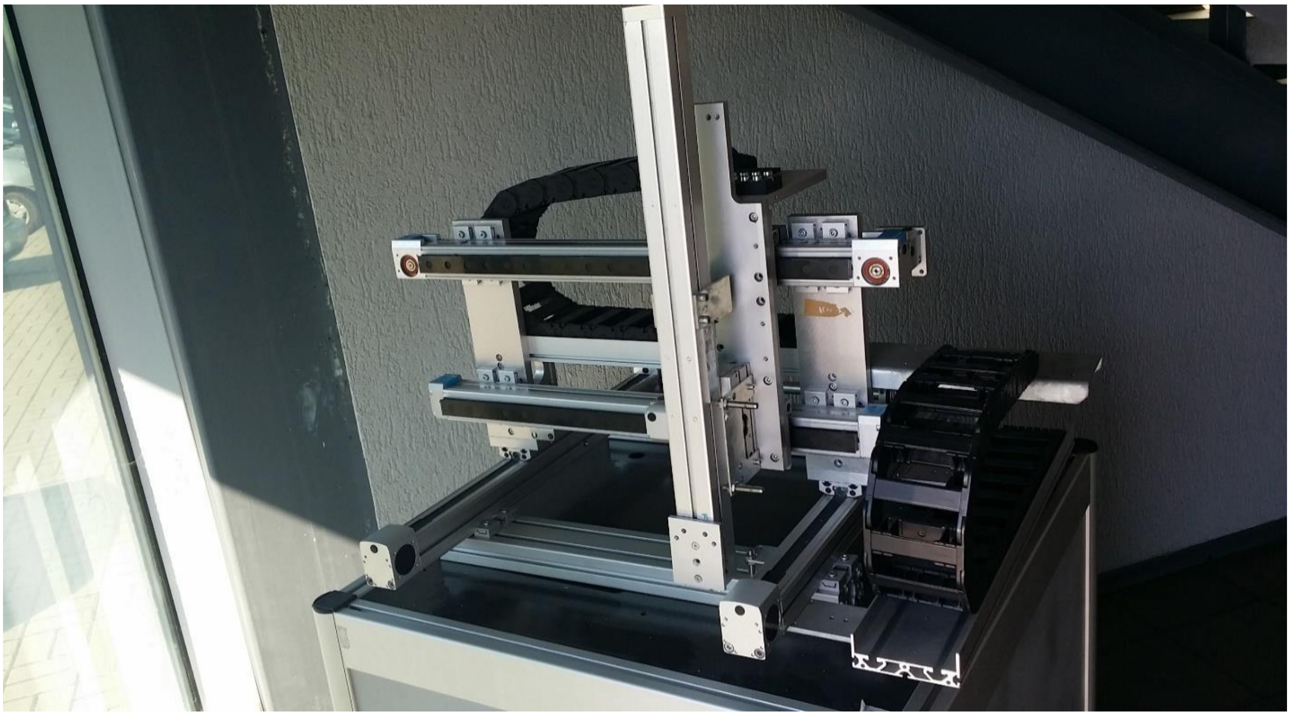
Annex

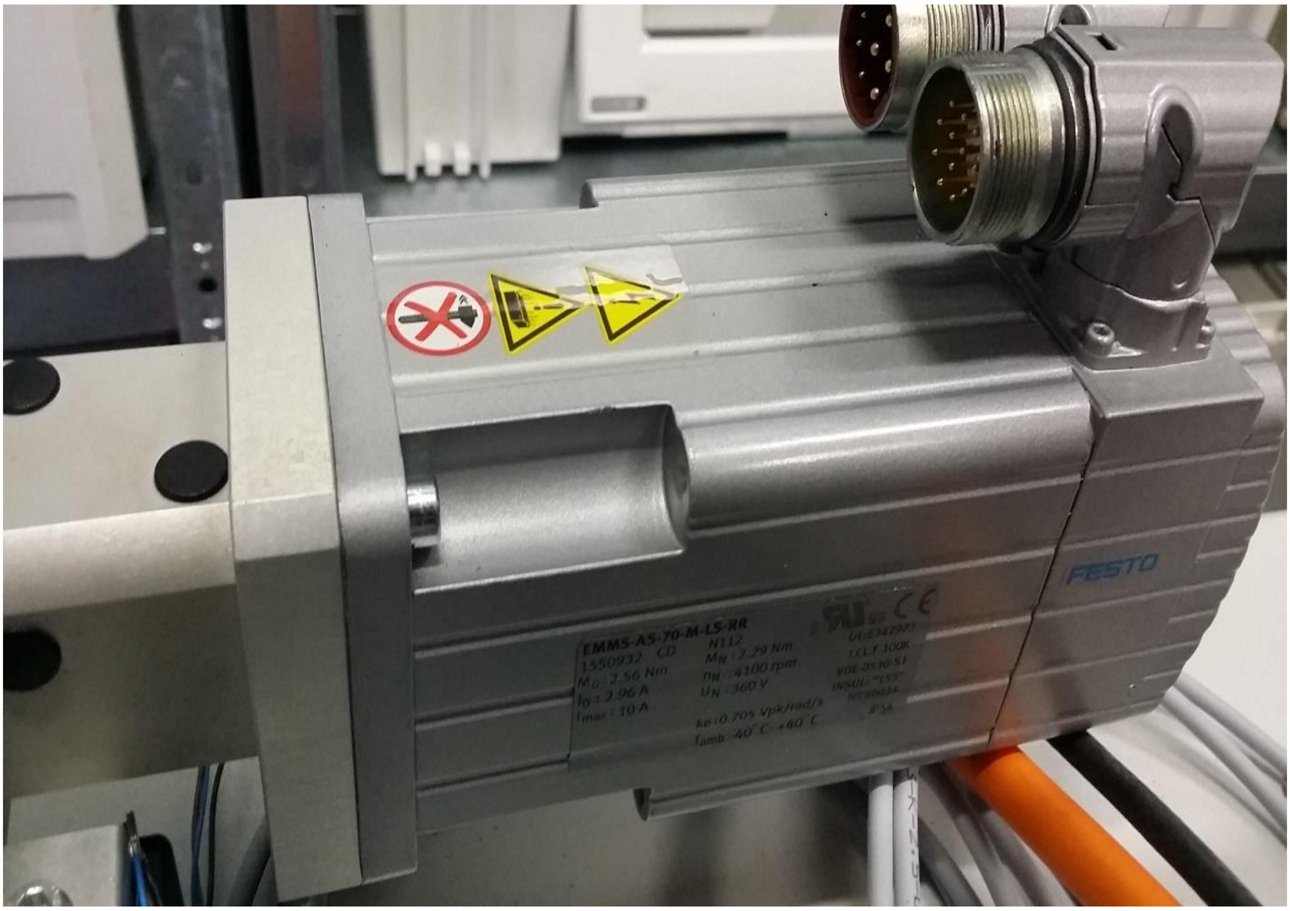
Annex 1. Full Electrical Scheme of the Electrical Box Made Using "AutoCAD Electrical".



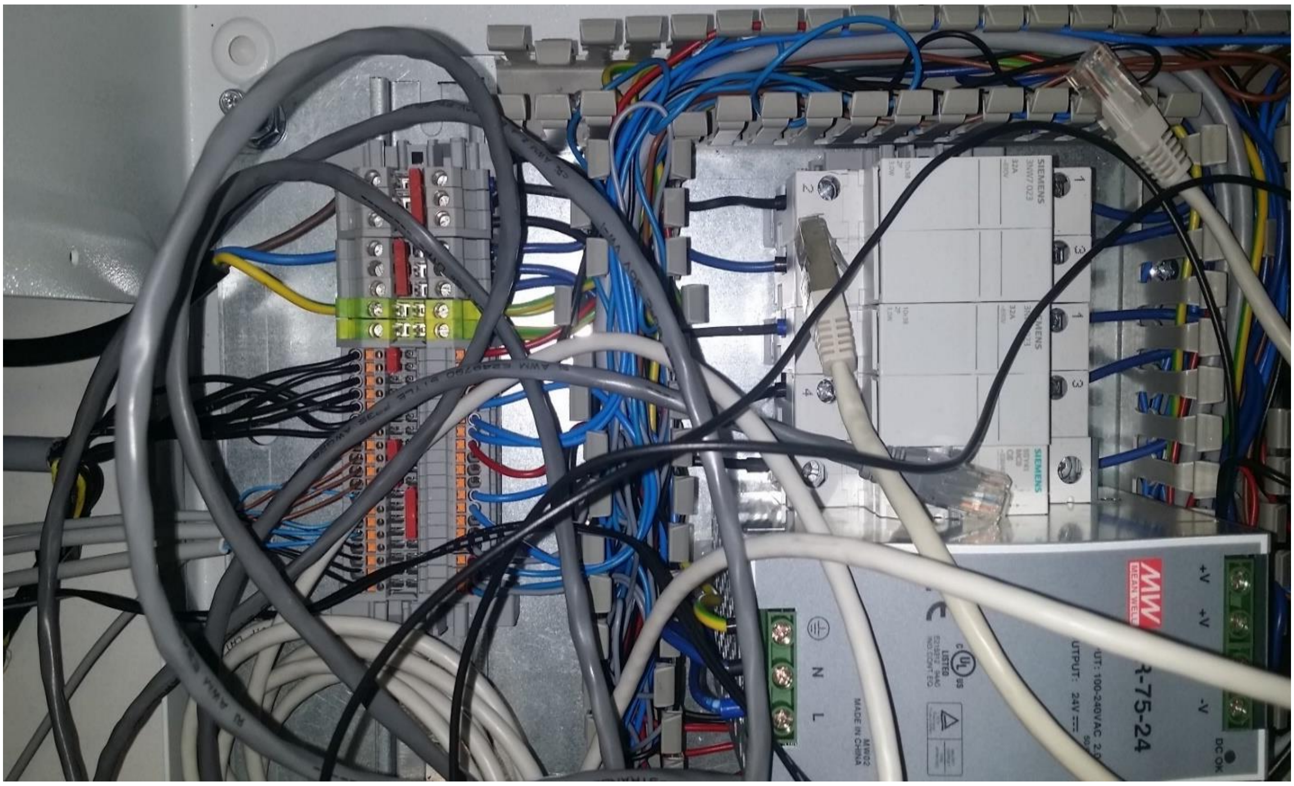
Annex 2. Not Completely Constructed 3D Manipulator Assembled by Company "Festo".



Annex 3. Servo Motor EMMS-AS-70-M-LS-RR Created by Company "Festo".

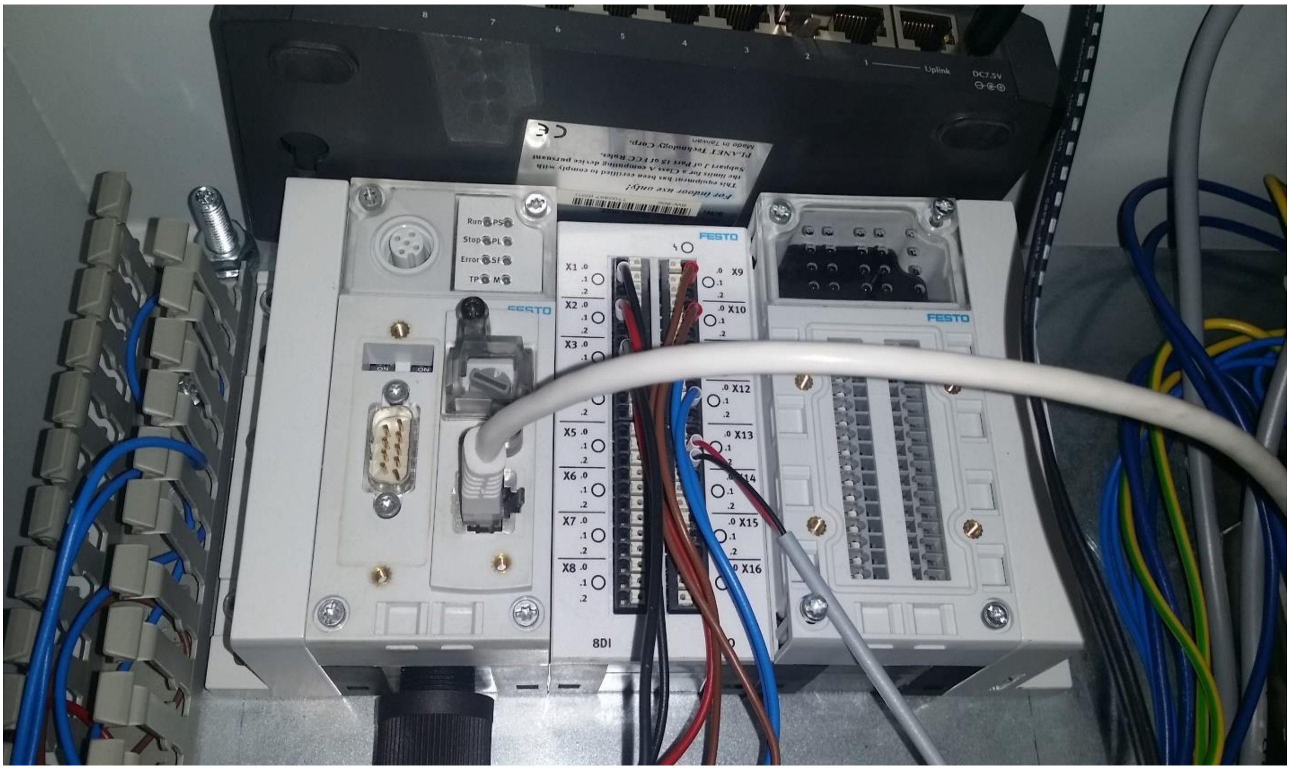


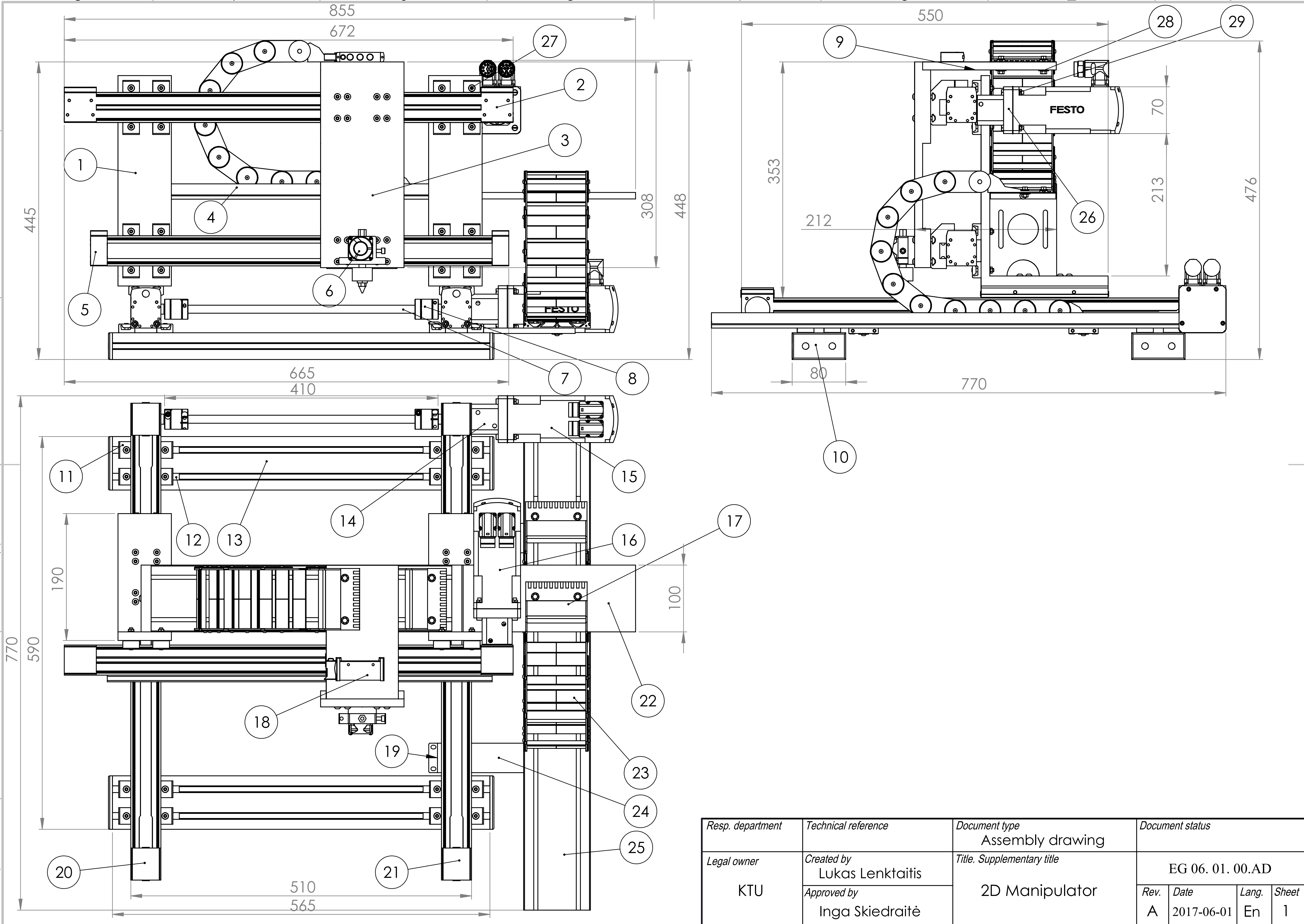
Annex 4. Terminal Blocks, Circuit Breaker, Supplementary Protectors, Wire Holders And Power Supplier Wiring And Position To Secure Safe Electronics Functionality In The Electrical Box.



Annex 5. Motor Controllers CMMP-AS-C2-3A-M0 for Both Motors Manipulation.

Annex 6. CPX's Controllers and Ethernet Router of the Electrical Box.





Resp. department	Technical reference	Document type	Document status
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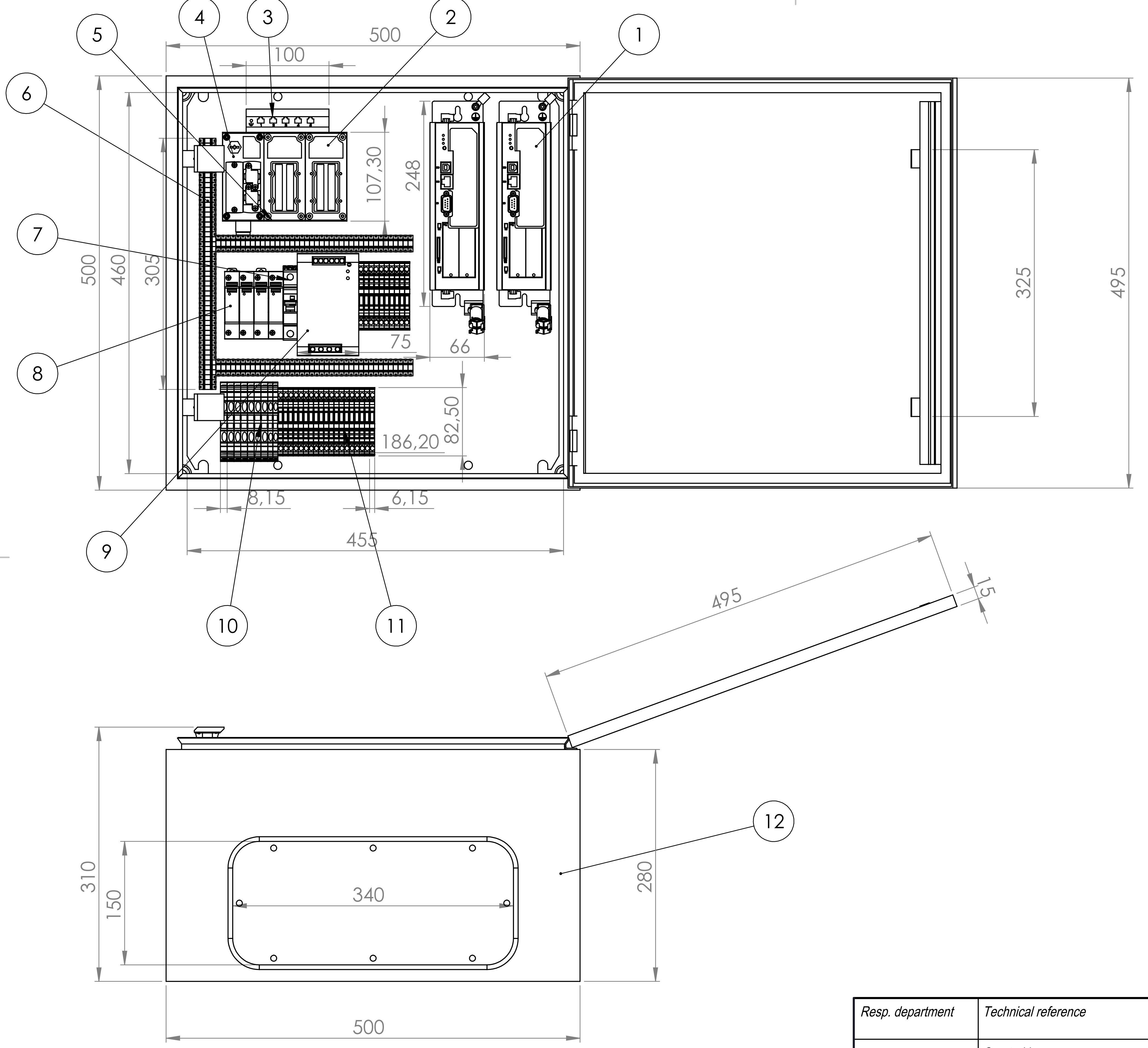
Legal owner	Created by Lukas Lenktaitis	Title. Supplementary title	EG 06. 01. 00.AD
KTU	Approved by Inga Skiedraitė	2D Manipulator	Rev. A · Date 2017-06-01 · Lang. En · Sheet 1

Format	Zone	No.	Designation	Name	Qty	Notes
A3			EG 06. 01. 00.AD	Documentation		
				Parts		
		1		Main Holder	2	
		2		Toothed Belt Axis	1	DGE-25-300-ZR-RF-LK-RB-GK-KG
		3		Main Axis Holder	1	
		4		Small Belt Holder I	1	
		5		Toothed Belt Axis	1	FDG-25-300-ZR-KF-GK
		6		Printer Head	1	
		7		Coupling	2	EAMC-40-66-11-15
		8		Shaft	1	
		9		Small Belt Holder II	1	
		10		Profile Plug	4	
		11		Central support	32	MUP-18/25
		12		Slot nut	20	NSTL-25
		13		Profile	2	
		14		Axial Kit	2	EAMM-A-F30-70A
		15		Servo Motor I	1	EMMS-AS-70-M-LS-RR
		16		Servo Motor II	1	EMMS-AS-70-M-LS-RR
		17		Belt fixers	4	
		18		Sub-Base	1	VUVG-L14-M52-MZT-G18-1P3
		19		Foot Mounting	2	HP-25
		20		Toothed Belt Axis	1	DGE-25-300-ZR-LV-RK-KG-KF-GK
		21		Toothed Belt Axis	1	DGE-25-300-ZR-RF-LK-RV-GK
		22		Big Belt Holder II	1	
		23		Belt	2	
		24		Big Belt Holder’s Fix	2	
		25		Big Belt Holder I	1	
		26		Motor Flange	2	EAMF-A-48A-70A
				Standard Items		
		28		Head Screw ISO 1207 - M5 x 30 - 30N	60	
		29		Hex Thin Nut ISO – 4035 – M5 - N	16	
		30		Plain Washer ISO 7092 - 5	16	

Resp. Department	Technical reference	Document type	Document status
		Assembly drawing	

Legal Owner	Created by	Title. Supplementary title				
KTU	Lukas Lenktaitis	2D Manipulator	EG 06. 01. 00.AD			
	Approved by		Rev.	Date	Lang.	Sheet
	Inga Skiedraitė		A	2017-06-01	En	1



Resp. department	Technical reference	Document type	Document status
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	Lukas Lenktaitis		
KTU	Approved by	Electric Box	Rev. A / Date 2017-06-01 / Lang. En / Sheet 1
	Inga Skiedraitė		

Format	Zone	No.	Designation	Name	Qty	Notes
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		1		Motor Controller	2	CMMP-AS-C2-3A-M0
		2		Manifold Block	2	CPX-AB-8-KL-4POL
		3		Ethernet Router	1	
		4		Interlink Block	1	CPX-GE-EV-S
		5		Interlink Block	2	CPX-GE-EV
		6		Wires Holder	10	
		7		Circuit Breaker	1	
		8		Supplementary Protector	2	
		9		Power Supplier	1	DR-75-24
		10		Conductor Terminal Block	30	
		11		Screw Terminal Block	8	
		12		Electric Box	1	

Resp. Department	Technical reference	Document type	Document status			
		Assembly drawing				
Legal Owner	Created by	Title. Supplementary title	EG 06. 02. 00.AD			
KTU	Lukas Lenktaitis	Electric Box				
	Approved by		Rev.	Date	Lang.	Sheet
	Inga Skiedraitė		A	2017-06-01	En	1