PPU College of Engineering and Technology
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Mechanical Department

Michatronics Engineering Project

Bachelor Thesis

Graduation Project

Pipes End Cleaning Machine

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Hebron – Palestine

December, 2012

Abstract

Pipes End Cleaning Machines, are used to perform lathing process in plastic coated steel pipes to remove a layer of plastic, and in this project a new end cleaning machine was designed, which included mechanical electrical and control systems, to replace the currently available machine in Future Iron Pipes factory (the sponsor of the project).

Since pipes were, and will always be of an important role in industrial and residential application, the existing machine needs to be replaced to improve the quality, reduce cost and increase the production rate of pipes.

إهداء...

إلى من خلق القلم فجعل المهندس خير الأمم إلى ربِ سماوتٍ سبع في ملكوته الأعلى وعرشه الأسمى .

إلى فلسطين :الأرضْ والإنسان...

إلى الجذور التي نبتت في الجنة فكانت ثمارُها ثلاثُ مهندسين شَقوا طريق الشمسِ للعلياء إلى الشموع التي ما فتئت تنحرق لتضيئ السبلَ لنا وعلى الدوامْ إلى من كان لزاماً علينا أن نشكرهم ونهيدهم هذا التواضع الهندسي إلى ذوينا قدسَ اللهُ سِرَهُمْ.

إلى اناسِ لولاهم لما كنا على ما نحن عليه اليوم إلى دائرة الهندسة الميكانيكية وكلية الهندسة والتكنولوجيا في جامعة بولتكنيك فلسطين لا سيما رجلٌ كان لهُ الفضلُ علينا إشرافاً وأخوةً وأبوةً الفاضل أ.م.حسين عمرو جزاهُ الله خير الجزاءْ إلى السادة المناقِشين الأفاضل د. يوسف السويطي أ.م. زهير وزوز و إلى الأخ و الصديق صاحب الرأي السديد م.محمد الشريف

لأهل السوق وذوي هذا المشروع المتواضع إلى مصنع أنابيب المستقبل ممثلاً بإدارته والعاملين فيه.

إلى إخواننا واخواتنا وزملائنا وأصدقائِنا وكل من كان له فضل عمل في دفع عجلة هذا المشروع

نهدي بكل تواضع مشروعنا هذا لعينوكم.

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Introduction

1.1 Project introduction

1.1.1 Overview

The project is sponsored by FIP (Future Iron Pipes), to design a machine that performs end cleaning processes on 3LPE steel pipes (3-Layered Polyethylene), which is removing a layer of plastic, ranging from 10-15cm in length and 3mm in thickness, depending on the size of the pipe, then creating a chamfer at the end of the process.

The cooperation of the manufacture and the university started, when a team from Palestine polytechnic University was visiting the local industries in a field trip, and the FIP owners, offered a graduation project opportunity, to replace the current end cleaning machine, which has a lot of problems and imperfections.

1.1.2 Purposes of the project

1. To improve the local industry, by applying engineering concepts, which will in return improve the overall Palestinian economy
2. To improve the final product quality of pipes.
3. To improve the members of the team, to be prepared to serve the local industry after graduation.
4. To build bridges between academic institutions and local industries.

1.1.3 Goals of the project

1. To fulfill the requirement for the engineering bachelor’s degree of Palestine Polytechnic University.
2. To gain a real life industrial experience, this enhances the team’s abilities in team-work, designing, and solving industrial problems.
3. To achieve a pre-graduation engineering field experience, this will make a good impression in the curriculum vitae, and a career-opportunity in FIP factory.
4. To apply mechatronics engineering principles and tools, to reach an optimal design of the end cleaning machine in quality and production rate.

5. To reduce the cost of the end cleaning process, by decreasing the number of operators, consumed power and materials.

1.1.4 Importance of the project

Pipes are the main, if not the only way to transport fluids, so as long as there isn't an alternative medium to transport fluids, beside the continuous growth of population and civilization, there will always be an increasing demand on pipes, which makes any progress in this field useful, it will even be at certain point a necessity to get better production rates, and less costs, which can be achieved through the enrollment of new technologies, and upgrading the already available ones.

1.2 About the manufacture (FIP)

1.2.1 Preview about the manufacture (FIP)

FIP (Future Iron Pipes) had been initiated in 2009 as the first privately owned large scale manufacturer of coated steel pipes in Palestine, and now it is considered one of the leading manufacturers of coated and lined carbon steel pipes in the Middle East region, with modern and robust, steel pipe coating technologies.

1.2.2 The problems in the current machine.

1. The installation using punches deforms the ends of pipes, which latter causes a problem in welding pipes together.
2. The chamfer at the end of turning, it was almost impossible to create a good chamfer, using the old cutting tool, and machine design.
3. When the operators install the pipe on the punches they compress it)using hydraulic system, which moves inward and outward the longitudinal axis of the pipe as a clamp), to prevent the pipe from slipping while turning, but this operation causes Buckling on the pipe.
4. Any relative angular velocity between the two punches will cause a twist on the pipe.
5. High failure rate of the system.

These are the main problems of the current machine; nevertheless it doesn't have any kind of automation abilities, or intelligent control.

1.2.3 The solution of the mentioned problems in other places

1. The pipe is installed on the rotating part using a gripper that holds the pipe gently from the inside without deforming it, nor exerting a resulting force on the longitudinal axis of the pipe to avoid buckling.
2. The usage of special cutting tools, which allows the creation of the chamfer while turning.
3. Accurate angular-velocity control, to prevent any relative velocity between the rotations of the two ends of the pipe.
4. Reliable design with low breakdowns rate.

1.3 Pipes manufacturing

1.3.1 Introduction

People have used pipes for thousands of years. Perhaps the first use was by ancient farmers who diverted water from streams and rivers into their fields. Archeological evidence suggests that the Chinese used reed pipe for transporting water to desired locations as early as 2000 B.C. Clay tubes that were used by other ancient civilizations have been discovered. During the first century A.D., the first lead pipes were constructed in Europe. In tropical countries, bamboo tubes were used to transport water. Colonial Americans used wood for a similar purpose. In 1652, the first waterworks was made in Boston using hollow logs.

Nowadays, pipes industry has become a major industry which supports the continuous growth of civilizations.

1.3.2 Pipes types.

These days markets, has a wide variety of pipes, which can be categorized depending on:

1. Material: Cast iron, ductile iron, steel, concrete, PVC, non-rigid plastic, copper, galvanized iron.
2. Lengths: A wide range of pipe's length these days, according to the applications they are used in. (FIP has 6-12.2 meter length pipes).

3. Diameter: There is also a wide range of pipe’s diameters these days, which also depends on the application they are used in (FIP has 3-16 inches pipes in diameter).
4. Finishing processes: Pipes could have many finishing operations, such as heat treatment, galvanizing, coating and etc…

1.3.3 Pipes applications.

1. Domestic water systems.
2. Pipelines transporting gas or liquid over long distances.
3. Scaffolding.
4. Structural steel.
5. As components in mechanical systems.
6. Casing for concrete pilings used in construction projects.
7. High temperature or pressure manufacturing processes.
8. Delivery of fluids, either gaseous or liquid, in a process plant from one point to another point in the process.
9. Delivery of bulk solids, in a food or process plant from one point to another point in the process.

1.3.4 The production of metallic pipes.

There are three different processes for metallic pipe manufacture.

1. Centrifugal casting of hot alloyed metal is one of the most prominent processes, ductile iron pipes are generally manufactured in such fashion.
2. Seamless (SMLS) pipe is formed by drawing a solid billet over a piercing rod to create the hollow shell. Seamless pipe withstands pressure better than other types, and is often more easily available than welded pipe.
3. Welded (also Electric Resistance Welded ("ERW"), and Electric Fusion Welded ("EFW") pipes, are formed by rolling plate and welding the seam.

1.3.5 Pipes coating and end cleaning processes.

Usually, before delivering pipes to the final costumers, they undergo what is called finishing processes, to increase the pipe's life time, by enhancing some properties (could be mechanical or chemical).

Pipes coating is one of the most common finishing processes, in the case of FIP's pipes, it is done by applying a 3-layered polyethylene (3LPE) which, provides maximum long-term corrosion resistance and mechanical enhancement to protect steel pipes.

After pipes being coated with the 3-layered polyethylene, the next stage is to remove 10-15 cm of this layer from both ends of the pipe (since pipes are coated continuously), to enable proper welding to connect pipes.

Chapter two

Current machine

2.1 Introduction

2.2 The shortages in the current machine in the manufacture

2.2.1 Mechanical shortages.

2.2.2 Control shortages.

2.2.3 Safety shortages.

Current machine

2.1 Introduction

The current machine has many problems, that effects the total production line in the manufacture, sometimes these problems causes a whole break down in the production process, and when this happens, it requires a lot of time to be solved, which causes undesired delays in the production line, moreover a lot of maintenance effort, this is all because of errors and other absent considerations in the machine, which will be improved and compensated in this project.

2.2 The shortages in the current machine in the manufacture

2.2.1 Mechanical shortages

1. The slider doesn't have enough inclination, thus the pipe won't roll all the way down to the end of the slider, see Fig.2.1.
2. There isn't a part or, a mechanism to stop the pipe from falling off the slider, see Fig.2.1.

Figure 2.1: The end of the slider, and how there is no limiting boundary that stop pipes from falling.

3. When the operators install the pipe in the rotating position they hold it, using punches, which moves inward and outward the Longitudinal axis of the pipe as a clamp, using hydraulic pistons, controlled manually each by a push bottom to hold the pipe, then by rotating these punches, they manage to turn the pipe and start the cutting operation see Fig.2.2, but using this method causes:
   a. Buckling on the pipe due to compression.
   b. Twisting along the pipe axis, due to relative rotational speed between the punches.
   c. This installation deforms the ends of the pipe.

Figure 2.2: Pipe fixing and rotating through cutting operation.

4. The machine only deals with specific range of pipes.
5. Moving pipes between the two sliders and along the machine stages is done manually by the operators.
6. The chamfer is done manually using grinding machine, which results in bad quality see Fig.4.3.

Figure 2.3: The chamfer.

2.2.2 Control shortages

1. Traditional control system that doesn't have any type of signal feedback, automation ability, supervision, nor diagnostic options, see Fig.2.4.
2. The lathe process is achieved manually, which leads to low accuracy and bad surface finish, see Fig2.5, and Fig.2.6.
3. Running and stopping the punch rotational motors, is on/off system, this doesn't allow speed control, besides there is no speed feedback, which causes the previously mentioned relative velocity between the two motor.
4. Controlling the punches movement is also done manually, without force or position feedback.

Figure 2.4: The control panel in the current machine.

Figure 2.5: Shows the knife holder in normal position.

Figure 2.6: Shows the knife holder in cutting position.

2.2.3 Safety shortages

The system doesn't have any kind of safety consideration, although there is at least two operators, and other employees which might be in the machine working range.

Chapter three

New machine

3.1 Introduction

3.2 Modules

3.2.1 The Slider.

3.2.2 The Mover.

3.2.3 The Roller.

3.2.4 The Punch and the Cutting Machine

3.2.4.1 The Punch.

3.2.4.2 The Cutting Machine.

New Machine

3.1 Introduction

The new machine design can be seen in Fig.3.1, it was divided into five modules, where each module is responsible of certain functions, to simplify the designing process, and the modules are:

1. The Slider.
2. The Mover.
3. The Roller.
4. The Punch and the Cutting Machine

At the early designing stages, these modules were being treated in an integrated manner to assure that each module fits perfectly with the others, by defining the exact function required from each module, and defining the movement range.

After the main constraints of each module were defined, they were treated separately, some weren’t changed from the original machine design, and other was designed from the scratch, section.3.2 briefly explains what was done in each module.

A wide range of designing software was used; table.3.1 lists all the software used in the design with brief description of each.

#	Software name	Description
1	Solidwork 2010	CAD tool, used for drawing 3D model, and stress analysis
2	Autocad 2007	CAD tool, used for 2D sketches.
3	Automation studio 5.0	Hydraulic and pneumatic simulation software, used to design the hydraulic and pneumatic systems
4	STAAD.pro v.8	3D structural analysis and design software, used for force analysis
5	Mitcalc 1.40-2D	Excel based software, used to choose bearings
6	Matlab 2010	Technical computing software, used in designing the control system.
7	Simatic step 7	Siemens PLC programing software, used to design the PLC software for the machine
8	Wincc flexible	HMI (humen machine interface) software, used to design the touch screen software.
9	Microsoft visio 2007	Flowchart designing software.
10	Proteus.7.6	Designing of schematic diagram for electrical system.

Table 3.1: List of the programs used in designing the machine.

Figure of the whole machine A3

3.2 Modules

3.2.1 The Slider

This is the first stage, where pipes are fed to the slider, from the previous stage (coating), the pipes are allowed to slide over these beams, till they reach the bumper, see Fig.3.2.

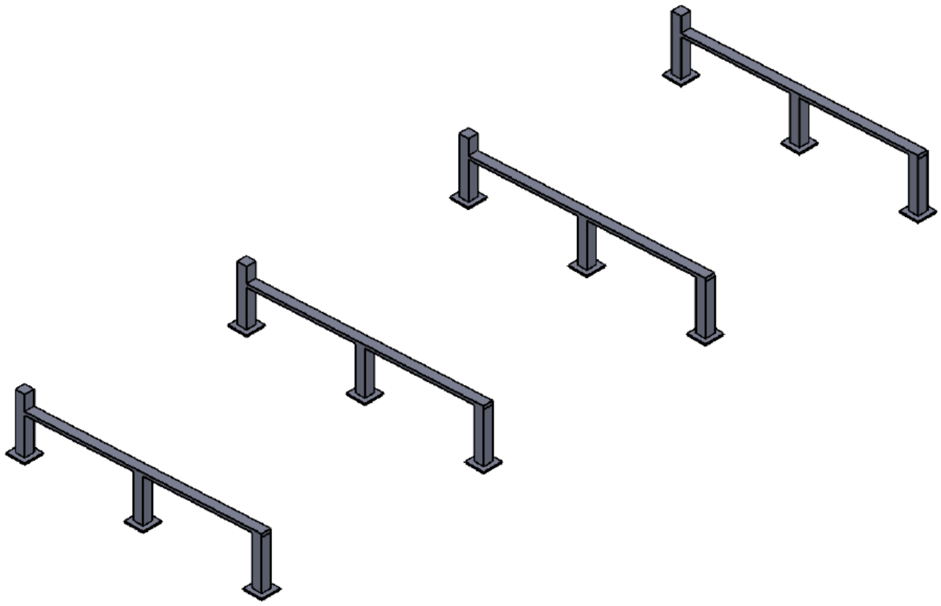

Figure 3.1: The Slider.

This module already exists in the current machine, but was improved as follows:

1. The inclination was adjusted, to allow the pipes to roll all the way till they reach the bumper.
2. A bumper was added to prevent pipes from falling out of the sliders.
3. A sensing element was added, to let the machine know if there are pipes on the slider or, if the slider is empty.

3.2.2 The Mover

This mechanism is responsible of moving pipes through the operation stages.

As it can be seen in Fig.3.3, it has two heads one to move the pipe from the slider to the roller, and the other, to move turned pipes from the roller to the output slider simultaneously.

This module didn't exist in the original machine, adding it solved the following problems:

1. Safety concern, by dispensing the operator from direct contact with the pipe while it is moving, which may cause injuries (like trapping the operator hand under the pipe).
2. Moving the pipe gently, without scratching the polyethylene layer when pushing it over the sliders edges.
3. Adding automation capability.

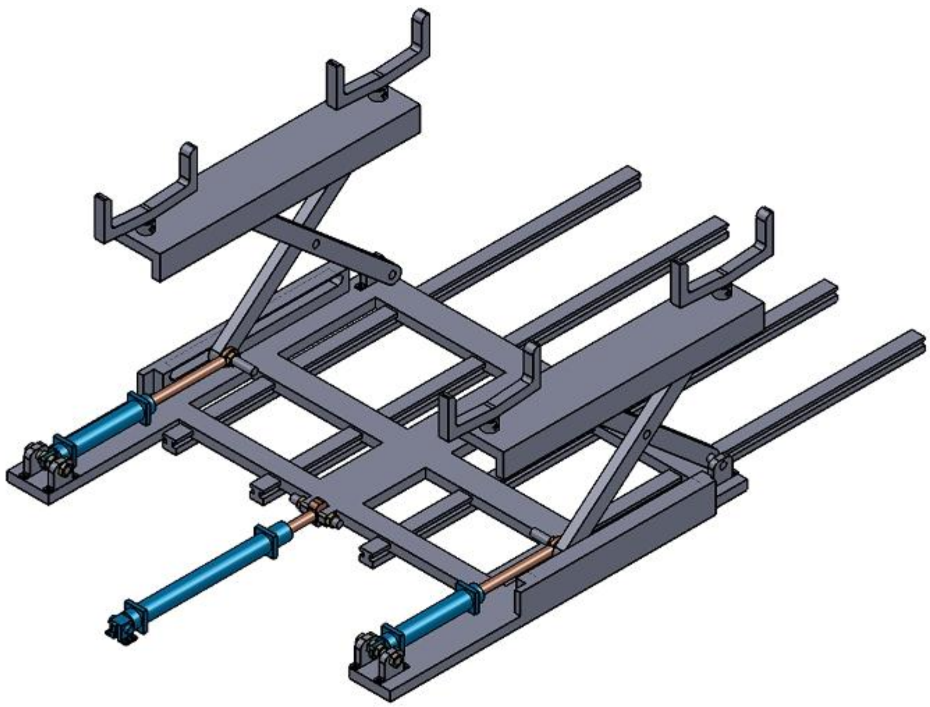

Figure 3.2: The Mover.

3.2.3 The Roller

This module rotates the pipe to be turned, see Fig.3.4, this mechanism didn't exist in the original machine, but it was copied from another machine in the factory (concrete machine), it solves the shortages in the current machine as follows:

1. Twisting that appears in the original machine due to relative rotation is avoided.
2. It overcomes the need for tightly fixing the pipe with the punches, this way no harm to the pipe's edges is caused, neither bending or buckling occur.

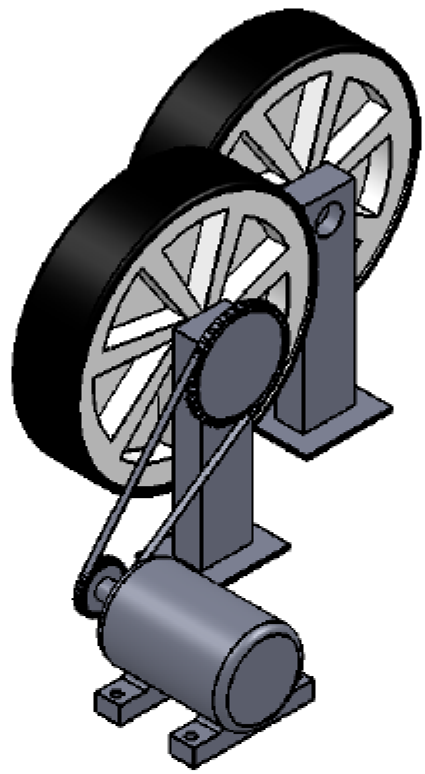

Figure 3.3: The Roller.

3.2.4 The Punch and the Cutting Machine

3.2.4.1 The Punch:

The punch module is used, to hold the pipe in position and prevent it from moving while being rotated see Fig.3.5.

This module already exists in the original machine, but it was improved and it's functionally been limited to hold the pipe in position without turning it, by doing these changes the following problems was solved:

1. Bending and, buckling are both avoided, since the required forces on the longitudinal axis of the pipe aren't large anymore.
2. Twisting is avoided as well, since the punches will rotate freely with the pipe.

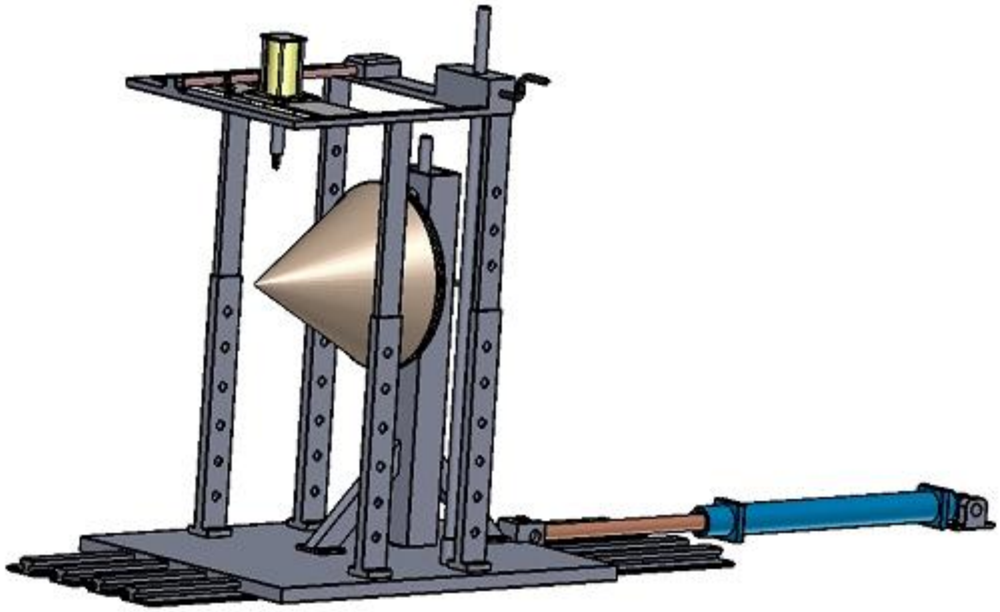

Figure 3.4: The Punch and the Cutting Machine.

3.2.4.2 The Cutting Machine:

This module moves the knife in two directions, the first direction is up and down using a piston, and the second direction is along the longitudinal axis by lead screw and a sliding cart which carries the piston, and cutting tool, see Fig.3.4.

This module solves the following problems in the original machine:

1. Better cutting quality, a pressure control will be used to apply the sufficient cutting force, to only cut the polyethylene layer without scratching the metal.
2. The chamfer will be created automatically:
   a. Ensures a good quality chamfer
   b. Safety concern, since there will be no need for an operator to do the chamfer manually, which may cause injuries.
3. Adding automation capability.
4. The cutting depth will be exact, this will overcome products variance. (The depth is approximated by the operator in the current machine).

Chapter four

Mechanical design

4.1 Introduction

4.2 The Slider

4.3 The Mover

4.3.1 Part description

4.3.2 Part selection and related calculations

4.3.2.1 The Jack force and stress analysis

4.3.2.2 Pistons selection and related calculations

4.4 The Roller

4.4.1 Part description.

4.4.2 Calculations and parts selection

4.4.2.1 Force calculations.

4.4.2.2 Inertia calculations.

4.4.2.3 Turning calculations.

4.4.2.4 Bearing selection.

4.4.2.5 Motor selection.

Mechanical design

4.1 Introduction

This chapter covers the mechanical design, related calculations and analysis of the machine, it is divided into sections, each section handles only one part of the machine, moreover some of these section were divided into subsections where needed as follows:

1. Part description: Describes each and every part of that section, their functionality and movement ranges.
2. Part selection and related calculations: The project has many selected parts according to certain criteria and calculations, the selection procedures, and required calculations were written in this subsection.

It should be noted, that through the design of this machine, a safety factor of at least 1.5 was applied, and even in some parts a higher safety factor was applied, to account for the dynamic responses which may occur, this way ensures avoiding all the probable failures that could happen, although the calculations were made at the maximum possible pipe weight, that the machine is supposed to turn.

4.2 The Slider

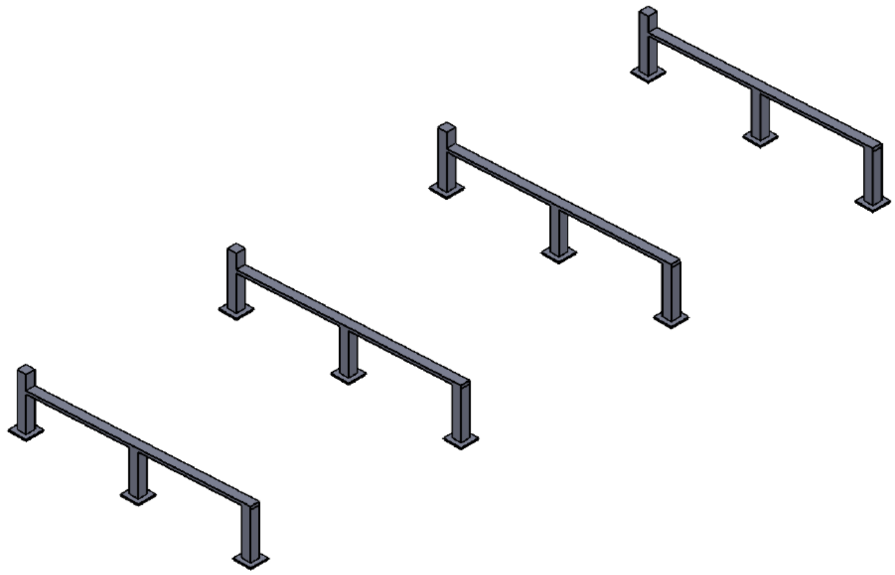

Figure 4.1: The Slider.

There was nothing much done to improve this part of the machine, what was basically done is adding a layer of rubber on the upper surface to provide softer contact between pipes and the slider to prevent pipes from being scratched, the other thing done, was increasing the inclination of the slider to let the pipes roll all the way down to the bumper.

4.3 The Mover

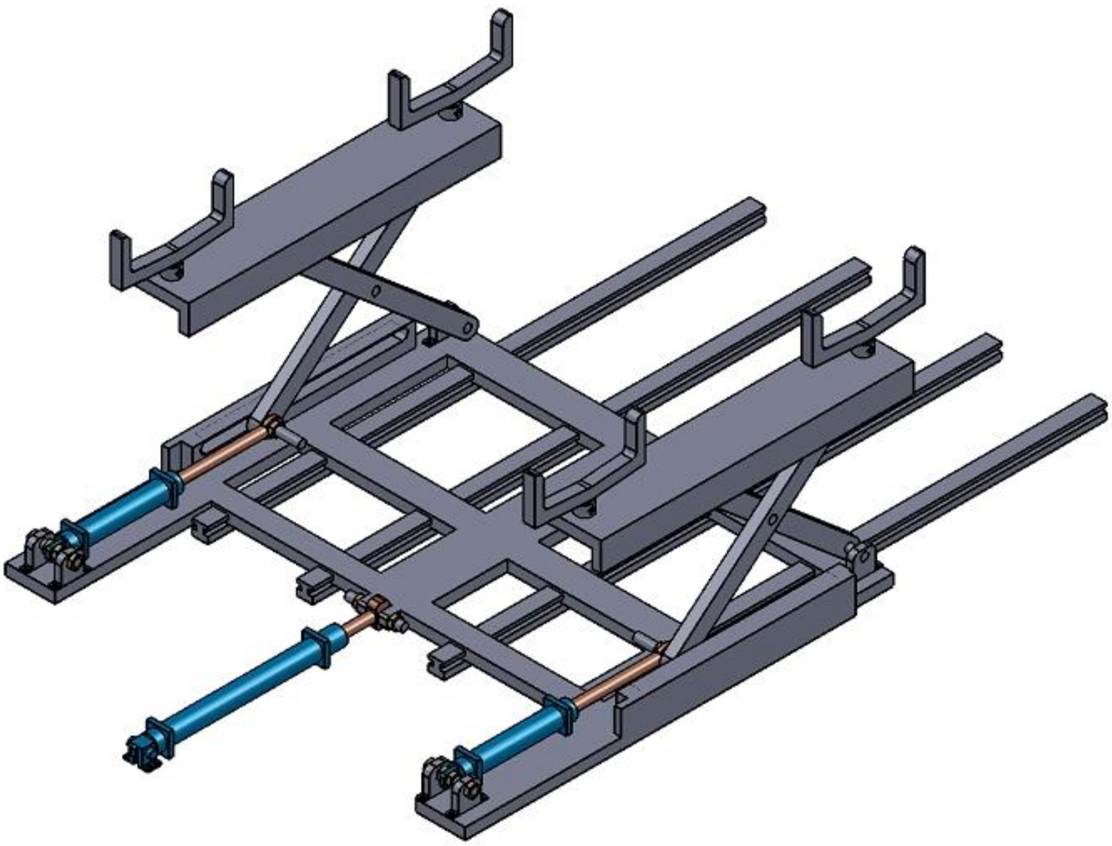

Figure 4.2: The Mover.

4.3.1 Part description

1. The Track: This part allows for the movement of the whole mover's body, along the slider alignment, to transport pipes from one location to another through the process stages, so it's length depends on the distance between, the center line of a pipe on the slider, and the center line of a pipe mounted on the roller, it should be calculated at the maximum pipe's radius available, also the mover's base length should be added to that distance. The length of the mover's base and the slider can be seen in Fig.4.3.

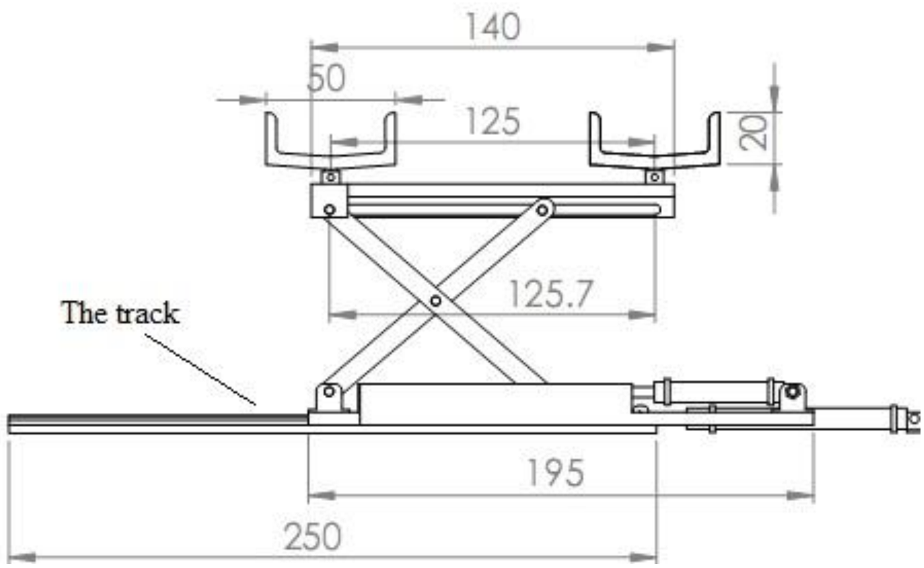

Figure 4.3: Side view of the mover, shows the base and the track lengths. (Dimensions are in cm).

2. Piston No.1: Moves the mover base with what it carries along the track. See Fig.4.4.

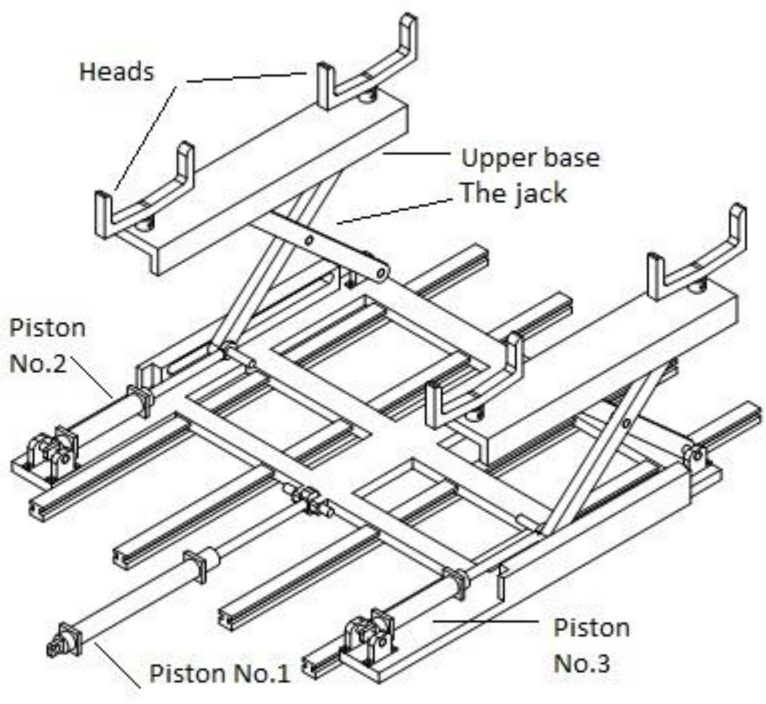

Figure 4.4: Mover’s parts.

3. Mover’s base: Designed to carry the mover’s parts, with tracks to support the jack’s (part No.4) sliding range, so its dimensions were chosen according to the required height of the jack.
4. The jack: This mechanism is used to support the required vertical movement of the pipe, Fig.4.5 and Fig.4.6 show the minimum and, maximum height of the Jack respectively.

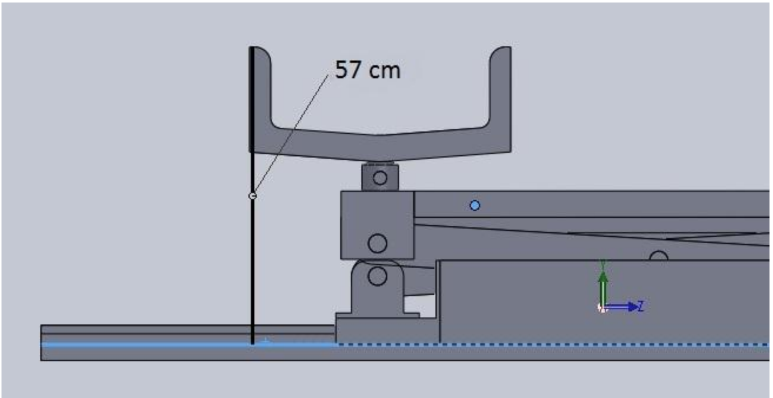

Figure 4.5: Minimum height of the Mover’s jack.

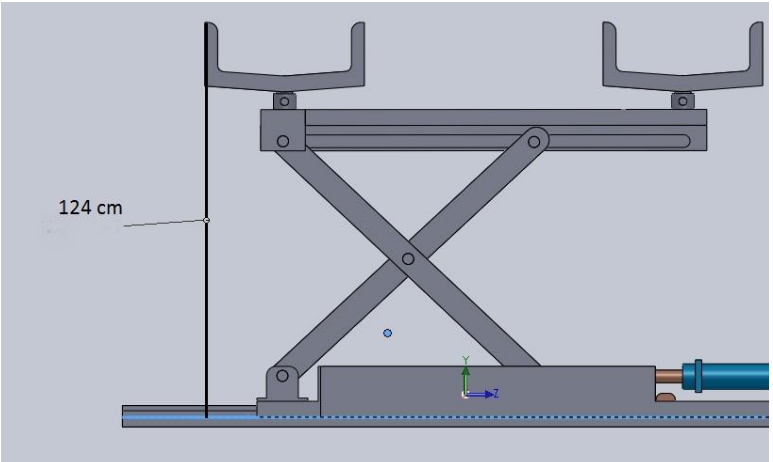

Figure 4.6: Maximum height of the Mover’s Jack.

5. Piston No.2: Used to drive the jack mechanism, see Fig.4.4.
6. Piston No.3: Identical to piston No.2, but two pistons were used to distribute the load, as can be seen Fig.4.4.
7. Upper base: Deigned with tracks (see Fig.4.4) to support the other sliding range of the jack, and to carry the heads.
8. Heads: It can be also seen in Fig.4.4, used to hold and carry pipes.

4.3.2 Part selection and related calculations

4.3.2.1 The Jack force and stress analysis

The material for the jack was chosen to be Steel AISI 1020, because of its availability in the local markets, Table.4.1 lists the properties of Steel AISI 1020.

Poisson's Ratio	0.29
Shear Modulus	7.7e+01 N/m^2
Density	7900 kg/m^3
Tensile Strength	420507000 N/m^2
Yield Strength	351571000 N/m^2
Thermal Expansion	1.5e-005 /K

Table 4.1: Steel AISI 1020 properties.

After finding the jack dimensions, reasonable cross sections were chosen for the beams, and was followed by force and stress analysis (see dimensions and cross sections in appendix A).

Fig.4.7 shows the force analysis of the jack using STAAD.pro software, from the results; Stress analysis for the jack at four different cases were obtained using Solidwork software, and verified that the maximum stress doesn't exceed the yield strength of the steel chosen.

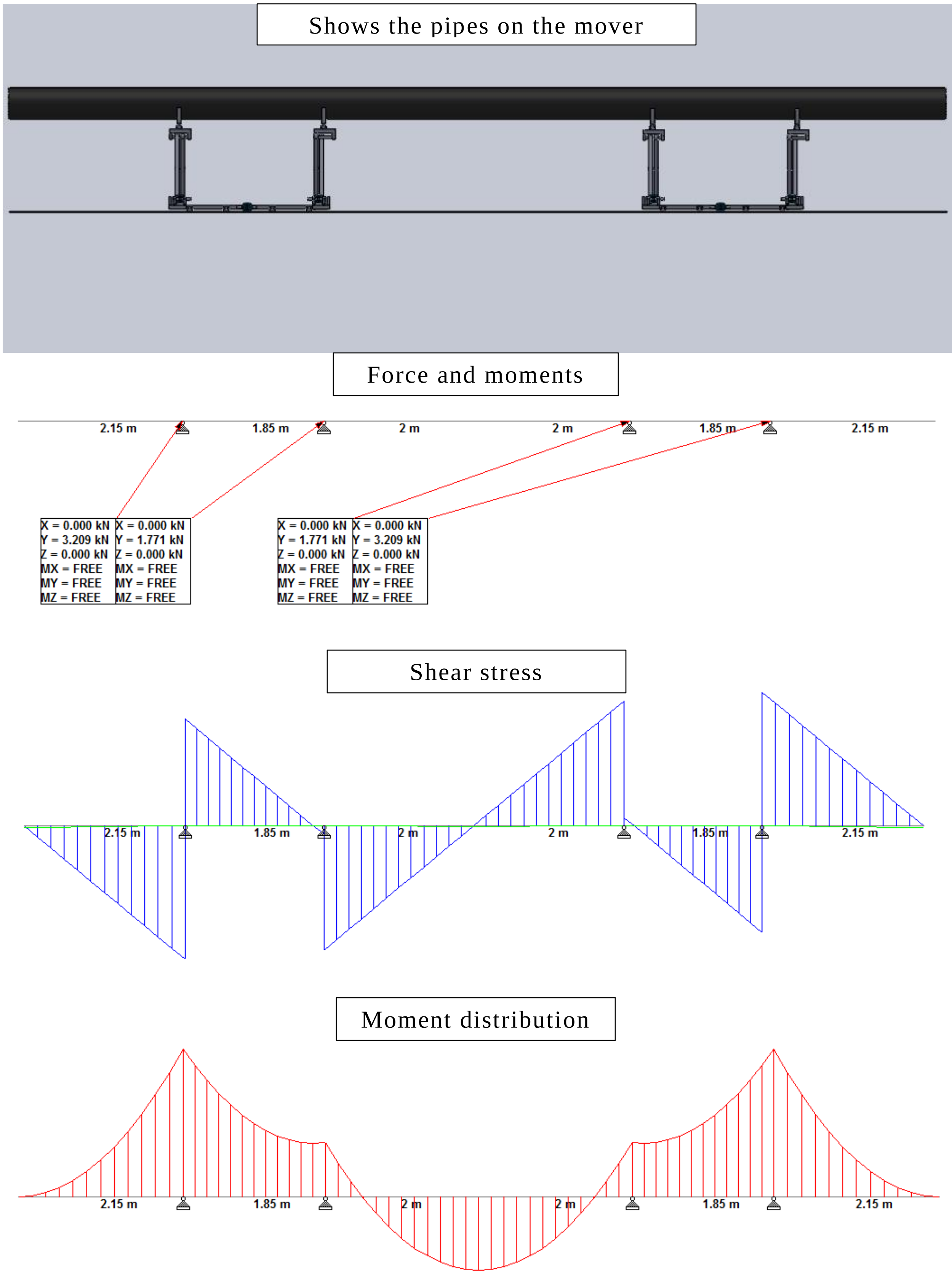

Figure 4.7: Mover’s force analysis using STAAD.pro.

Case No.1

This position is at the lowest level of The Mover, loaded with two of the maximum pipe weight available.

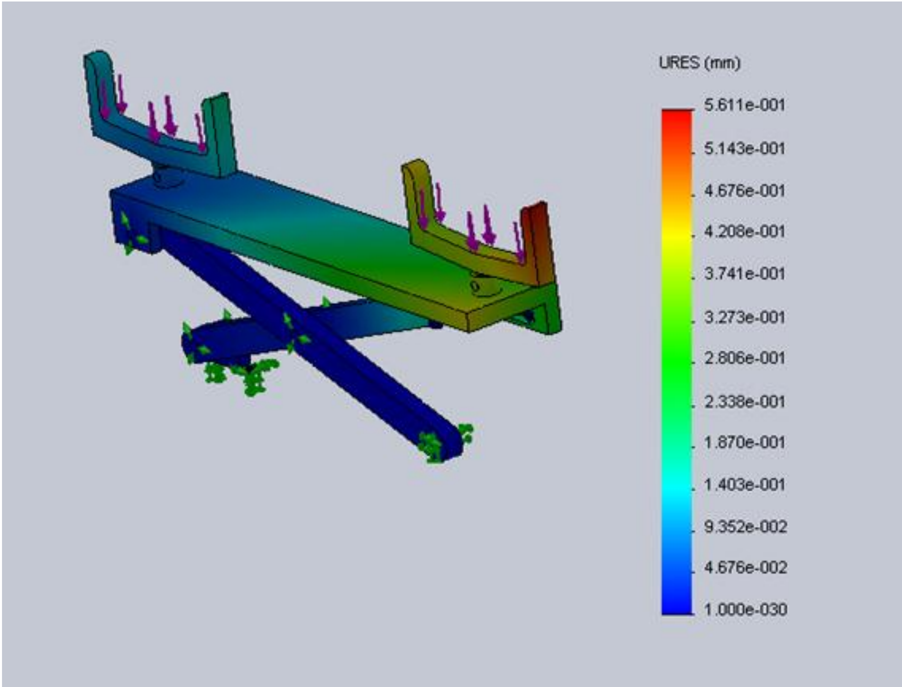

Figure 4.8: Mover's deflection at position No.1.

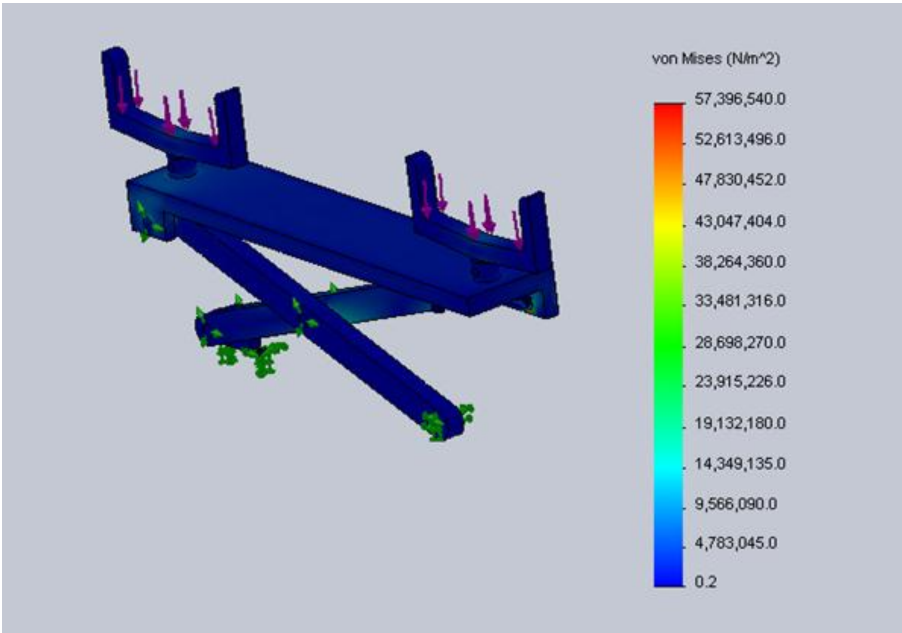

Figure 4.9: Mover's von Misses stresses at position No.1.

At case No.1, the maximum stress value was found to be approximately 57 Mpa which is about seven times less than the yield strength of the steel used (350Mpa).

Case No.2

This position is at the highest level of The Mover, loaded with two of the maximum pipe weight available.

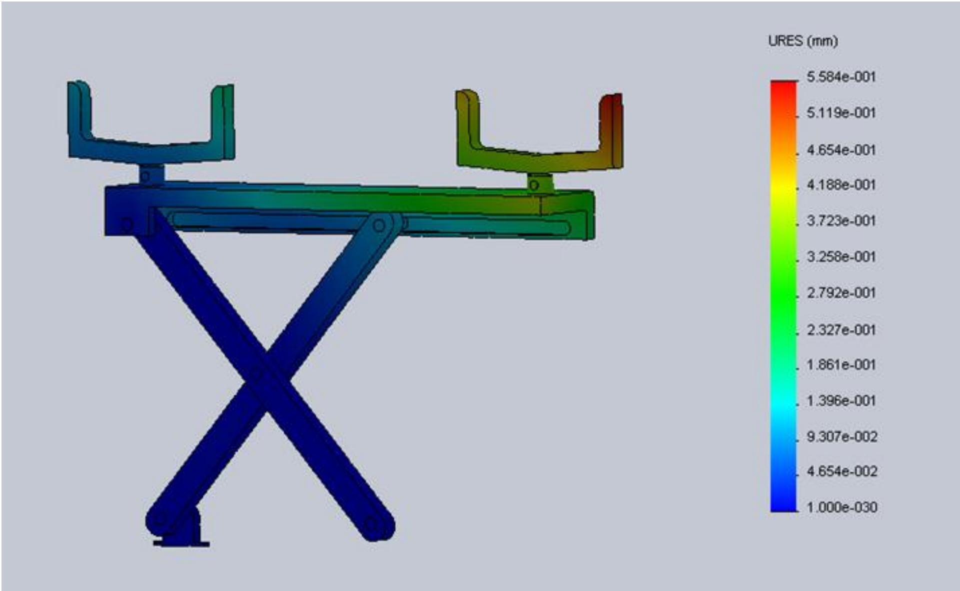

Figure 4.10: Mover’s deflection at position No.2.

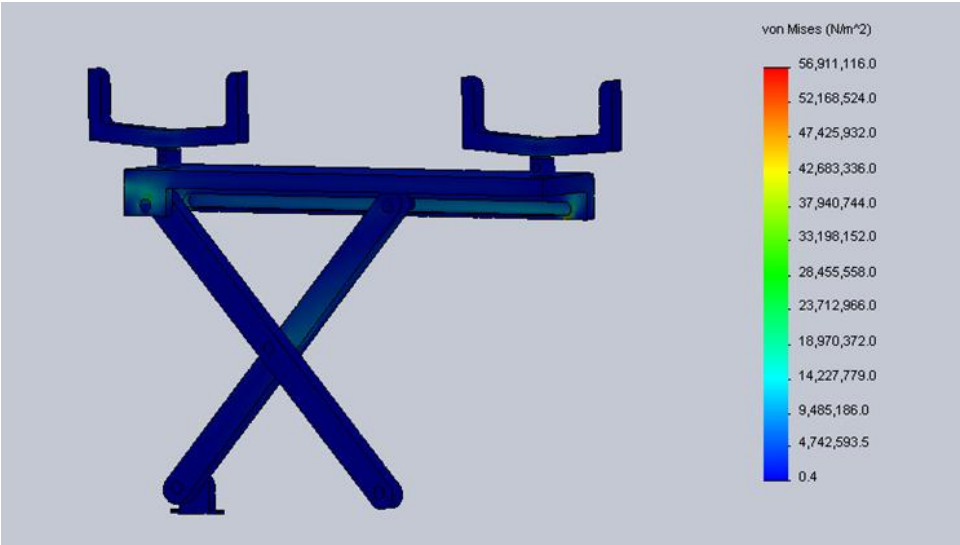

Figure 4.11: Mover’s von Misses stresses at position No.2.

At case No.2, the maximum stress value was found to be approximately 57 Mpa which is about seven times less than the tensile strength of the steel used (350Mpa).

Case No.3

This is at the lowest level of The Mover, loaded with one pipe of the maximum weight available.

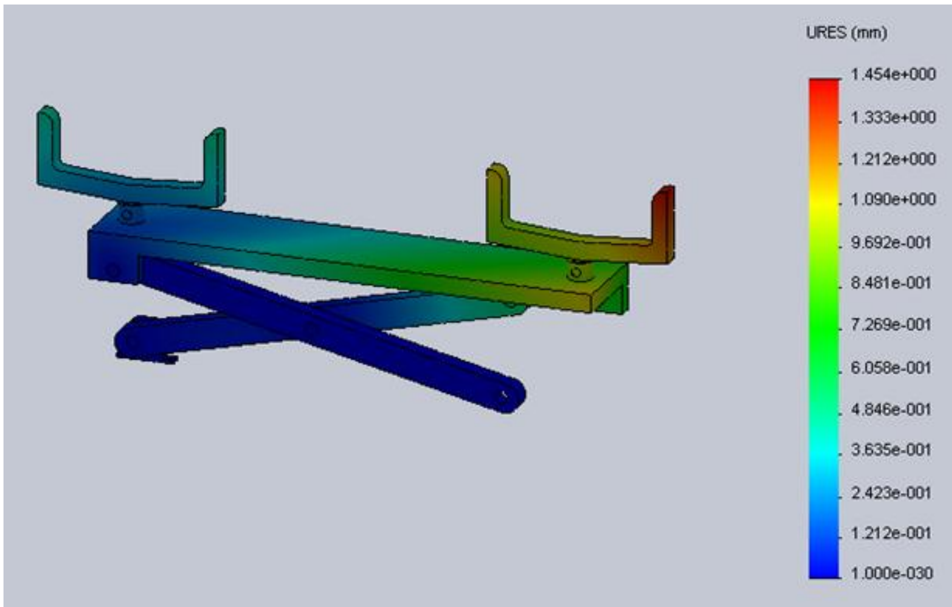

Figure 4.12: Mover’s deflection at position No.3.

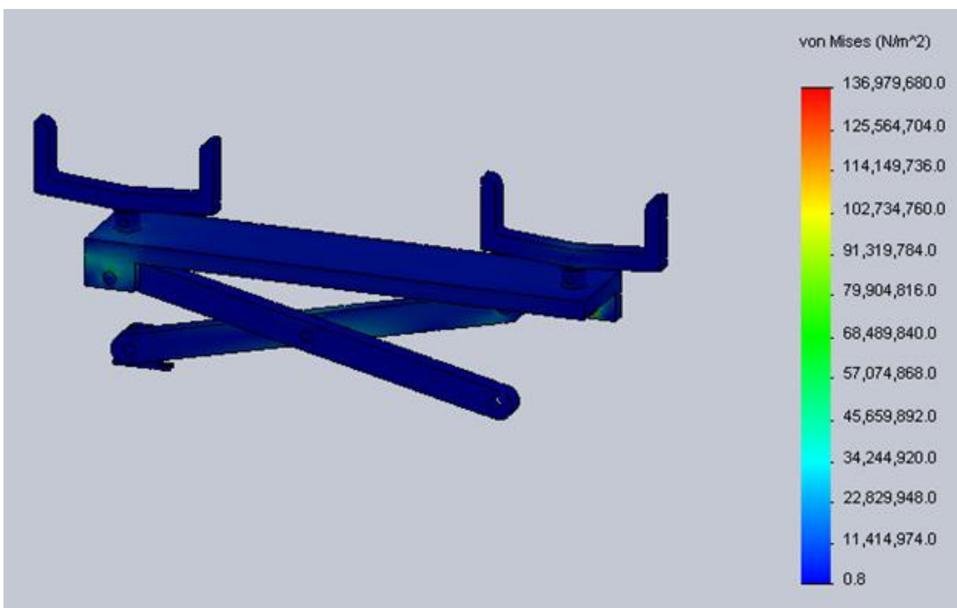

Figure 4.13: Mover’s von Misses stresses at position No.3.

At case No.3, the maximum stress value was found to be approximately 137 Mpa which is about two and a half times less than the tensile strength of the steel used (350Mpa).

Case No.4

This is at the highest level of The Mover, loaded with one pipe of the maximum weight available.

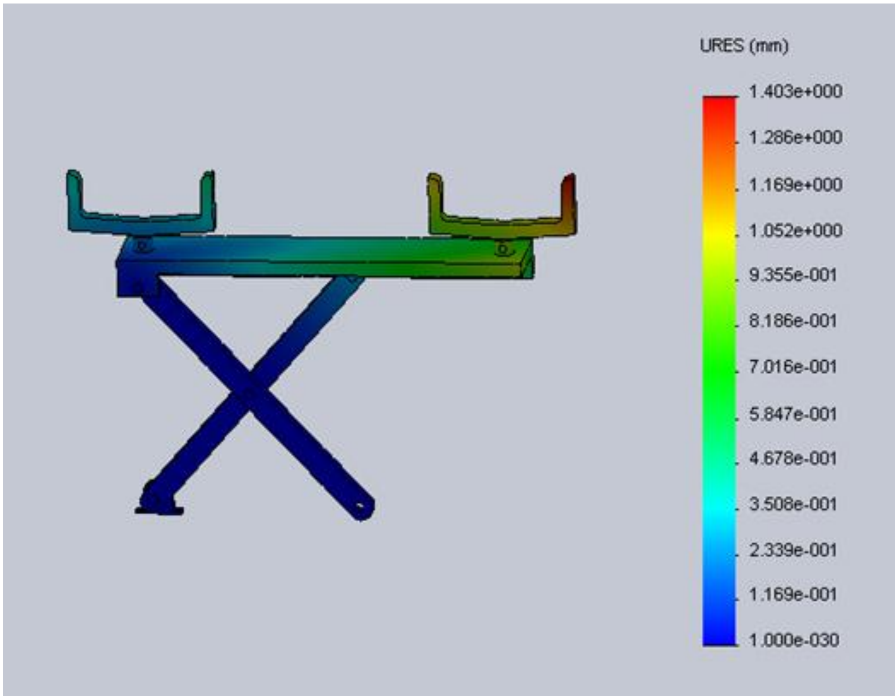

Figure 4.14: Mover's deflection at position No.4.

Figure 4.15: Mover's von Misses stresses at position No.4.

At case No.4, the maximum stress value was found to be approximately 120 Mpa which is about three times less than the tensile strength of the steel used (350Mpa).

Table.4.2 summaries the results of stress analysis for the above four cases, it can be seen that the lowest safety factor is in case No.3 and equals 2.5 which is a considered to be acceptable.

Case	Maximum stress (Mpa)	Yield strength (Mpa)	Safety factor
No.1	57	350	6.1
No.2	57	350	6.1
No.3	137	350	2.5
No.4	120	350	2.9

Table 4.2: Stress analysis summery.

4.3.2.2 Pistons selection and related calculations

As it has been mentioned, the mover requires three pistons to do its function, see Fig 4.4.

1. Piston No.1: moves the mover along the track.
2. Piston No.2 and No.3: these two pistons are identical, they push and retract the sliding edges of the jack to open and close it.

To choose these pistons, two main specifications are required, the stroke and the force supported.

Choosing piston No.1

$$f = (mg + P_w) \times \mu + (m + P_m) \times a \qquad \text{Eq. 1}$$

Where:

m: Mass of the mover.

P_w: Approximated pipe's weight reflected at piston.

P_m: Approximated pipe's mass reflected at piston.

μ: Friction coefficient between two steel surfaces.

a: Acceleration, calculated from velocity profile in Fig.4.16.

g: Gravitational acceleration.

The load was found using the STADD software, while the mover's mass was found using Solidwork software, as for the acceleration it will be found from the velocity profile in Fig.4.16.

$a = v/t \ (m/s^2)$ Eq. 2

Where:

v: Final speed (m/s).

t: Rise time (the time required to reach v).

$$a = 5 \times 10^{-2}/1 = 0.05 m/s^2$$

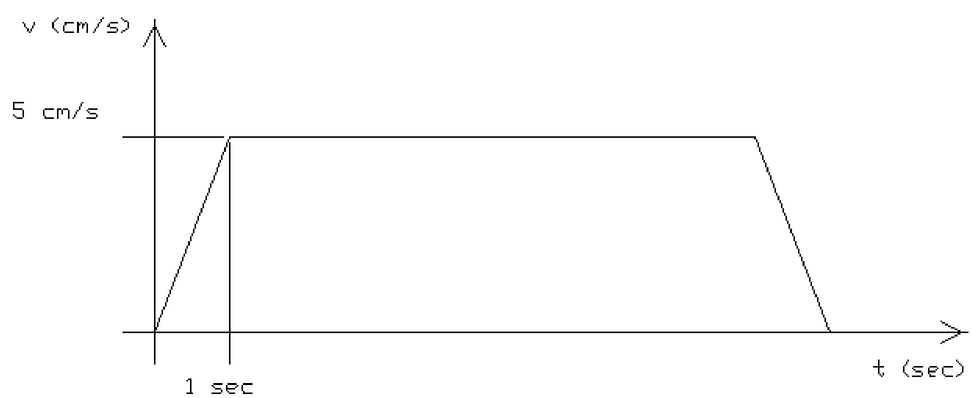

Figure 4.16: Velocity profile of pistons.

$$f = (168 \times 9.81 + 12800) \times 0.75 + (168 + 1280) \times 0.05 = 10.9 \text{ kN}$$

With a safety factor of 2, the force becomes:

$$f = 21.8 kN$$

Piston No.1 stroke = 120cm

From these two specifications it was found that the piston "Maxim (218-357) "fulfills the need see appendix A.

Choosing piston No.2+3

Using Eq.1. again.

$$f = (36 \times 9.81 + 6400) \times 0.75 + (36 + 640) \times 0.05 \cong 5.1\ kN$$

With a safety factor of 2, the force becomes

$$f = 10.2kN$$

Piston No.2 and No.3 stroke = 40 cm

From these two specifications we found that the piston “Maxim (218-322)“ fulfills the need see appendix A.

4.4 The Roller

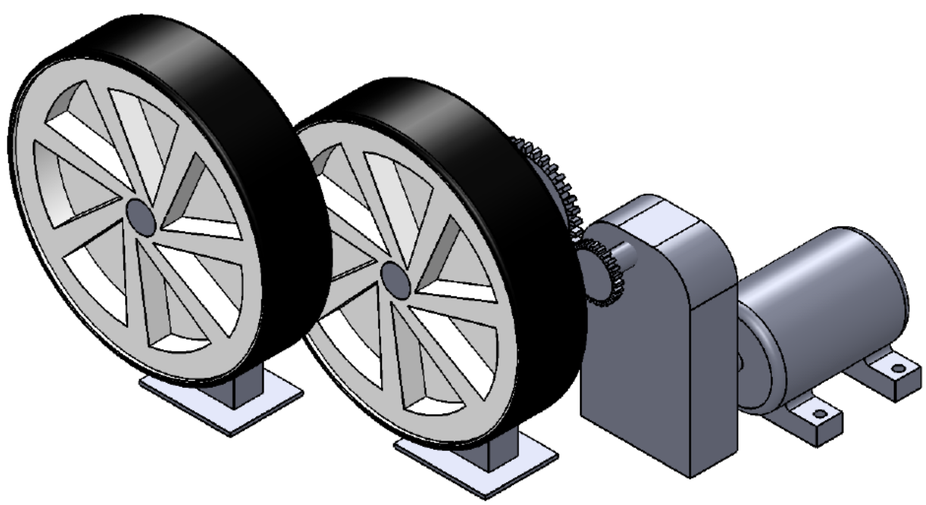

Figure 4.17: The Roller.

4.4.1 Part description

1. Wheel No.1: This wheel is rotated by a motor through gears and gearbox, and accordingly rotates the pipe mounted between it and wheel No.2, this rotation should occur without slippage thus, the contact surface between the wheel and the pipe is covered with rubber to increase friction.
2. Wheel No2: this wheel acts as a supporting wheel to hold the pipe on the roller mechanism, and it rotates freely.

3. Gears: ratio 1:1 to transfer the rotation from the gearbox to wheel No.1.
4. Bearings: to allow for smooth rotation of the wheels, with as much low friction as possible.
5. Gearbox: used to reduce the rotational speed of the motor from 1200-1400 to 30rpm.
6. Induction motor: the main actuator, explained in section.4.4.2.5.

4.4.2 Calculations and parts selection

4.4.2.1 Force calculations

Fig.4.18 shows the free-body diagram for the rollers with a pipe of the maximum weight available mounted on them.

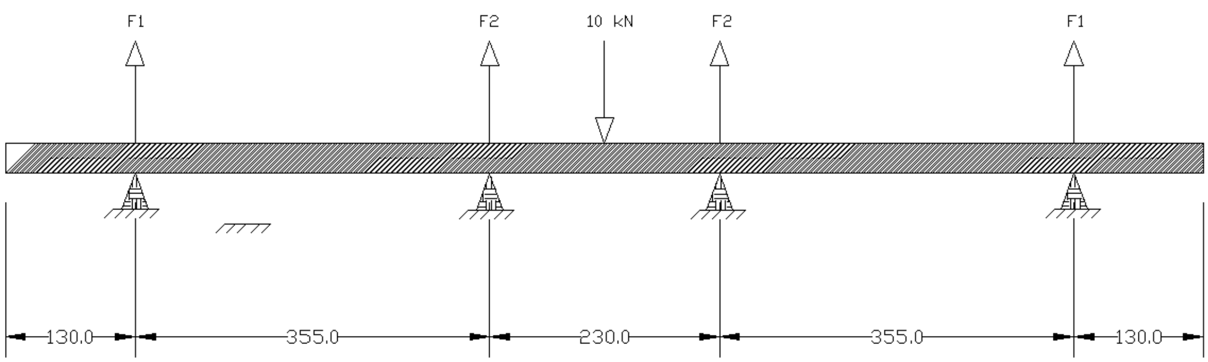

Figure 4.18: Free body diagram for the Rollers.

At static equilibrium:

$$\sum f_y = 0 \qquad \text{Eq. 3}$$

$$2 \times f_1 + 2 \times f_2 = 10kN \qquad \text{Eq. 4}$$

$$\sum M_0 = 0 \qquad \text{Eq. 5}$$

$$\sum M_0 = f_1 \times 3.55 - 10kN \times 4.7 + f_1 \times 5.85 + f_2 \times 9.4 \qquad \text{Eq. 6}$$

Solving Eq.4 & Eq.5 gives:

$$f_1 = 3514.6N$$

$$f_2 = 1485.3N$$

These are the forces that the maximum weight available pipes apply on the rollers.

4.4.2.2 Inertia calculations

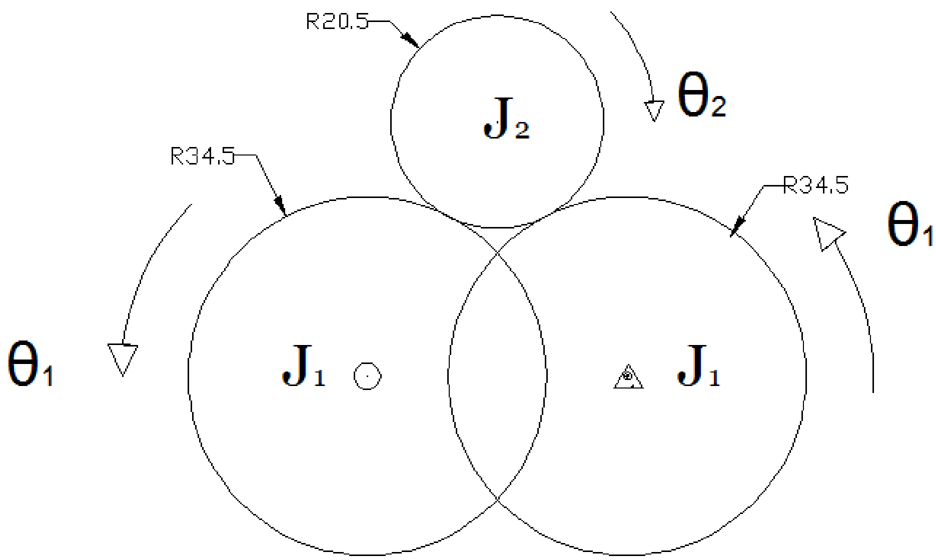

Figure 4.19: Equivalent inertia of the roller.

Using conservation of energy principle, and assuming no losses.

Kinetic energy of the system equals the sum kinetic energy of the sub systems.

$$0.5 \times j_{eq} \times \dot{\theta}_{eq}^{2} = 0.5 \times (2 \times j_1) \times \dot{\theta}_1^{2} + 0.5 \times j_2 \times \dot{\theta}_2^{2} \qquad \text{Eq. 7}$$

Where:

j_{eq}:the equivalent inertia of the system at the motor.

$j_1 = 3.36\ kg.m^2$, from Solidwork software.

j_2: the largest available pipe's inertia reflected to one roller.

$$\dot{\theta}_2^{2} = (r_1/r_2)^2 \times \dot{\theta}_1^{2} \qquad \text{Eq. 8}$$

$$j_2 = (m \times r)/2 \qquad \text{Eq. 9}$$

Where :

m: Mass of the pipe (1000kg).

r: Radios of the pipe (0.20 m).

$$j_2 = 20.6\ kg.m^2$$

Substituting Eq.7 & Eq.8 in Eq.6 we get:

$$j_{eq} = 2 \times j_1 + \frac{r_1}{r_2} j_2 = 66.2\ kg.m^2$$

4.4.2.3 Turning calculations

The rotational speed of the pipe were chosen to be 30 rpm, this will results in an appropriate cutting speed that suits the turning of polyethylene, besides turning the pipe at this speed will avoid significant dynamic behaviors such as vibration, which requires further complexities in the machine.

$$v = \omega_p \times r_1 \qquad \text{Eq. 10}$$

Where:

v: Cutting speed (m/s).

ω_p: Angular velocity of the pipe (rev/s).

r_1: Radious of pipe.

$$\omega_r = \omega_p \times (r_1/r_2) \qquad \text{Eq. 11}$$

Where:

ω_r: Angular velocity of the roller (30rpm= 3.14rad/s).

r_2: Radius of the roller (345mm).

r_1: Radius of the pipe.

From Eq.10 and Eq.11, the cutting speed becomes:

$$v = \omega_r \times r_2 \qquad \text{Eq. 12}$$

$$v = \frac{30}{60} \times 0.345 = 0.1725 \ m/s$$

4.4.2.4 Bearing selection

Mitcalc 1.40_ 2D excel based software, was used to find an appropriate bearing, which can support:

1. Rotating speed of 30rmp.
2. Radial load= 4000N, pipe's weight (section 4.4.2.1), plus the wheel weight (from Solidwork ≅ 500N).

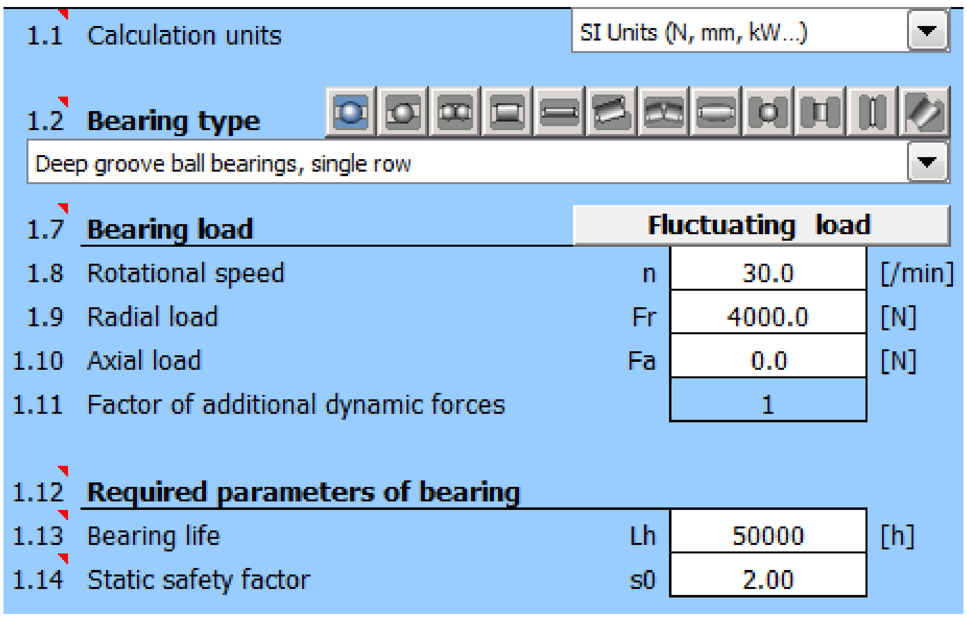

Figure 4.20: Mitcalc 1.40_ 2D input screen for roller bearing.

As for the safety factor, and the bearing life were chosen to be moderate common values, for these inputs the software found that bearing ***6304ETN9*** is the smallest bearing size found that can support these conditions, Fig.4.21 shows the bearing dimensions.

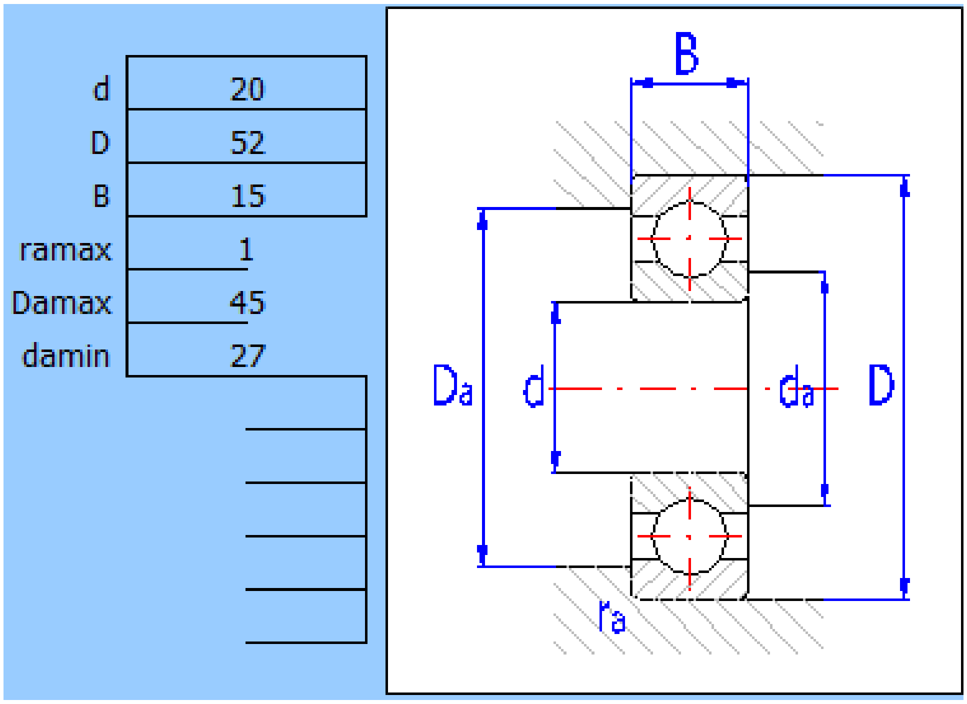

Figure 4.21: ***6304ETN9*** Roller bearing dimensions.

4.4.2.5 Motor selection

As it has been stated in the turning calculations, the pipe will be required to rotate with a speed of 30 rpm, to achieve this speed an induction motor of 1200 rpm and a gearbox of ratio 40:1 were used.

The torque required to rotate a pipe for one roller:

$$\tau = j_{eq} \times \alpha \qquad \text{Eq. 13}$$

Where:

τ: Torque required.

$j_{eq} = 66.2\ kg.m^2, see\ section$ 4.4.2.2.

$\alpha: The\ angualr\ acceleration.\ 0 - 30\ rmp, rise\ time = 1\ sec$

$$\alpha = \omega_f / t \qquad \text{Eq. 14}$$

Where:

ω_f: Final angular velocity (30 rpm)

t_r: Rising time (1 sec).

$$\alpha = \frac{30 \times 2\pi}{60}/1 = \pi\ rad/s^2$$

$$\tau = 66.2 \times \pi = 207.24\ N.m$$

The torque reflected through the gearbox:

$$\tau_{reflected} = \tau_{in}/r \qquad \text{Eq. 15}$$

Where:

r: The ratio of the gearbox

τ_{in}: Input torque to gearbox

$$\tau_{reflected} = 207.24/40 \cong 5N.m$$

The power of the motor to drive this torque at 1200 rpm:

$$\rho = \tau_{reflected} \times \omega \qquad \text{Eq. 16}$$

Where:

ρ: Power required from motor (Watt).

$\tau_{reflected}$: Torque required from motor (N.m).

ω: Angular velocity (rad/sec)

$$\rho = 5 \times \left(1200 \times \frac{2 \times \pi}{60}\right) = 0.86\ watt$$

Considering safety factor and the availability in markets, a motor with 2hp and 1200rpm was chosen.

4.4.2.6 Gearbox selection

A gearbox with 40:1 ratio and 2hp input is required.

4.5 The Punch and the Cutting Machine

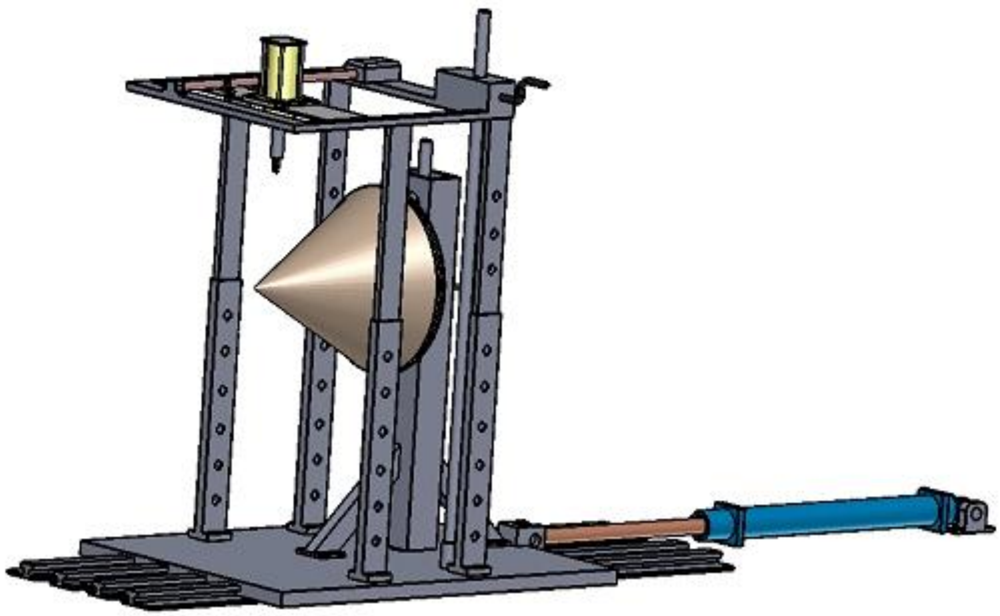

Figure 4.22: The Punch and the Cutting Machine.

4.5.1 Introduction

This part consists of two main mechanisms mounted on the same frame, the cutting machine and the punch; they were mounted on the same frame because they both move on the same direction along the pipe's elongation.

To avoid complexity in the chapter, each section will be divided into three sub section main frame, cutting machine, and punch.

4.5.2 Part description

4.5.2.1 Main frame

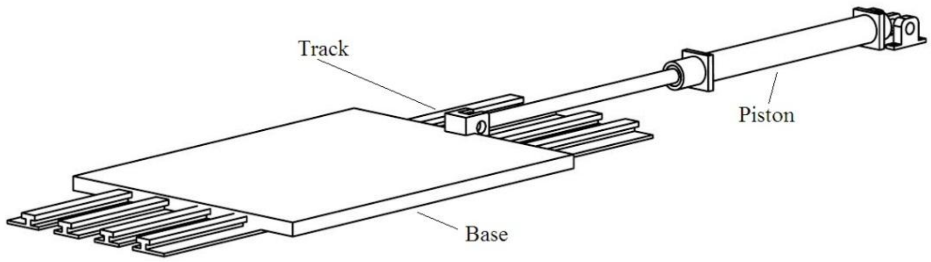

Figure 4.23: Parts of the Main frame.

1. Track: provides a path for the mechanism to move on, its length depends on the pipes' lengths the machine supports, since it should allow for a pipe with the maximum length to be mounted on the roller without hindering its way at the minimum position of the mechanism, on the other hand the mechanism should lock the pipe between the two punches' heads for the shortest pipe available at the minimum position, the distance between these two position added to the length of the base results the total track length.
2. Base: Carries the cutting machine and The Punch on the track.
3. Piston: Moves the base along the track.

4.5.2.2 Cutting machine

1. Supporting frame: Holds the cutting machine parts, at different height stages. As it can be seen in Fig.4.24, the beams which support the frame, have an array of holes made for pins, the holes are separated from each other with different distances to match the height required for the cutting machine since it turns different pipes' sizes, but it will be required to manually change this height each time different pipe's size is worked.
2. Supporting frame power screw: Provides a smooth way for changing the supporting frame height.
3. Sliding base: Carries the knife and the knife's piston (parts No.5+6), and slides along the sliding track on the top of the supporting frame see Fig.4.24, to precisely cover the distance of turning along the pipe.

4. Sliding base lead screw: Converts the rotational motion of the DC motor into translation motion to move the sliding base.
5. Dc motor: To drive the sliding base power screw

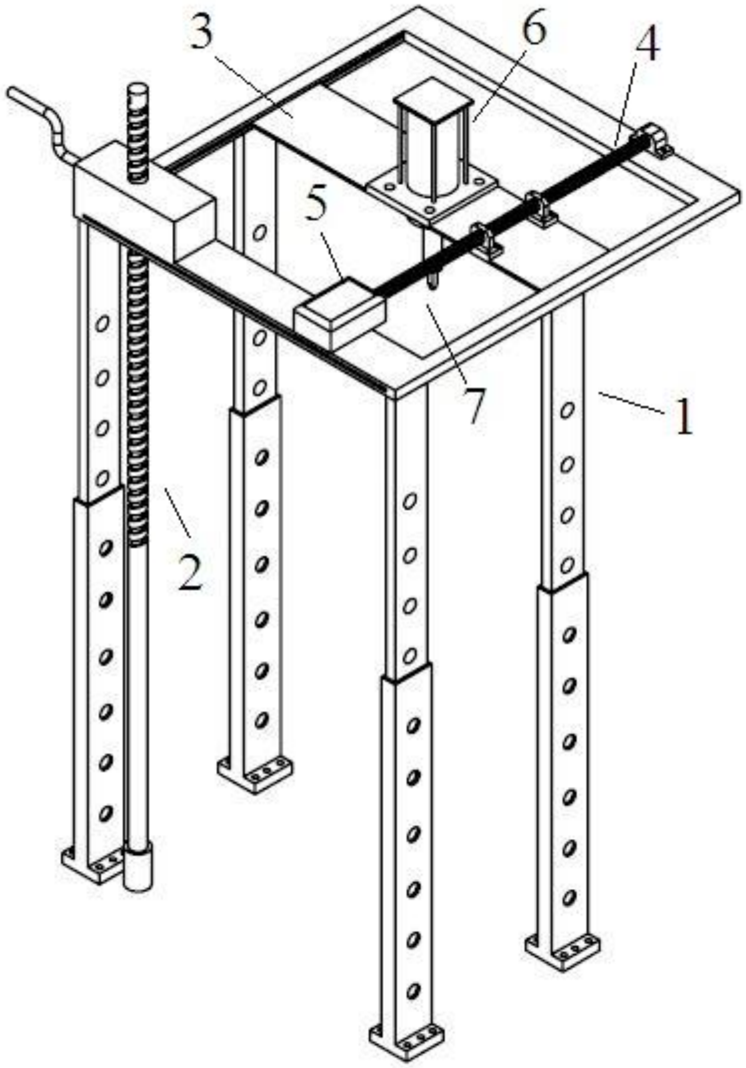

Figure 4.24: Parts of the Cutting machine, 1-supporting frame, 2-supporting frame power screw, 3-sliding base, 4-sliding base power screw, 5-DC motor, 6-knife piston, 7-knife.

6. Knife piston: Controls the height of the knife. After adjusting the height of the main supporting frame, this piston allows for a precise control of the knife position while turning the pipe, moreover using a piston for this purpose also overcomes the imperfection that pipes have, since most of the turned pipes will

not be perfectly rounded rather, there will be places where the knife should move up and down to reach for all the plastic layer and avoid scratching the metal depending on the direction of the deflection.

7. Knife: Check section 4.5.3.5.

4.5.2.3 Punch

1. Supporting frame: Hold the punch's head, at different elevations.
2. Supporting frame power screw: Provides the required vertical movement of the punch to match the center line of different pipe's sizes.
3. Punch's head: Conical shaped body, which locks the pipe from both ends, to prevent it from running away while being rotated.

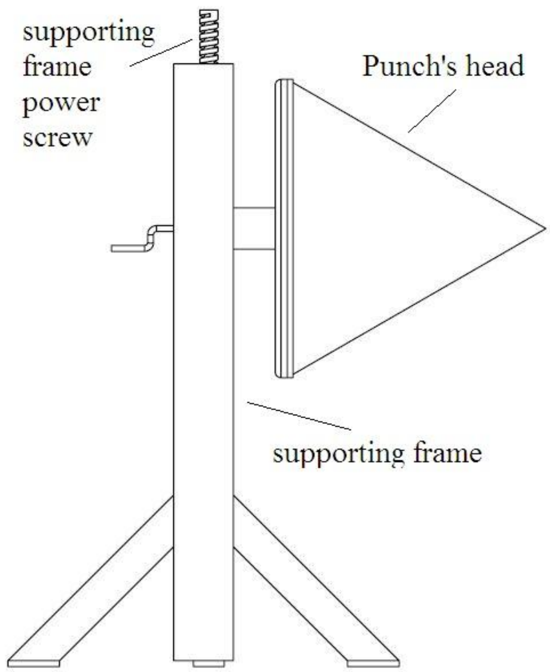

Figure 4.25: Parts of the Punch.

4.5.3 Calculations and part selection

4.5.3.1 The Punch pressure and force calculation

As described earlier the punches are used to hold the pipe on position while being rotated, this is done by applying an axial load on the pipe using the punches' heads, which rotate freely with the pipe, but prevent it from moving in other direct-ions.

The movement and the force for the punch heads are delivered through the main frame pistons, these pistons were chosen to be identical to the main piston used in the mover, for assembly simplification, also taking in consideration that the pressure capability of the piston used in the mover exceeds the pressure required by the one used for the punch.

To calculate this pressure, the main criteria were to avoid deforming the pipes' edges, where the contact between the head and the punches occur.

$$S_y = 350\ Mpa\ for\ steel$$

$$S_{sy} = S_y \times 0.577 \qquad \text{Eq. 17}$$

$$S_{sy} = 201.9\ Mpa$$

But as it can be seen the pressure that deforms the edges is so large, comparing to the purpose, which is only holding pipes in position while being rotated, so after finding the allowable pressure for the piston from this pressure, only a part of this pressure will be exerted and will be modified experimentally.

The pressure required from the piston to apply the allowable pressure on each size of pipes is calculated as follows:

$$P_p = F_P / A_{ps} \qquad \text{Eq. 18}$$

Where:

P_p: Pressure required on the piston.

F_P: Force required from the piston calculated using Eq16.

A_{ps}: The piston's rod area at the extension side, which equals 6.11*10^{-3} m^2

$$F_p = P_a \times A_{pi} \quad \text{Eq. 19}$$

Where:

P_a: Allowable pressure before deformation 201.9 Mpa

F_p: Allowable force that the pipe holds before deformation.

A_{pi}: Cross sectional area of the pipe

Table.4.2 summarizes the results of calculations. After finding the required piston pressure for the allowable pressure before deforming the edges, only part of it were considered and as it has been `mentioned it will be modified experimentally.

$\emptyset_{out}$ (inch)	$\emptyset_{out}$ (mm)	$\emptyset_{in}$ (mm)	Cross section area (m^2)	Required pressure on piston (Mpa)	Exp values (Mpa)
3	88.9	79.38	1.26*10^{-3}	41.6	1
4	114.3	104.78	1.71*10^{-3}	56.5	1.5
6	168.3	158.78	2.45*10^{-3}	80.96	1.8
8	219.1	209.58	3.2*10^{-3}	105.7	2
10	273.1	263.58	4.01*10^{-3}	132.5	2.4
12	323.9	314.38	4.77*10^{-3}	157.6	3
16	406.4	396.88	6*10^{-3}	198.3	4

Table 4.3: Punch piston alowable pressure

4.5.3.1 Choosing the punch bearing

The same software used in choosing the roller bearing was also used to choose the punch bearing, but with different inputs where:

1. Rotating speed= 30rmp.
2. Radial load= 200N, the weight of the punch head (from Solidwork software).

3. Axial load= 24400N, calculated in section 4.5.3.1.

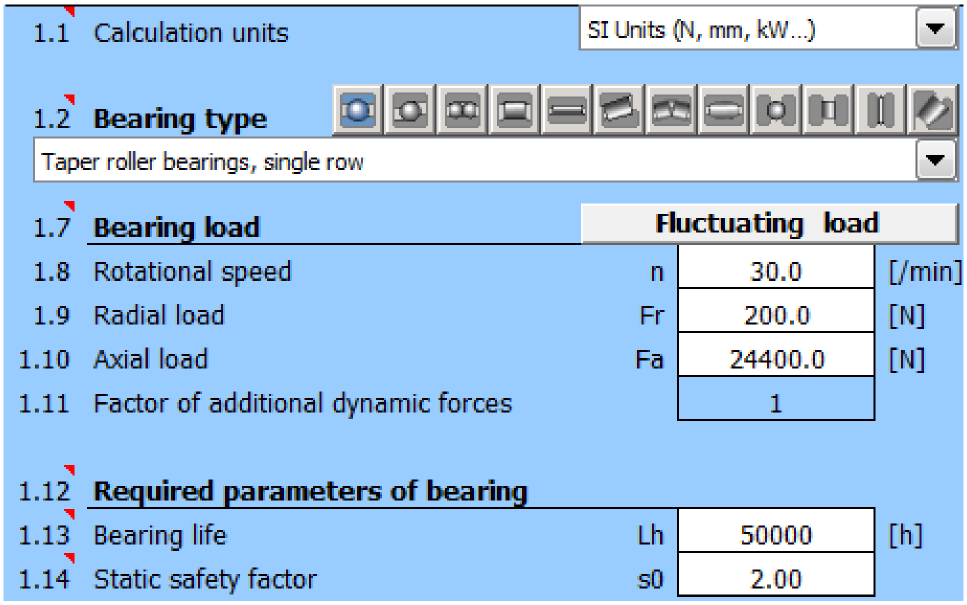

Figure 4.26: Mitcalc 1.40_ 2D Punch bearing input screen.

As for the safety factor, and the bearing life were chosen to be moderate common values, for these inputs the software found that bearing ***31308 J2/QCl7C*** is the smallest bearing size found that can support these conditions, Fig.4.27 shows the bearing dimensions

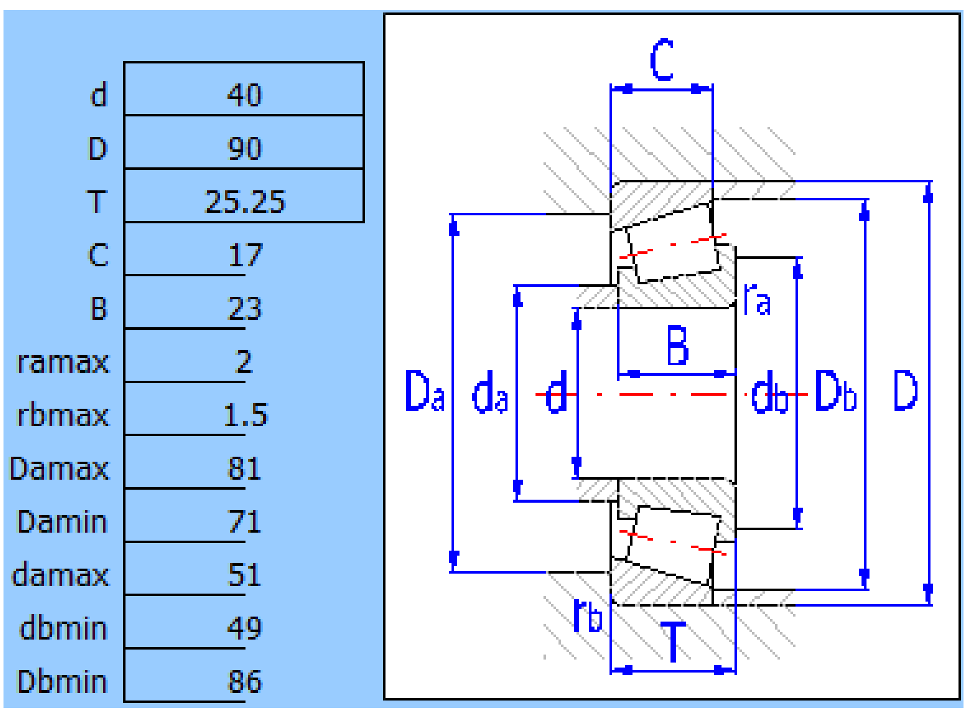

Figure 4.27: Bearing 31308 J2/QCl7C Punch bearing dimensions.

4.5.3.5 Knife selection and force analysis

Fig.4.28 shows the knife's profile chosen for the project, the areas of the faces are listed in table.4.3, these areas were used in the calculating the forces of cutting of each face.

Face #	Area (m$^{2)}$
1	9.78×10^{-6}
2	7.39×10^{-6}
3	4.086×10^{-6}
4	1.897×10^{-5}

Table 4.4: The area of each face of the knife

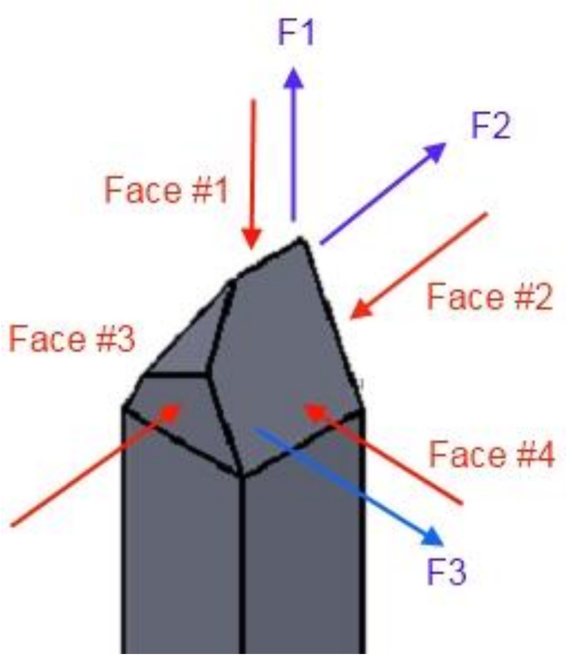

Figure 4.28: Knife's profile and faces.

4.5.3.5.1 Forces calculations

Three forces results on the knife through the cutting operation, because the HDPE-layer will resist being deflected and cut, these forces can be calculated approximately by considering the resistance of the layer due to its shear strength and area of effect, this can be calculated as follows:

$$f_n = \tau_{xy} \times A \qquad \text{Eq. 20}$$

Where:

f_n: Resultant force (N).

T_{xy}: Shear strength of HDPE (23 Mpa)

A: Area of sheared surface (from table.4-3).

$$f_1 = \left(A_{f1} + A_{f2} + A_{f3} + 2 \times A_{f1}\right) \times \tau_{xy} \qquad \text{Eq. 21}$$

$$f_1 = 5.92 \times 10^{-5} \times 23 \times 10^{6} \cong 1362N$$

$$f_2 = A_{f2} \times \tau_{xy} \qquad \text{Eq. 22}$$

$$f_2 = 7.39 \times 10^{-6} \times 23 \times 10^{6} \cong 170N$$

$$f_3 = A_{f4} \times \tau_{xy} \qquad \text{Eq. 23}$$

$$f_3 = 1.897 \times 10^{-5} \times 23 \times 10^{6} \cong 436.31$$

It should be noted, that these forces are the maximum forces that might results or applied on the knife, and the real values will be adjusted experimentally.

4.5.3.5.2 Stress analysis

Fig.4.29 and Fig.4.30 show the knife-deflection and the knife-von misses' stress respectively, due to $f_2$and f_3, using Solidwork software, it can be seen that the stress doesn't exceed the yield strength of the carbon steel.

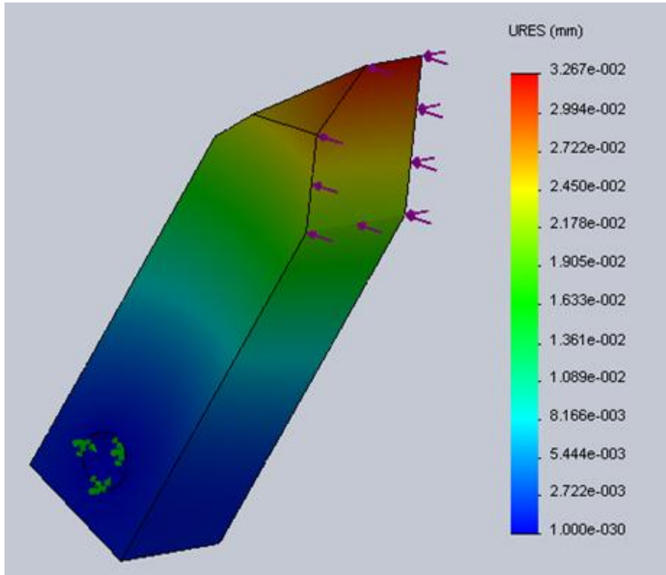

Figure 4.29: The knife deflection.

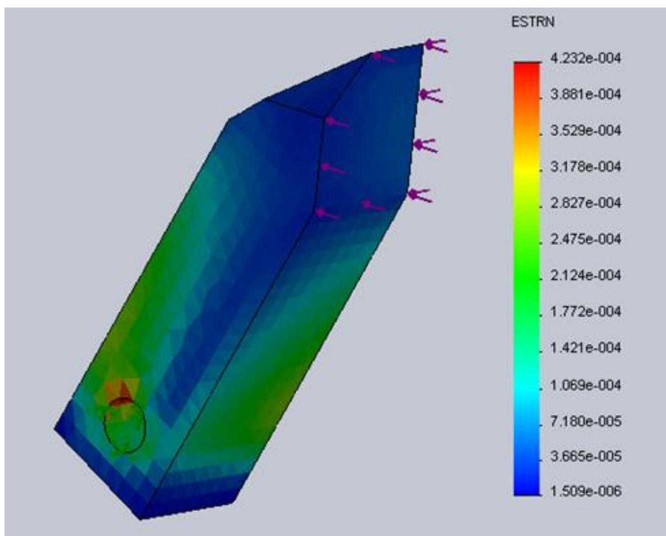

Figure 4.30: The von misses' stress of the knife.

4.4.3.3 Cutting tool pistons selection

The cutting tool (knife), were mounted on a piston instead of a rigid link, to overcome the imperfect circular profile issue of the pipe, moreover the piston will be operating at a constant pressure, to prevent the knife from cutting into steel or being cracked, since steel has much higher shear strength than HDPE and requires higher pressure for cutting, in other words the steel surface in case of contact with the knife will exert pressure large enough to prevent the knife from cutting into it or being broken.

Note that the pressure required in this operation is relatively small, thus a pneumatic piston will be chosen.

$A = F/P$ Eq. 24

Where:

P: Piston input pressure, chosen to be 5 bars.

A: Cross sectional area of the piston rod in the extension side.

F: Force applied by the piston, check section 4.5.3.5.

$$A = 1362/(5 \times 10^5) = 1.4 \times 10^{-3} m^2$$

4.5.3.4 Choosing power screws

4.5.3.4.1 Cutting machine lead screw

This lead screw is responsible of moving the sliding base of the cutting machine, so it is required to overcome the force required to move the knife along the pipe (F_2 from section 4.5.3.5) , and the friction losses cause by the lead screw itself.

The lead screw is required to move the sliding base 15cm/30second to be synchronized with the rotation of the pipe, so if we chose a single threaded square power screw with a diameter of 16mm, and pitch diameter of 2mm, the speed and the torque of the motor required to drive the lead screw is calculate as follows:

$v = n/t$ Eq. 25

Where

v: The lead scree rotational speed.

n: Number of the lead screw revolutions.

t: Time the lead screw has to move the whole distance (0.5 min).

$n = l/d_p$ Eq. 26

Where:

n: Number of revolution

l: Traveled distance (1m).

d_p: Pitch diameter (2mm).

$$n = 150/2 = 75\ rev$$

$$v = 75/0.5 = 150\ rpm$$

$$F = (f_1 + w_m) \times \mu * + f_2 \qquad \text{Eq. 27}$$

Where:

F: The force required by the lead screw motor.

f_1: Section 4.5.3.5.

f_2: Section 4.5.3.5.

μ: The coefficient of friction between the lead screw and nuts (μ= 0.15).

w_m: Weight of the sliding base and other components mounted on it (6 kg from Solidwork software).

$$F = (1362 - 6 \times 9.81) \times 0.15 + 170 \cong 365N$$

$$T = \frac{F \times d_m}{2} \times \left[\frac{l + \pi \times \mu \times d_m}{\pi \times d_m - \mu \times l}\right] \text{ [4]} \qquad \text{Eq. 28}$$

Where:

T: The torque required by the lead screw motor.

F: Is the total force to be moved by the scre.

d_m: Mean diameter of the screw = d- p/2.

l: Length of power screw.

μ: The coefficient of friction between the lead screw and nuts (μ= 0.15).

$$d_m = d - {}^{p}/_{2}$$ Eq. 29

Where:

d: Diameter of screw.

p: Pitch diameter.

$$T = \frac{365\times15}{2}\times\left[\frac{1+\pi\times0.15\times15}{\pi\times15-0.15\times1}\right] \cong 27\ N.m$$

4.5.3.4.2 Cutting machine jack screw

Operated manually, and is responsible of setting the height of the cutting mechanism, since the machine handle different pipe's sizes.

The force this power screw drivers is basically the weight of the mechanism held above it, which is approximately 670N from Solidworks software.

Trapezoidal screw MULI 1 (see appendix A) was chosen, it can handle up to 5KN.

4.5.3.4.3 Punch jack screw

Operated manually, and is responsible of setting the height of the punch, because of the different sizes of pipes turned.

The force required from this jack screw to lift is the weight of the punch's head and its mechanism, which is approximately 450N from Solidwork software.

Trapezoidal screw MULI 1 (see appendix A), which was chosen earlier for the cutting mechanism is also chosen for the punch mechanism as well, it can handle up to 5kN.

Chapter five

Hydraulic and Pneumatic system

5.1 Hydraulic system

5.1.3.6 Calculating total oil volume in the system

5.1.3.6.1 Oil volume in tubes.

5.1.3.6.2 Oil volume in pistons.

5.1.3.7 Pump selection.

5.1.3.8 Filer selection.

5.2 Pneumatic system.

Hydraulic and Pneumatic system

5.1 Hydraulic system

5.1.1 Introductions

In this chapter the hydraulic system will be covered in two sections as follows:

Section 5.1.2 (The hydraulic circuit): Shows the whole hydraulic schematic diagram, and then explains the blocks one by one.

Section 5.1.3 (Hydraulic calculations and selections): Shows pressure, flow calculations, and the procedure for choosing each component.

5.1.2 Hydraulic circuits

Fig.5.1. shows the total hydraulic system, which is explained in the following subsection, part by part.

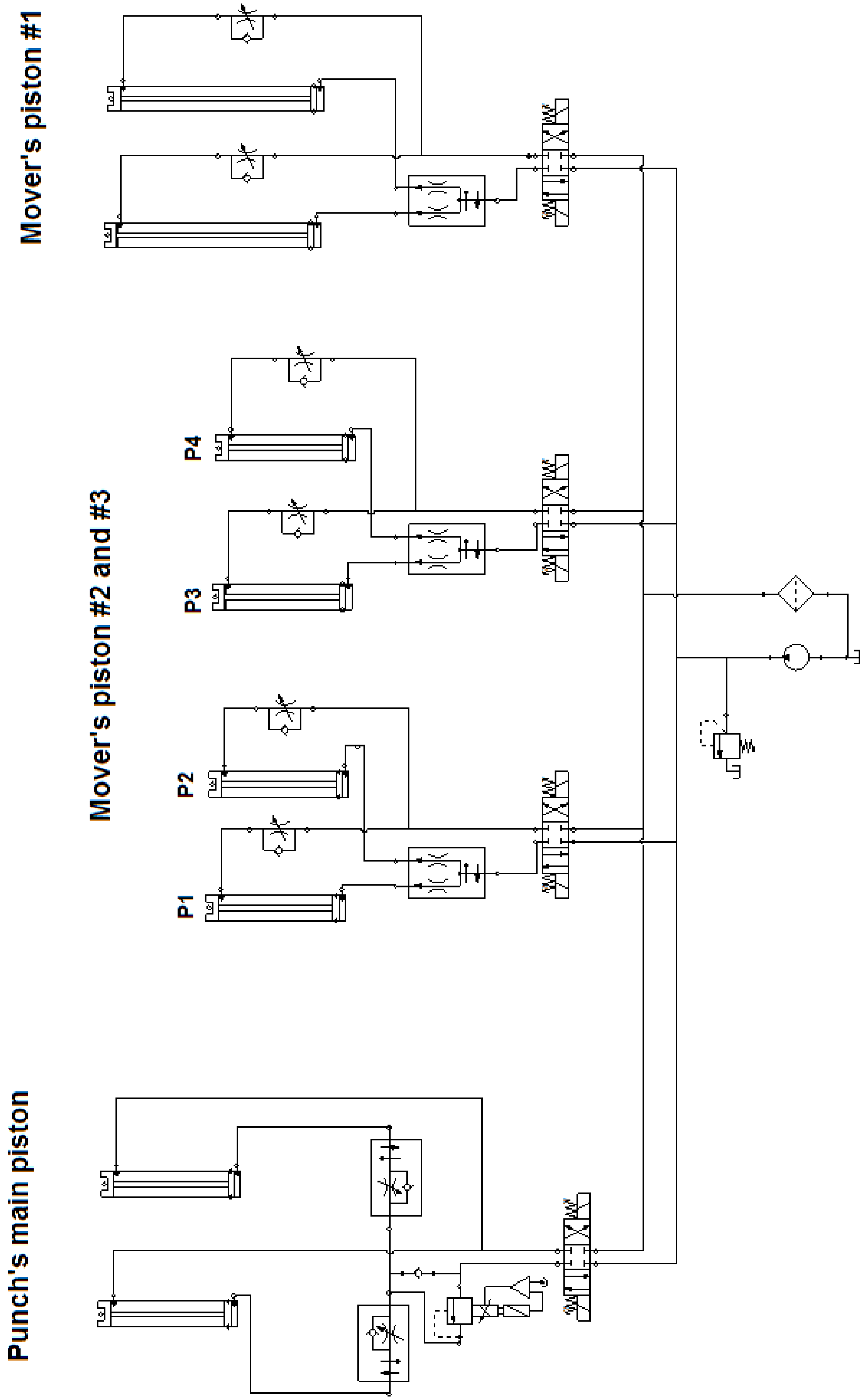

Figure 5.1: The overall hydraulic system.

5.1.2.1 Mover's piston #1

Fig.5-2. shows the hydraulic circuit for the two mover's main piston, recall that these pistons moves the whole mover body to move the pipe from one location to another through the stages of process, to achieve this movement each component of the circuit does a specific role as described:

1. P1 and P2: They are two identical double acting pistons, which convert the pressure into a translation motion.
2. Valve #1 and valve #2: Two identical variable non return throttle valves, they are responsible of limiting the flow in the retraction phase of the pistons only, because in the retraction phase the pistons are not loaded and thus will retract faster if the flow weren't limited.

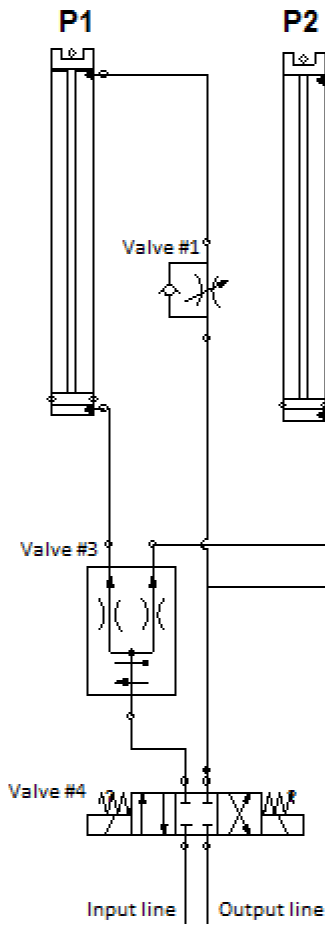

Figure 5.2: Mover Piston #1 hydraulic circuit.

3. Valve #3: Pressure and temperature compensated flow divider, which is responsible of limiting the flow rate to the pistons, and dividing the flow equally between the two pistons to maintain synchronized movement.
4. Valve #4: 4/3 way double-electric-control directional valve, it is responsible of choosing the mode of operation (extension, retraction, lock).

5.2.1.2 Mover's piston #2 and #3

Fig.5-3 shows the hydraulic circuit for the pistons used in the movers' jacks, each of these pistons is responsible of movement of one jack, and the four jacks movement should be synchronized with each other, the circuit Fig.5-3 does that as described:

1. P1, P2, P3 and P4: They are four identical double acting pistons, which convert the pressure into translation motion.

2. Valve #1, #2, #3 and #4: They are four identical variable non return throttle valves, they are responsible of limiting the flow in the retraction phase only, since in the retraction mode the pressure will be acting in the same direction of the load, so if there weren't flow control the retraction will be so much faster than the extension and may cause impact.

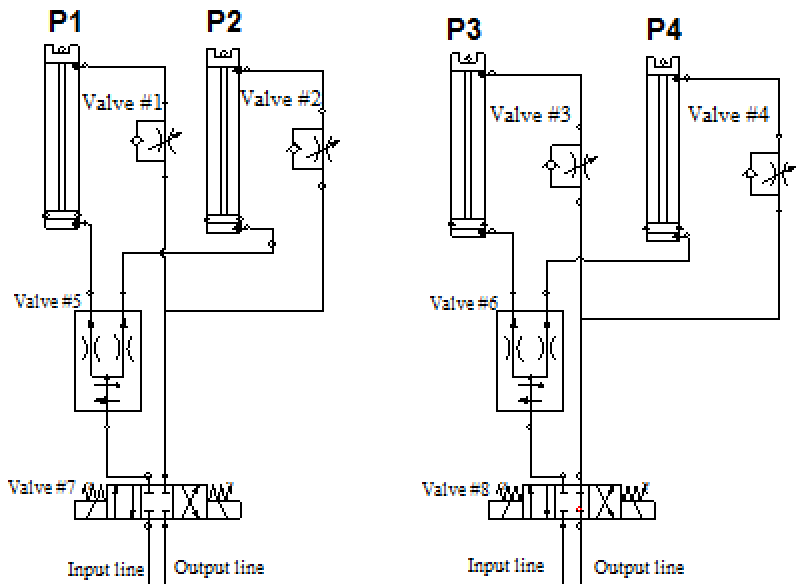

Figure 5.3: Mover's piston #2 and #3 hydraulic circuit.

3. Valve #5 and #6: They are two identical pressure and temperature compensated flow dividers, responsible of limiting the flow rate of the pistons, and dividing it equally between the two pistons to maintain synchronized motion.
4. Valve #7 and #8: They are Two identical 4/3 way double electrical control N.C directional valves, responsible of choosing the mode of operation (extension, retraction, lock).

5.2.1.3 Punch main piston

Fig.5-4 shows the hydraulic circuit for the Punches' pistons, these pistons should apply constant pressure on the punches heads to hold the pipe in position; this is done using the hydraulic components in Fig.5-4 as described next:

1. Pistons P1 and P2: They are two identical double acting pistons, which convert the pressure into translational motion.
2. Valve #1 and #2: They are two identical pressure and temperature flow control valves, they are required to limit the flow rate of the pistons, to limit the speed.

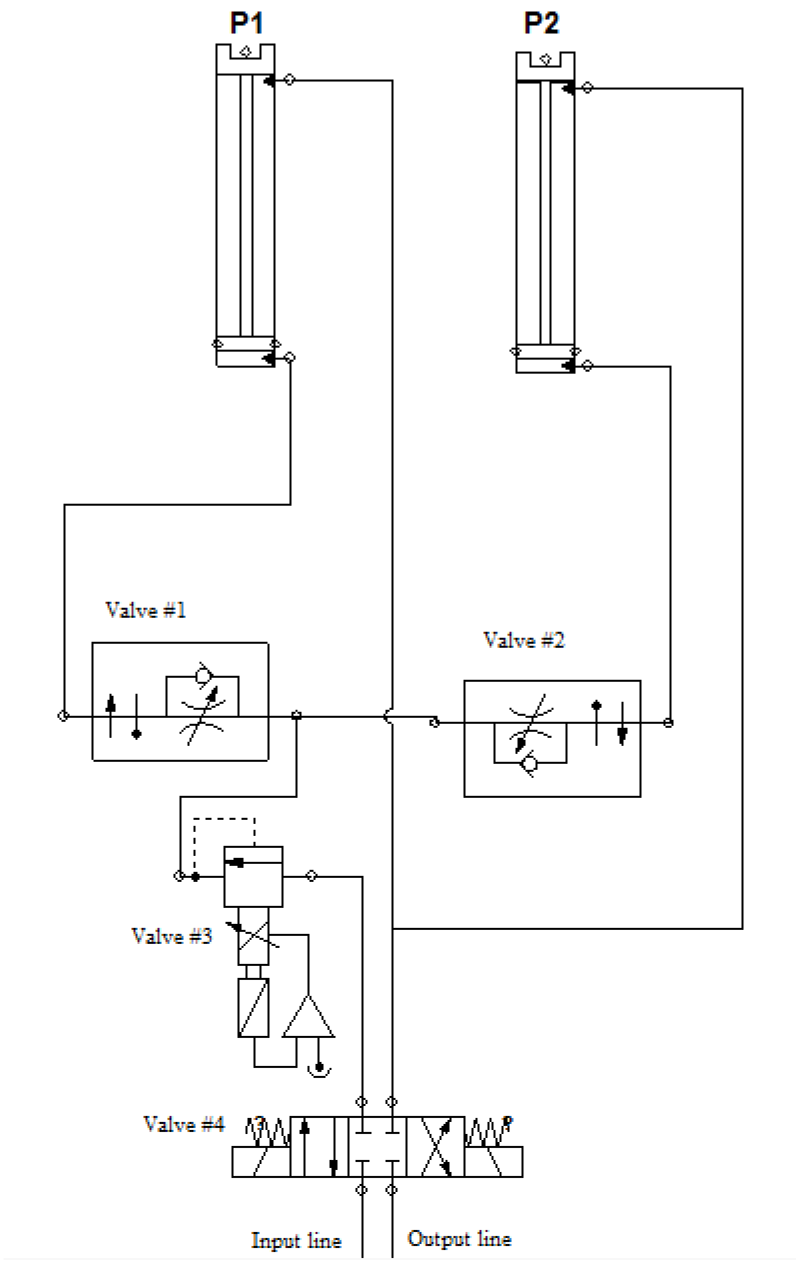

Figure 5.4: Punch main piston hydraulic circuit.

3. Valve #3: Proportional pressure regulator valve, responsible of controlling the level of pressure applied at the pistons, since there is a particular pressure required for each pipe-size as table.4-2 shows.
4. Valve #4: 4/3 way double-electrical-control N.C directional-valve, responsible of choosing the mode of operation (extension, retraction, lock).

5.1.3 hydraulic calculations and selections

The flow and pressure required for each piston should be calculated first, to find the required overall pressure and flow of the system.

5.1.3.1 Mover's piston #1

5.1.3.1.1 Pressure calculation

$P = F/A$ Eq. 30

Where:

P: Pressure applied on the piston.

F: Force required from the piston, calculated in section.4.3.2.2.

A: Piston cross sectional area for the extension side, found from the data sheet of the piston.

$$P = 10.9 \times \frac{10^3}{(6.11 \times 10^{-3})} = 1.78Mpa$$

5.1.3.1.2 Flow calculation

$Q = V \times A$ Eq. 31

Where:

Q: Flow rate

V: The speed of the piston, calculated in section 4.3.2.2.

A: Cross sectional area of the piston, for the extention phase.

$$Q = 0.05 \times 6.11 \times 10^{-3} = 0.31 \times 10^{-3}\ m^3/s$$

For two pistons, $Q = 0.31 \times 10^{-3} \times 2 = 0.62 \times 10^{-3}\ m^3/s$

5.1.3.2 mover’s piston #2 or #3

5.1.3.2.1 Pressure calculation

Using Eq.1:

$$P` = 5.1 \times \frac{10^3}{(3.11 \times 10^{-3})} = 1.64Mpa$$

5.1.3.2.2 Flow calculation

Using Eq.2

$$Q = 0.05 \times 3.155 \times 10^{-3} = 0.158 \times 10^{-3}\ m^3/s$$

For four pistons, $Q = 0.158 \times 10^{-3} \times 4 = 0.632 \times 10^{-3}\ m^3/s$

5.1.3.3 Punch’s main frame piston

5.1.3.3.1 Pressure calculation

the required pressure from the punch’s main frame piston was calculated earlier in section.4.5.3.1, and the highest requried pressure was for the 16 inch pipe and equals 4 Mpa.

5.1.3.3.2 Flow calculation

Using Eq.2

$$Q = 0.05 \times 6.155 \times 10^{-3} = 0.158 \times 10^{-3}\ m^3/s$$

For two pistons, $Q = 0.31 \times 10^{-3} \times 2 = 0.62 \times 10^{-3}\ m^3/s$

5.1.3.4 Total pressure and flow caculation

After finding all the individual flow rates and pressures, the total flow rate and total pressure required from the pump to operate the system can be calculated.

Using the Hydraulic-electrical analogy, the resulted equivalent hydraulic system is shown in Fig.5-5, it was done by replacing pistons with resistance, flow rate by current and pressure by voltage drop.

The flow rate required from the pump, is the highest flow rate required in network, in this case, it is the flow rate of the mover’s piston #2 and #3 (0.63 $litter/sec$).

To account for the leakage and unaccounted flows, a safety factor of 1.5 is added to the required flow, so the required flow of the system becomes:

$$Q = 0.63 \times 1.5 \cong 1\ litter/sec$$

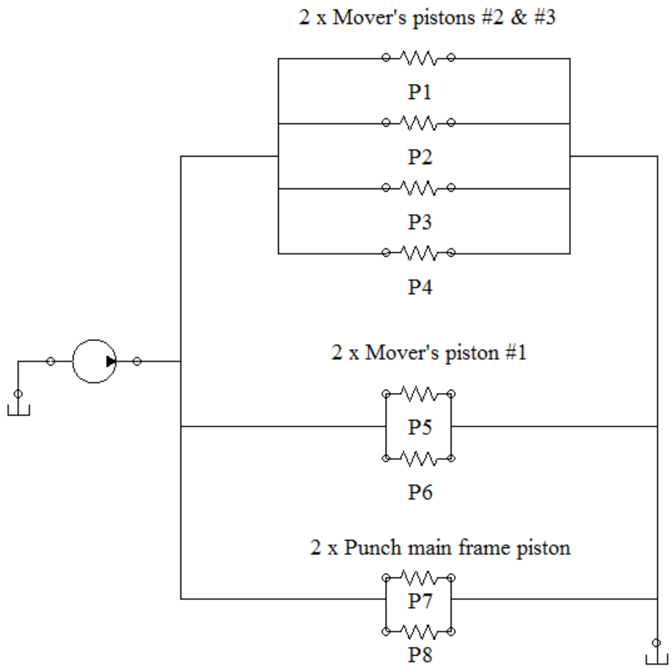

Figure 5.5: Hydraulic-electrical analogy circuit.

In Fig.5-5:

P_1=P_2=P_3=P_4=1.64 Mpa

P_5=P_6=1.78 Mpa

P_7=P_8=4 Mpa

The required pressure equals the maximum pressure required at one parallel line:

$$P_{required} = P_7 = P_8 = 4\ Mpa$$

With a safety factor of 1.5 the total pressure becomes:

$$P_{required} \times 1.5\ (safety\ factor) \cong 6Mpa$$

5.1.3.5 Hose calculations and selection

$$A = Q/V \qquad \text{Eq. 32}$$

Where:

A: The cross-sectional area of the hose.

Q: The flow rate.

V: The mean velocity of the fluid in the system, were chosen to be 5m/s.

$$A = \frac{\pi}{4} \times (ID)^2 \qquad \text{Eq. 33}$$

where:

ID: hose diameter.

From Eq.3 and Eq.4:

$$ID = \sqrt{\frac{4 \times Q}{\pi \times V}} \qquad \text{Eq. 34}$$

$$ID = \sqrt{\frac{4 \times 1 \times 10^{-3}}{\pi \times 5}} \cong 16mm$$

Tube (EFG6K-10) was found to be suitable for the hydraulic system.

5.1.3.6 Calculating total oil volume in the system

5.1.3.6.1 Oil volume in tubes

The total length of tubes in the system is approximately 30m.

$$V = A \times L \qquad \text{Eq. 35}$$

Where:

V: The oil volume in tubes.

A: The cross-sectional area of tube.

L: Total length of tubes.

$$V = \pi \times (8 \times 10^{-3})^2 \times 30 \cong 6 \times 10^{-3} m^3 = 6\ litters$$

5.1.3.6.2 Oil volume in pistons

5.1.3.6.2.1 Mover's piston #1 and punch's main frame piston

$$V = A \times L \qquad \text{Eq. 36}$$

Where:

V: The volume of piston.

A: The cross-sectional area of piston.

L: Length of piston.

$$V = 6.11 \times 10^{-3} \times 1.21 \cong 7.4 \times 10^{-3} = 7.4\ litters$$

5.1.3.6.2.2 Mover's piston #2 or #3

Using Eq.7

$$\mathrm{V} = 3.11 \times 10^{-3} \times 0.406 \cong 1.27 \times 10^{-3} = 1.27\ \text{litters}$$

After finding the amount of oil in each part of the system, the total amount of oil is:

$$\mathrm{V_t} = \mathrm{V_{tubes}} + 4 \times \mathrm{V_{p\#1}} + 4 \times \mathrm{V_{P\#2,\#3}} \qquad \text{Eq. 37}$$

$$\mathrm{V_t} = 6 + 4 \times 7.4 + 4 \times 1.27 \cong 41$$

Adding a safety factor of 1.5, to account for the oil in valves, and, or other un-accounted parts, the amount of oil in the system becomes:

$$\mathrm{V} = 41 \times 1.5 \cong 60\ \text{litters}$$

5.1.3.7 Pump selection

From section.5.1.3.4, it was found that the pump required should have a head pressure of 6 Mpa, and a flow rate of 1 litter/sec, variable volume vane pump STANDAR SV-20, from appendix A was found to fulfill the requirements, it operates at 2000 psi, and at 1800rmp it can deliver up to 68 litter/min.

The pump, filter and tank, will be placed in a position, to make the hose length as close as possible to each other, to reduce the difference between the pressure drops and make the flow as symmetry as possible for synchronizing purpose.

5.1.3.8 Filer selection

Tank mounted return line filter,10TEN0063-H20XLA00-P2,2-M. can filter up to 80 litter/min, data sheet is in appendix A.

5.2 Pneumatic system

As it has been mentioned earlier, in section.4.5.2.2, the position of the cutting tool is controlled using a pneumatic piston operating at constant pressure, to overcome the imperfection of the pipe circulation, Fig.5-6 shows the schematic diagram of the pneumatic system required for this operation, followed by a description for the roll of each part in the circuit and how they were chosen.-

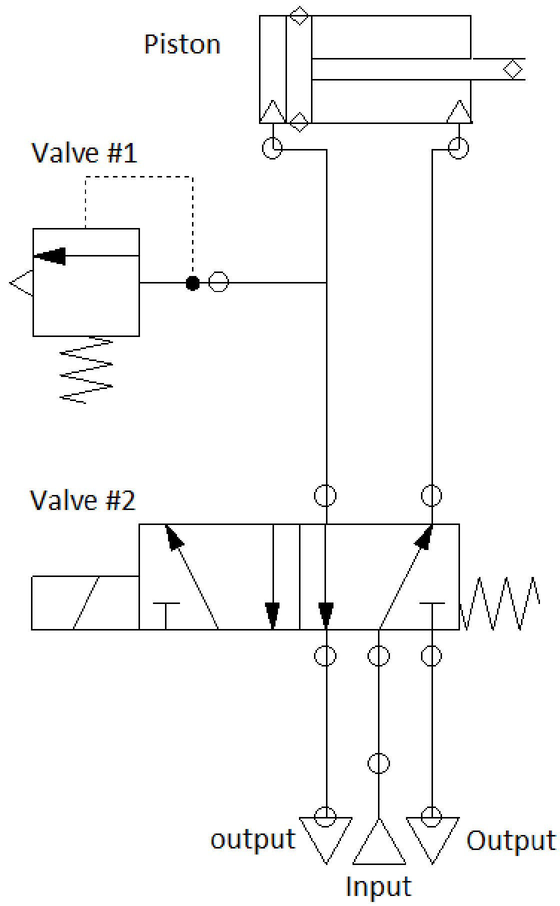

Figure 5.6: Pneumatic system circuit.

1. Piston: Double acting cylinder chosen in section.4.5.3.3.
2. Valve #1: Pressure relief valve, responsible of limiting the pressure on the piston, this way a constant value of pressure is applied on the piston, it can be tuned manually.
3. Valve #2: 5/2 way, N.C directional valve, if its input value is low it retracts the piston, and when it is set to high, it will allow the pressurized air to extend the piston.

A pneumatic system already exist in the factory, so instead of adding a new compressor, and filter, the cutting machine only needs a pressurized line with not less than 5 bars, connected to the input of each cutting machine, besides the relief valve is set at 5 bar, this way it can be assured that the piston is always operating at constant pressure.

It should be also noted, that the value of the relief valve can be adjusted latter in case the normal force of the knife piston was too high, since the calculation of the normal force needed for cutting were obtained in an over estimating manner.

Chapter six

Control system

6.1 Introduction

6.2 Flow chart

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6.2.2 Automatic mode.

6.2.3 Manual mode.

6.2.4 Fine adjustment.

6.3 Calculations and information required for designing the control system

6.3.1 Distance required to reach the cutting starting point for each pipe size

6.3.2 Relation between voltage and position of the linear potentiometer.

6.3.3 Relation between voltage and pressure of the proportional valve.

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6.3.4.3 PID block diagram in PLC

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6.3.4.3.4 Block Diagram.

6.3 HMI (Human Machine Interface)

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6.4.3 Automatic mode page.

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6.4 Wiring diagrams

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6.4.4 LDR (light dependent resistance) circuit.

6.4.5 Hydraulic valves wiring diagram.

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6.4.7 DC motor driving circuit and wiring diagram.

6.4.8 AC motor driving circuit and wiring diagram.

Control system

6.1 Introduction

As it has been mentioned in chapter two, one of the problems that the current machine has, is the lack of control, this was solved in the new machine, where a PLC (programmable logic controller) based control system was designed, this made adding automation capability and safety precautions possible, which is explained in details through this chapter.

The control unit was chosen to be Siemens S7-313C PLC (Datasheet in appendix B) because of to its reliability, availability, simplicity, and its ability to operate in industrial environments. As for the HMI (human machine interface) KTP1000 Basic DB touch screen (datasheet in appendix B) was chosen to provide simple way of operation and control of the machine.

The second section of this chapter explains the operation of the machine using flow chart, followed by detailed words description, the third section covers all the calculation required in building the control system, and the last section shows the HMI design and describes it.

6.2 Flow chart

The flow chart was divided into four parts to fit it in A4 papers, and still be readable, so while tracking the flow chart, it should be noted that the terminal which are called TS and TE means Tree Start and Tree Ends respectively, and each tree is printed on one page.

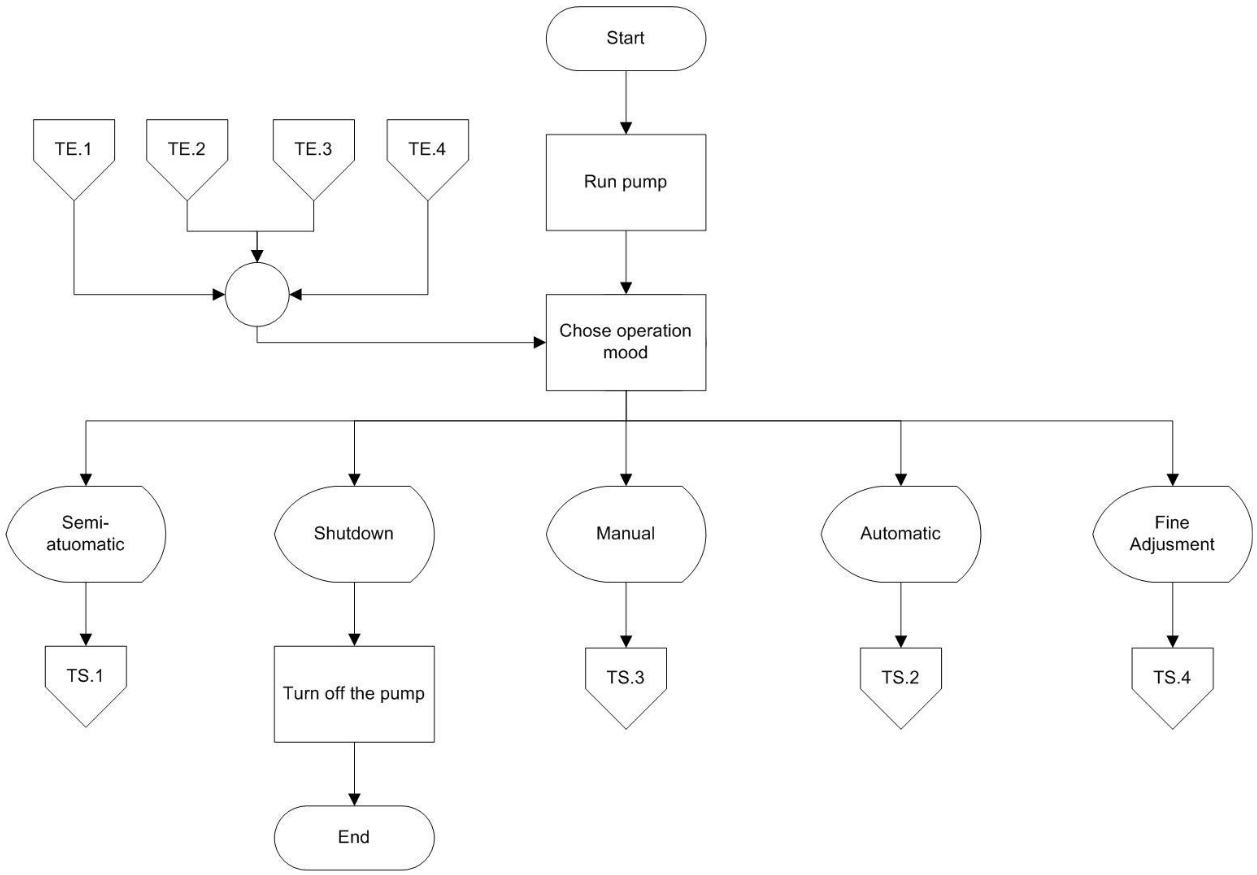

Figure 6.1:First part of the flowchart.

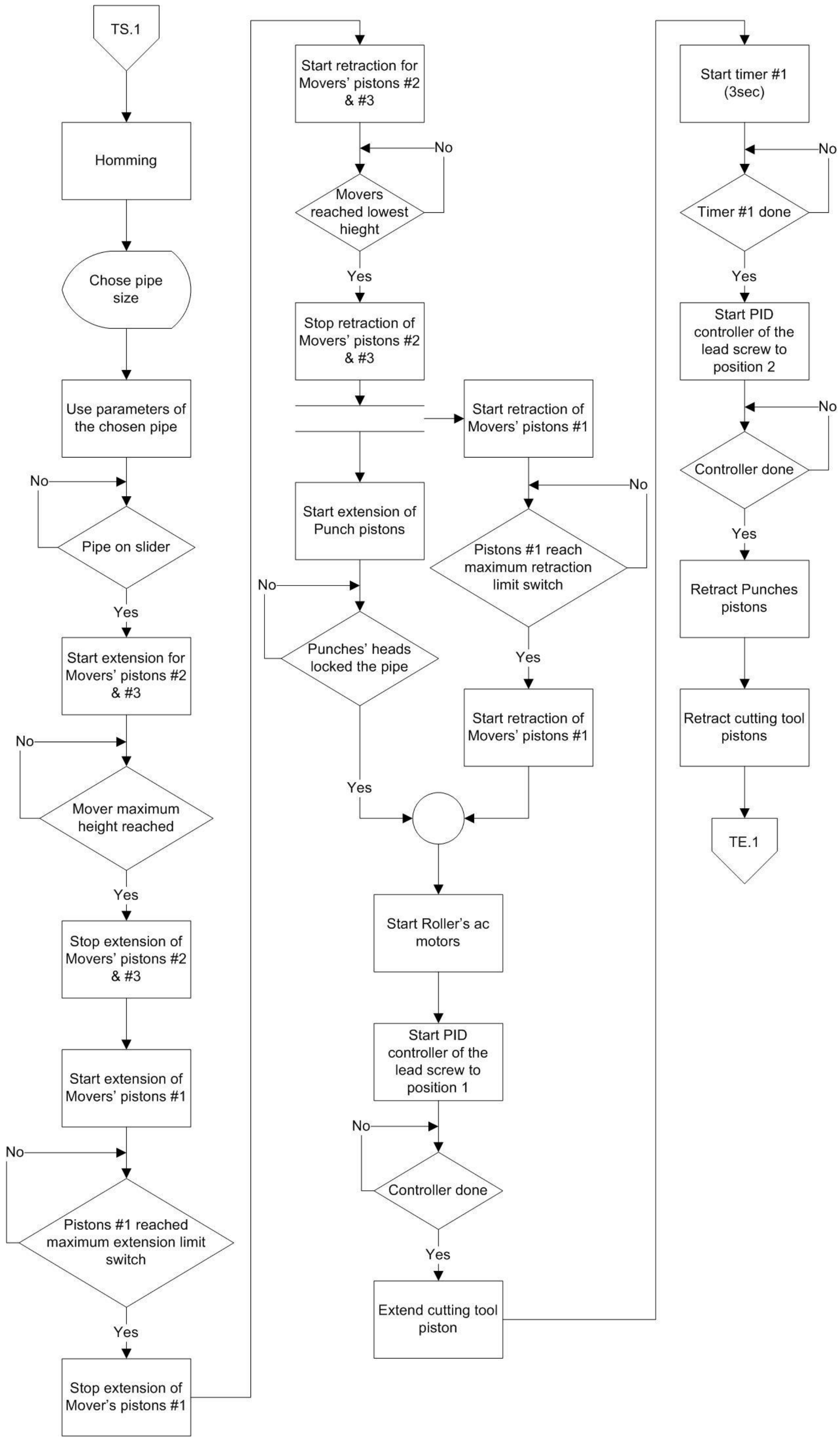

Figure 6.2: Second part of the flow chart, Semi-automatic mode.

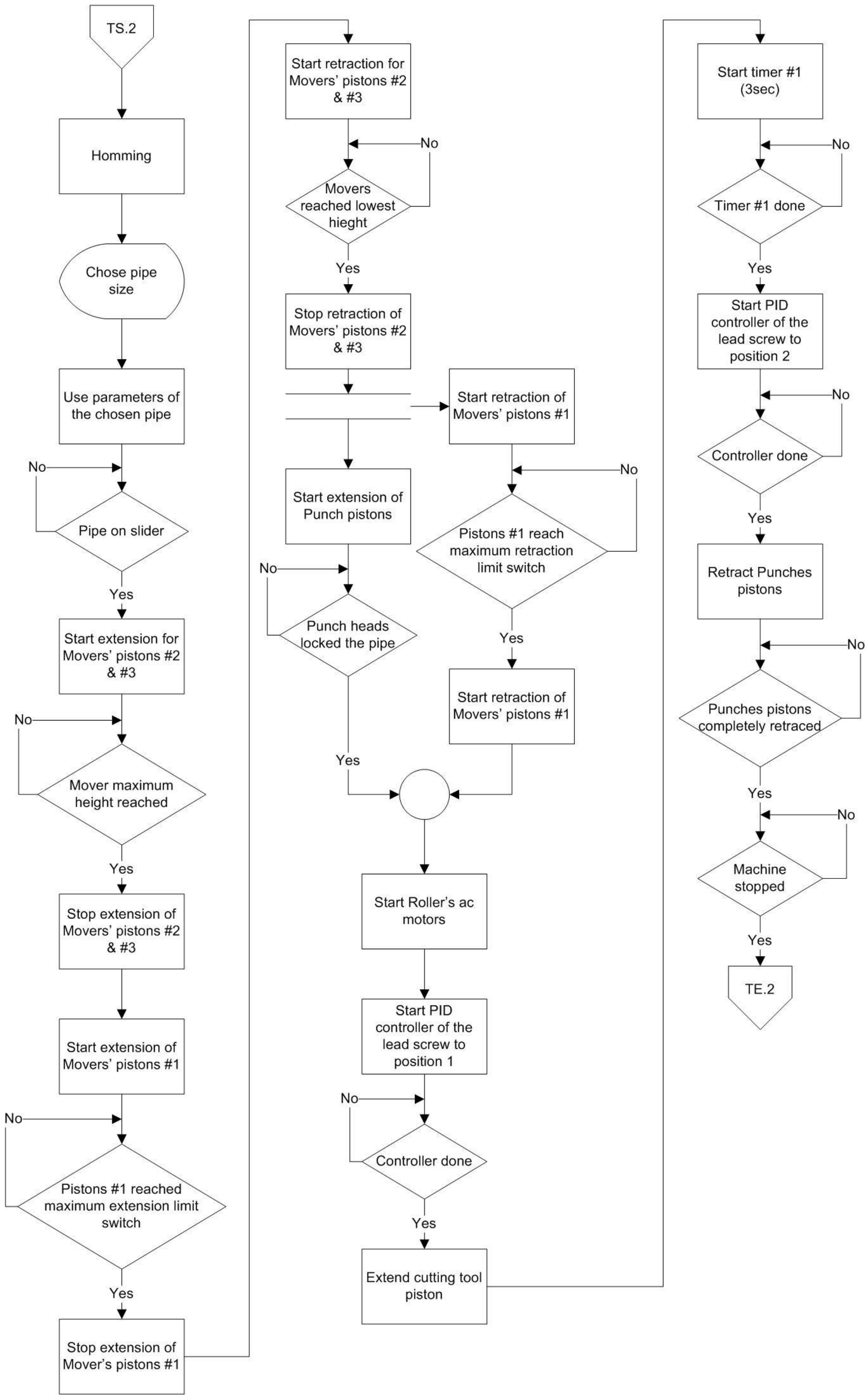

Figure 6.3: Third part of the flowchart automatic mode.

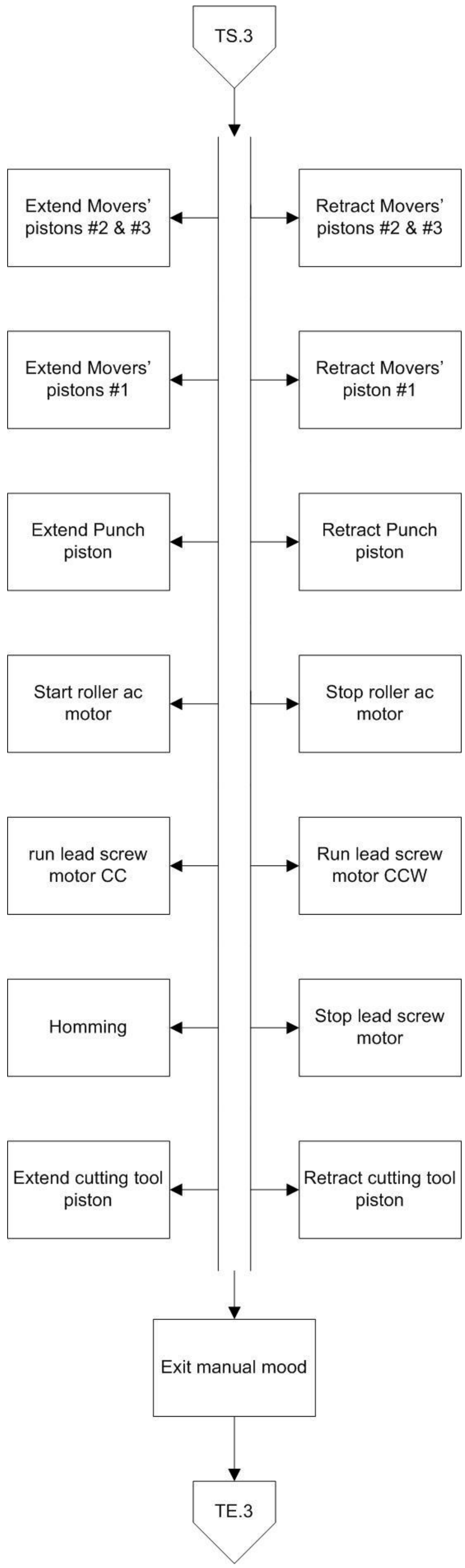

Figure 6.4: Fourth part of the flowchart, manual mode.

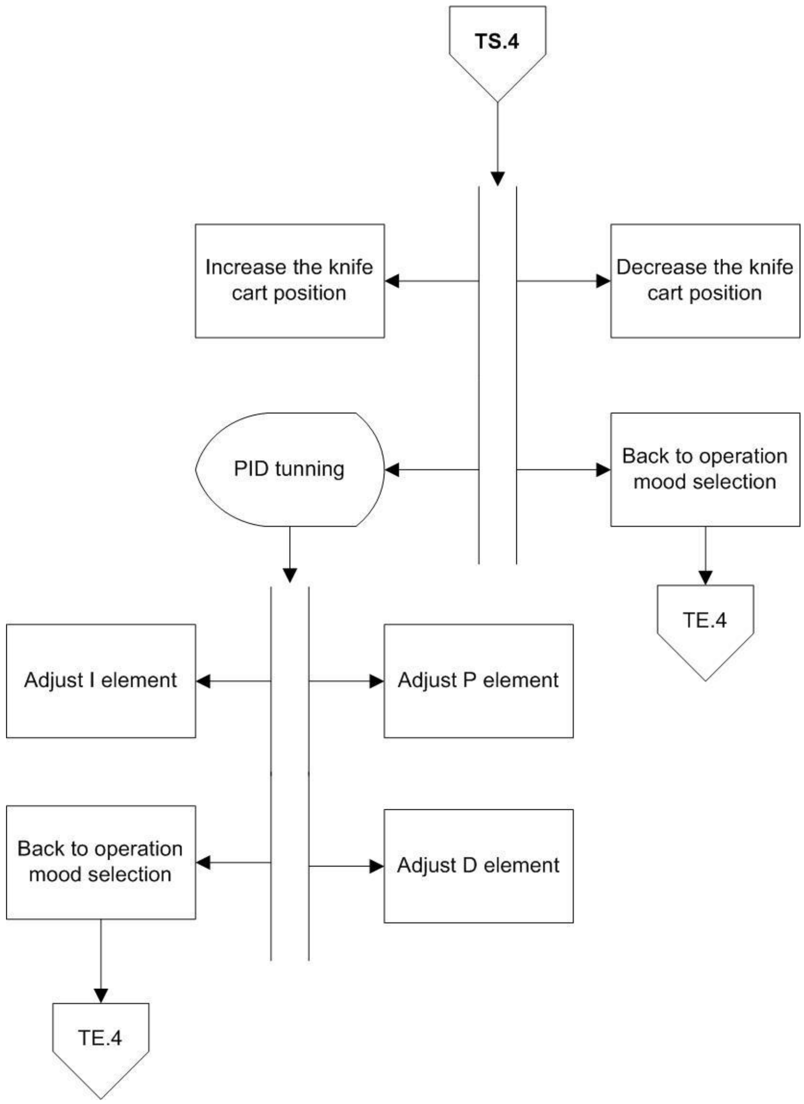

Figure 6.5: Fifth part of the flow chart, fine adjustment.

Fig.6.1 shows the beginning of the flowchart, it can be seen that operator either chose one of the modes, or chose to turn off the machine, the modes are:

1. Mode 1: Semi-automatic Fig.6.2.
2. Mode 2: Automatic Fig.6.3.
3. Mode 3: Manual Fig.6.4.
4. Mode 4: Fine adjustment Fig.6.5.

Each mode is explained separately as follows:

6.2.1 Semi-automatic

This mode completes only one cycle of the machine, and then goes back to the beginning of the flow chart to the choose operation mode input screen, as described next:

First process in the semi-automatic tree is homing, it brings back all the machine parts to its original positions, but if the machine was shut down properly, its parts will be left in the homed position so this block is only for assurance that everything is in position before operation starts, this this block is basically required in case one or more parts weren't in original position at the beginning of the operation.

Next, an input screen will appear on the touch screen, and the operator will be required to choose the size of pipe to be worked, since the machine can work different pipes sizes, and each pipe has its own parameters: The pressure required from the punch, and the position of the cutting tool.

After adjusting the operation mode and the pipe size, the control system checks the state of the slider, if there is a pipe waiting to be worked or not, as long as there is no pipes on the slider the machine will keep waiting till a pipe is inserted.

Once a pipe was spotted on the slider, the machine starts the operating as follows:

The first process that machine does, is moving the pipe from the Slider to the Roller, the sequence of this process is shown in the eight blocks that come after the decision block (pipe on slider) see Fig.6.2.

At this point, the machine has a pipe on the roller, and then as it can be seen in the flow chart the next two processes are done in parallel:

1. The Punches' pistons extend till the Punches' heads lock on the machine.
2. The Movers' pistons #1, retract till they reach the minimum retraction position.

After completing these two operations, the Rollers' motors are turned on, and then the Cutting Machine sliding base motor will be driven by the PID controller to the starting position of cutting.

At this point, there is a pipe mounted on the rollers which is rotating, and the cutting tool is above the starting position of cutting, then the cutting tool piston extends and a countdown timer begins counting for three seconds, this timer is required to provide time enough for the pipe to complete one cycle, and that way the chamfer is done, then the PID controller drives the motor backward to cover the 15 cm of cutting.

Once the PID control reach the final position, the cutting tool piston retracts and the Punches' pistons retracts as well, these are all the operation required in one cycle of the machine, so after finishing the cycle the flowchart goes back to the operation mode selection block as shown in Fig.6.1 and the operator will be asked to choose the operation mode again.

6.2.2 Automatic mode

This mode is identical to semi-automatic mode, but instead of going back to the mode selection block after finishing one cycle, it goes into a loop that only ends if the stop button is pressed see Fig.6.3.

6.2.3 Manual mode

This mode allows the operator, to control the movement of each block manually and separately from other block, as it can be seen in Fig.6.4 all of the actuators of the machine are available to be controlled without restrictions, plus there is a block to exit the manual mode, it sends the operator back to the mode selection screen again.

6.2.4 Fine adjustment

This mode allows the operator, to change the parameters of a specific operations, the first one is the beginning position of the cutting operation, and the second one is the gains of the PID controller responsible of the cutting stroke (Section 6.3.4.2).

6.3 Calculations and information required for designing the control system

6.3.1 Distance required to reach the cutting starting point for each pipe size

The distance that the punch goes into the pipe differs from one size of pipes to another, this means the distance between the edge of the pipe and the cutting tool in its homed position also differs when working different pipes sizes. This variable distance was considered in the control system, it can be seen in Fig.6.2 and Fig.6.3, that the controller drives the lead screw motor to position 1 see Fig.6.6.

Position 1 is one of the parameters saved in the PLC program, table.6.1 list the value of position 1 with reference to homed position of the cutting tool for each pipe size, along with the time to reach the position.

Pipe diameter (inch)	Position 1 (cm)	Time (sec)
3	51.2	80
4	49	70
6	44.5	60
10	35.7	50
12	31.3	40
14	27	10
16	22.5	30

Table 6.1: Position required from the cutting tool, for each pipe size.

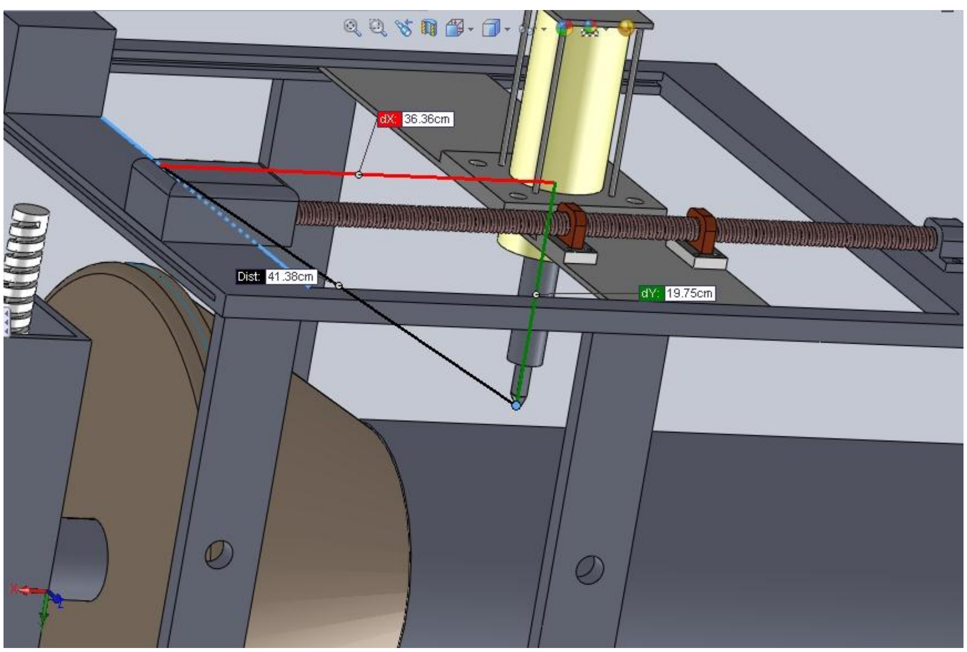

Figure 6.6: Shows the distance meant by position 1.

6.3.2 Relation between voltage and position of the linear potentiometer

The potentiometer ranges from, 5-10k ohm, for 0-75cm length (Appendix A), if the input voltage was 5Volt, the relation between the voltage and distance is as shown in Fig.6.7, and the respective mathematical relation will be as follows:

$$V_o = \frac{\mathrm{dy}}{\mathrm{dx}} \mathrm{L} + 2.5 \quad \text{Eq. 38}$$

Where:

V_o: The output voltage of the potentiometer.

L: The current length of the potentiometer.

$\frac{\mathrm{dy}}{\mathrm{dx}}$: The slope of curve in Fig.6.5 and equals 0.033.

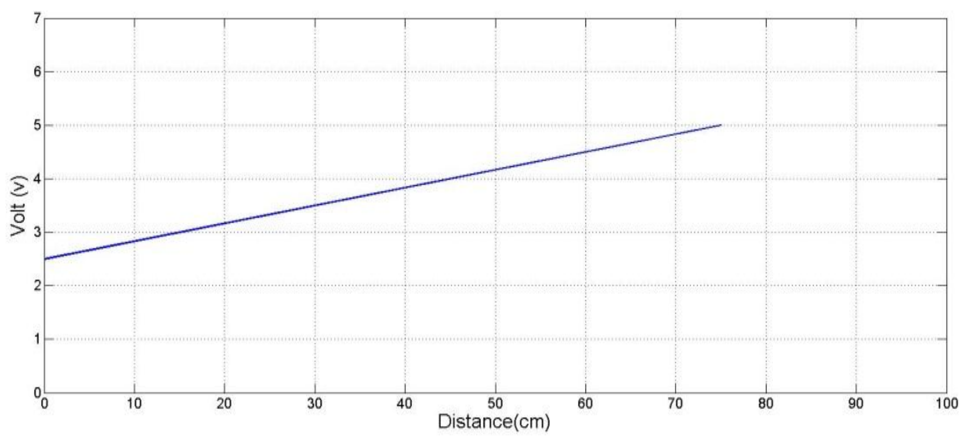

Figure 6.7: The relation between distance and voltage of the potentiometer

The voltage feedback of the potentiometer for each distance of jack is listed in table.6.2 , which was made using Eq.1 and table.6.1.

Pipe diameter (inch)	Position 1 (cm)	Volt feedback of the potentiometer(V)
3	51.2	4.1896
4	49	4.117
6	44.5	3.969
10	35.7	3.678
12	31.3	3.533
14	27	3.391
16	22.5	3.243

Table 6.2: Voltage from potentionmeter for each distance of the cutting tool cart.

6.3.3 Relation between voltage and pressure of the proportional valve

From the data sheet of the proportional valve (Appendix B), it was found that at the maximum command voltage the pressure is maximum, and the relation between the pressure and volt is linear, this can be represented mathematical as follows:

$$V_c = V_{reff} \times (P_{out}/P_{max}) \qquad \text{Eq. 39}$$

Where:

V_c: Command voltage, the input voltage.

V_{reff}: Reference voltage, which the input voltage is compared to.

P_{out}: The output pressure of the valve.

P_{max}: The maximum pressure of the valve (200 bar).

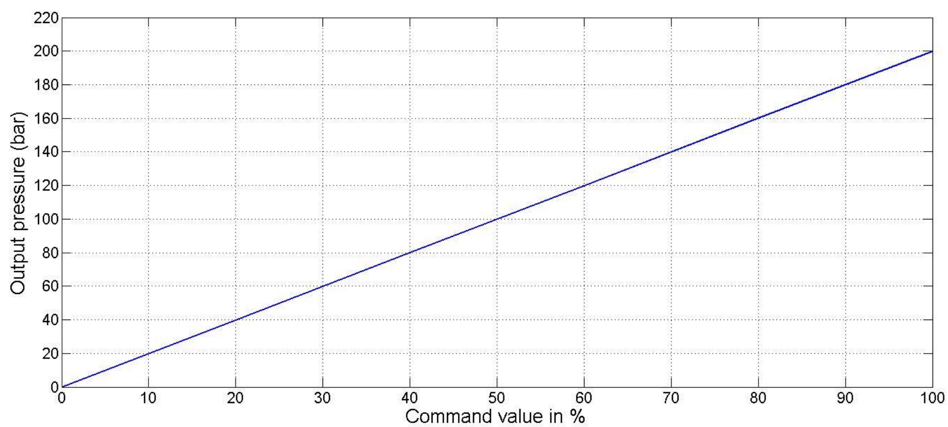

Figure 6.8: The relation between the input voltage and out pressure of the proportional valve.

The voltage values required to be applied on the proportional valve for each pipe size are listed in table.6.3, it was calculated using Eq.4 and table 4.3.

$\emptyset_{out}$ (inch)	Exp values (bar)	Voltage required on the proportional valve (volt)
3	10	0.5
4	15	0.75
6	15	0.75
8	20	1
10	24	1.2
12	30	1.5
16	40	2

Table 6.3: The voltage required for each pipe size.

6.3.4 Designing the PID controller

There are two cases for the system, the first case is the extension phase of the cart when the motor is required to go to the beginning of the cutting position without load, and the other case is the retraction phase of the cart, when it is loaded with torque resulting from the cutting operation.

6.3.4.1 First case

To build a controller for the system, a mathematical model should be found, Fig.6.10 shows equivalent model of the system, and Eq.5 is the respective mathematical model of the system.

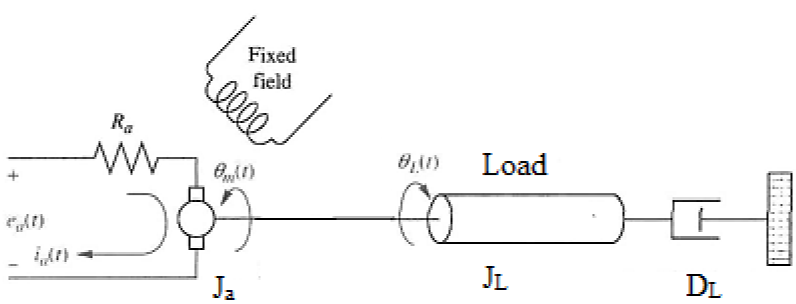

Figure 6.9: Equivalent model of the system.

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_t/(R_a \times J_m)}{s \times \left[s + \frac{1}{j_m}\left(D_m + \frac{K_t \times K_b}{R_a}\right)\right]}$$ [2] Eq. 40

Where:

$\theta_m(s)$: The output of the system (Rad).

$E_a(s)$: The input to the system (volt).

D_m: The equivalent damping of the system ($D_m = 1323\ N.ms/rad$).

$$J_m = J_l + J_a$$ Eq. 41

Where:

J_m: The equivalent inertia of the system, from Solidwork software.

J_l: Load inertia, from Solidwork software.

$$J_m = 3 + 5 = 8\ kg.m^2$$

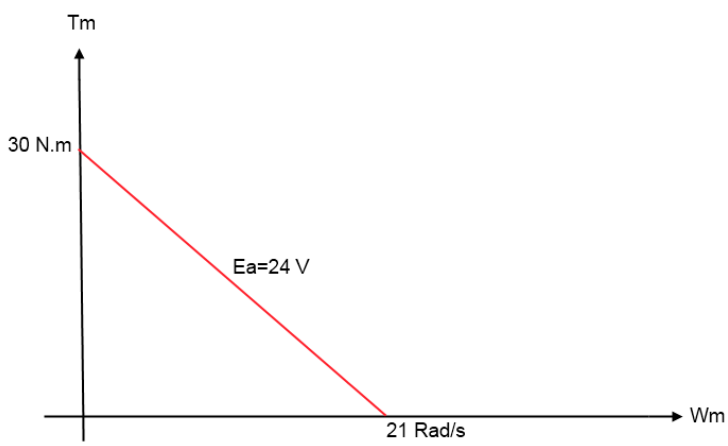

Figure 6.10: The characteristic curve of the motor.

From the characteristic curve of the motor Fig.6.11, it was found that:

$\tau_{stall} = 30N.m$

$\omega_{no\ load} = 21\ Rad/sec$

$e_a = 24V$

$$\frac{K_t}{R_a} = \frac{\tau_{stall}}{e_a}$$ [2] Eq. 42

$$\frac{K_t}{R_a} = \frac{30}{24} = 1.25$$

$$K_b = \frac{e_a}{\omega_{no\ load}}$$ [2] Eq. 43

$$K_b = \frac{24}{21} = 1.142$$

$$\frac{\theta_m(s)}{E_a(s)} = \frac{1.25/8}{s \times \left[s + \frac{1}{8}(1323 + 1.25 \times 1.142)\right]} = \frac{0.156}{s \times (s + 165.5)}$$

Using Eq.9, the mathematical model with respect to angel, was transformed to be with respect to distance.

$$\theta = x \times d_p$$ Eq. 44

Where:

θ: The angular displacement (rad).

x: Distance in meter.

d_p: Pitch diameter (2mm).

$$\theta = 2 \times \pi = 2 \times 10^{-3} \times x$$

$$\theta = \frac{x}{\pi}$$

$$\frac{X(s)}{E_a(s)} = \frac{0.5}{s \times (s + 165.5)}$$

Using MATLAB software, the state space representation was found as follows:

$\dot{x} = Ax + Bu$ [2] Eq. 45

$y = Cx + Du$ [2] Eq. 46

$$A = \begin{bmatrix} 165.55 & 0 \\ 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$C = [0 \quad 0.5]$$

$$D = [0]$$

The eigenvalues of the system was found to be:

$$eig_{1,2} = 0, -165.55$$

As it can be seen none of the eigenvalues of system are positive but one of them equals zero so the system is marginally stable.

The natural frequency of the system using MATLAB was found to be:

$$\omega_n = 26.4\ Hz$$

To avoid aliasing phenomena, the sampling rate of the controller must be ten times greater than the natural frequency, so the frequency of the controller should be at least (264 Hz).

Using MATLAB also to check the stability of the system, it was found that the controllability matrix:

$$M_c = \begin{bmatrix} 1 & -165.55 \\ 0 & 1 \end{bmatrix}$$

The rank of M_c, was found to be two using MATLAB, and since the rank equals the number of states, the system is controllable.

To find the response of the system, MATLAB/Simulink were used, the Simulink model without a controller with a ramp input is shown in Fig.6.12.

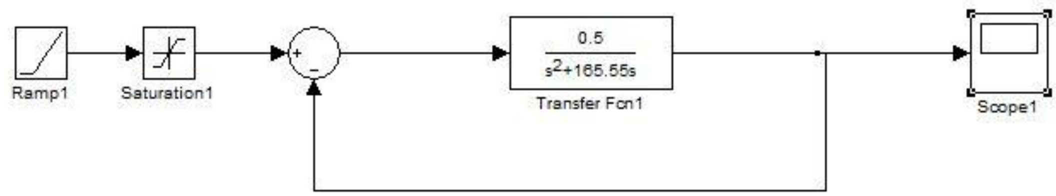

Figure 6.11: MATLAB/Simulink model of the system without controller.

It can be seen in the Fig.6.13 that the response of the system is unstable, this is due to the ramp input, although the system in natural is marginally stable, but this is because ramp input adds two poles at origin and this was the causes of instability.

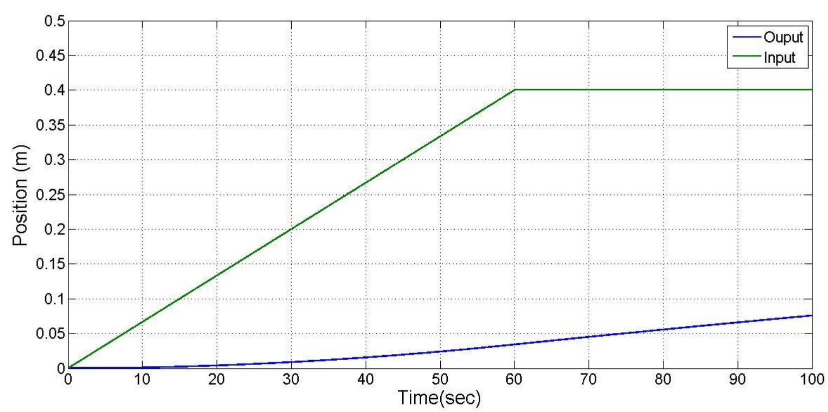

Figure 6.12: The uncontrolled response of the system for ramp input.

A PID controller was designed to enhance the response of the system to reach zero steady state error and to increase the response time with negligible overshoot using MATLAB/Simulink /SISO-tool, Fig.6.13 shows the Simulink model of the system with PID controller.

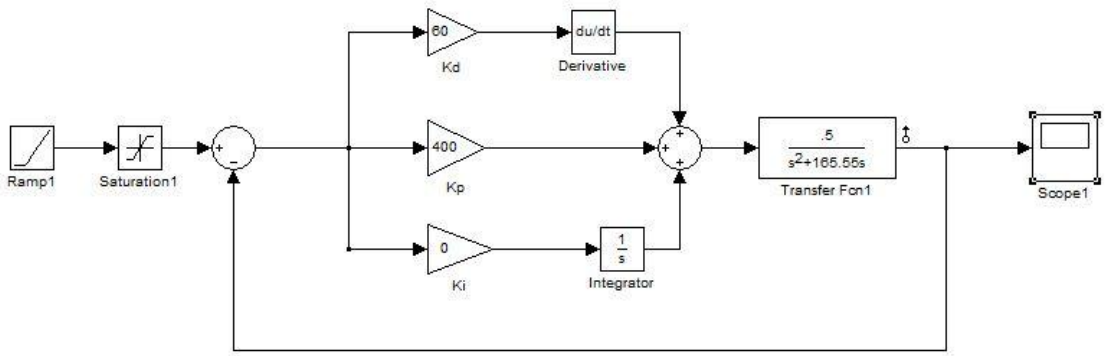

Figure 6.13: MATLAB/Simulink model of the system with PID controller.

For each pipe size, there is a different ramp input see section.6.3.3, for simulation only one of these cases was used Fig.6.14 shows the response and the input for the controlled system, it can be seen that the response of the system now reaches the required position with good performance.

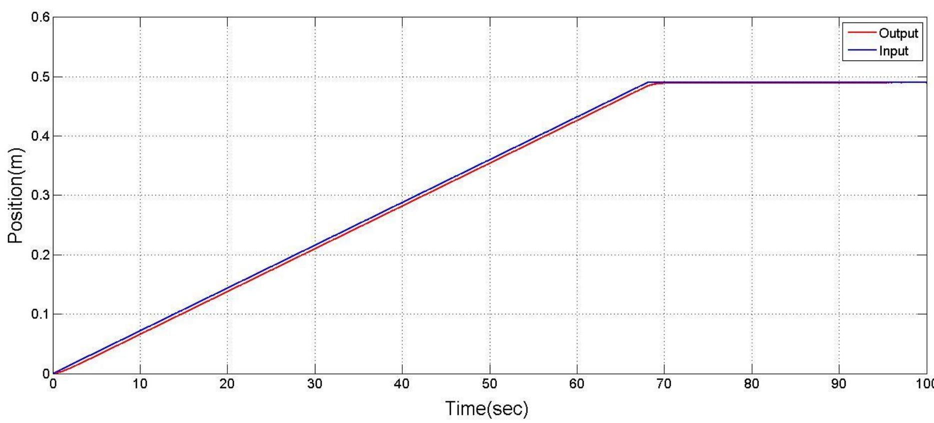

Figure 6.14: The response of the controller system for ramp input.

6.3.4.2 Second case

In this case, there will be an additional torque added to the model, resulted from cutting, this will effect the response of the system, to overcome this problem, two PID controllers were designed in PLC, one for the first case and another one for the second case, the second PID controller for the second case will be tuned experimentally, its gains will be initially the same of the first PID controller. It will be seen in section.6.3, that one of the touch screen pages was designed for this purpose.

6.3.4.3 PID block diagram in PLC[3]

6.3.4.3.1 Introduction

FB "CONT_C" is used on SIMATIC S7 programmable controllers to control technical processes with continuous input and output variables. During parameter assignment , you can activate or deactivate subfunctions of the PID controller to adapt the controller to the process.

6.3.4.3.2 Description

Apart from the functions in the set point and process value branches, the FB implements a complete PID controller with continuous manipulated variable output and the option of influencing the manipulated value manually, table.6.4 explains the parameters of the PID FB.

Parameter	Description
P_SEL	PROPORTIONAL ACTION ON The PID actions can be activated or deactivated individually in the PID algorithm. The P action is on when the input "proportional action on" is set.
I_SEL	INTEGRAL ACTION ON The PID actions can be activated or deactivated individually in the PID algorithm. The I action is on when the input "integral action on" is set.
D_SEL	DERIVATIVE ACTION ON The PID actions can be activated or deactivated individually in the PID algorithm. The D action is on when the input "derivative action on" is set.
CYCLE	SAMPLING TIME The time between the block calls must be constant. The "sampling time" input specifies the time between block calls.
SP_INT	INTERNAL SETPOINT The "internal setpoint" input is used to specify a setpoint.
PV_PER	PROCESS VARIABLE PERIPHERAL The process variable in the I/O format is connected to the controller at the "process variable peripheral" input.
GAIN	PROPORTIONAL GAIN The "proportional value" input specifies the controller gain.
LMN_PER	MANIPULATED VALUE PERIPHERAL The manipulated value in the I/O format is connected to the controller at the "manipulated value peripheral" output.

Table 6.4: Describes the function of each parameter for the PID block in Siemens steps 7 software.

6.3.4.3.3 PID Algorithm

The PID algorithm operates as a position algorithm. The proportional, integral (INT), and derivative (DIF) actions are connected in parallel and can be activated or deactivated individually. This allows P, PI, PD, and PID controllers to be configured. Pure I and D controllers are also possible.

6.3.4.3.4 Block Diagram

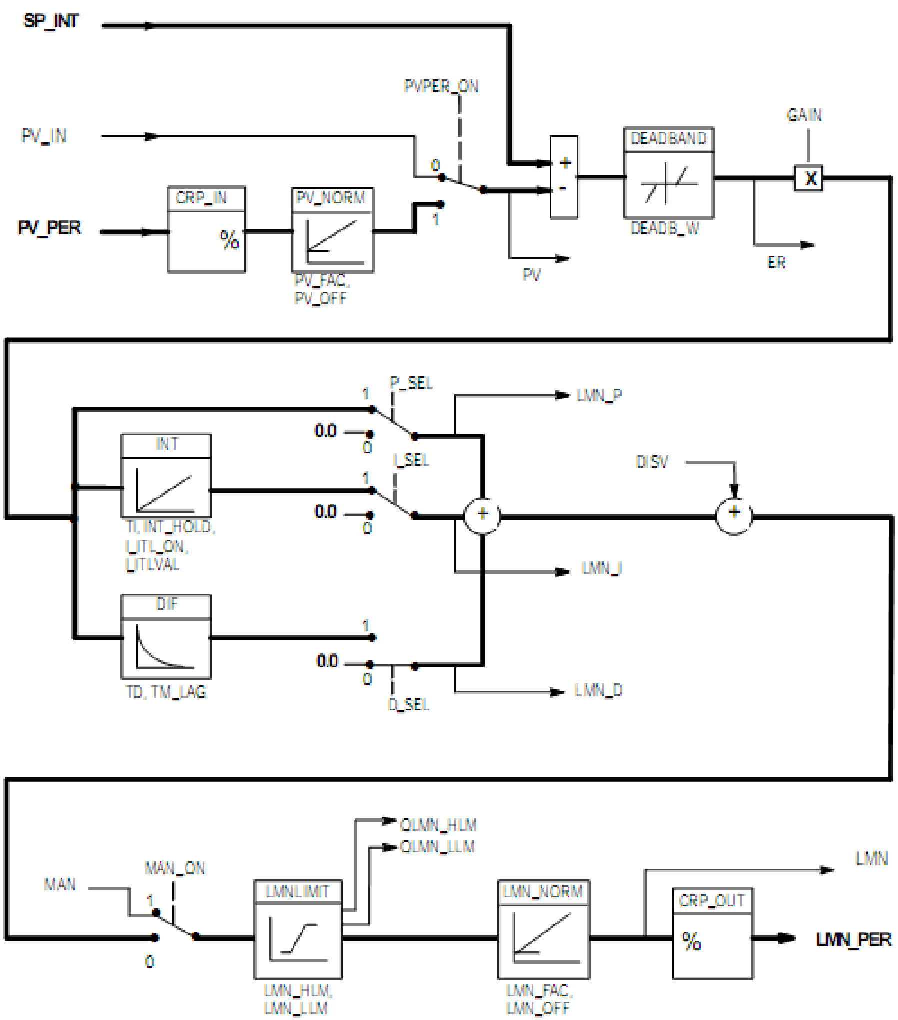

Figure 6.15: PID block diagram in Siemens Step7 software.

6.3 HMI (Human Machine Interface)

Instead of using traditional HMI, which will probably consist of many switches and a number of LEDS and LCD, a touch screen was used, which will provide more compact and less wire control panel, moreover less complicated and easier HMI to deal with, so any operator which was familiar with the current machine, will find easy to learn and operate the new machine.

it should be noted that the touch screen panel, consist basically of a number of pages connected with each other, so the operator can navigate among them, each page is responsible of certain set of functions, so each will have a number of pushbuttons, these pushbuttons are connected to the memory location of the PLC controller through ***IF1B*** interface bus, each one of the touch screen software is explained and showed as follows:

6.4.1 Main page

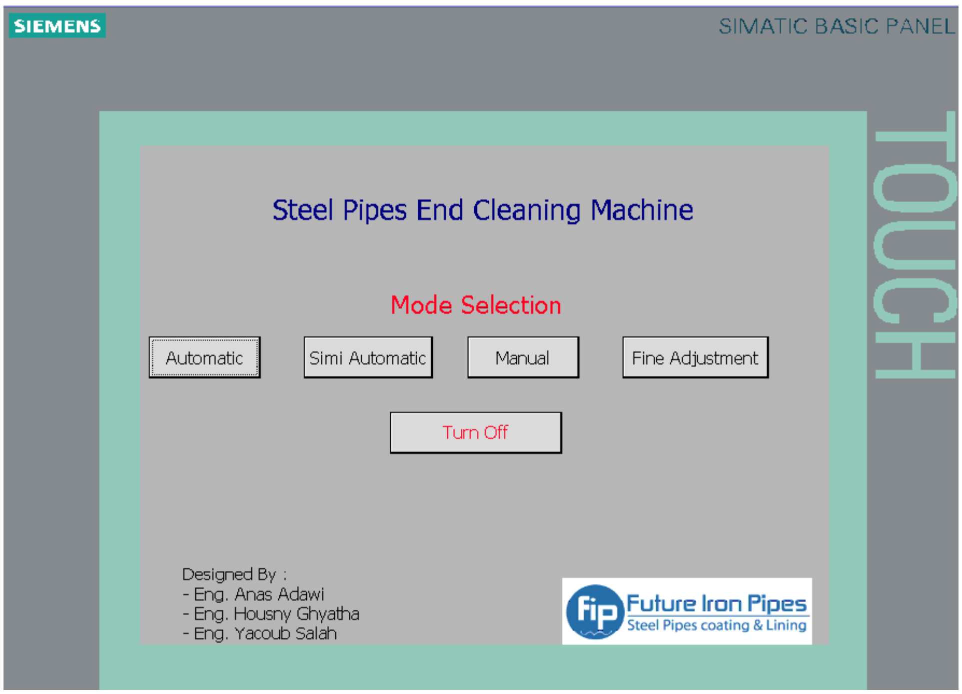

Figure 6.16: The main page of the touch screen.

This is the first page that will appear on the touch screen once the machine is turned on, as it was explained in the operation of the machine in the flow chart section, the operator will be asked to choose the mode of operation, or chose to turn off the machine, this page will allow the operator to choose one of the four mentioned option as it can be seen in Fig.6.7 each click will navigate the operator to a new page, these pages are named with respect to the pushbutton function key name.

6.4.2 Choosing pipe diameter size page

This page is for choosing the size of pipes the operator welling to work, this page will appear after choosing the automatic or semi-automatic operation mode, Fig.6.8 shows the pipe diameter selection page.

Figure 6.17: Pipe size selection touch screen page.

The next page that comes after this one depends on the mode of operation, if it was selected to be semi-automatic, the machine will finish one cycle and the next page will be the mode selection page again, but if it was in the automatic mode, the next page will be shown in section.6.4.3.

Moreover, this page is also responsible of updating the parameters of the machine, that is related to the size of the pipe, such as the pressure of the punch, and the distance required from the cutting tool piston to move in the extension stroke.

6.4.3 Automatic mode page

The page will appear after selecting the pipe size in the automatic mode, see Fig.6.9.

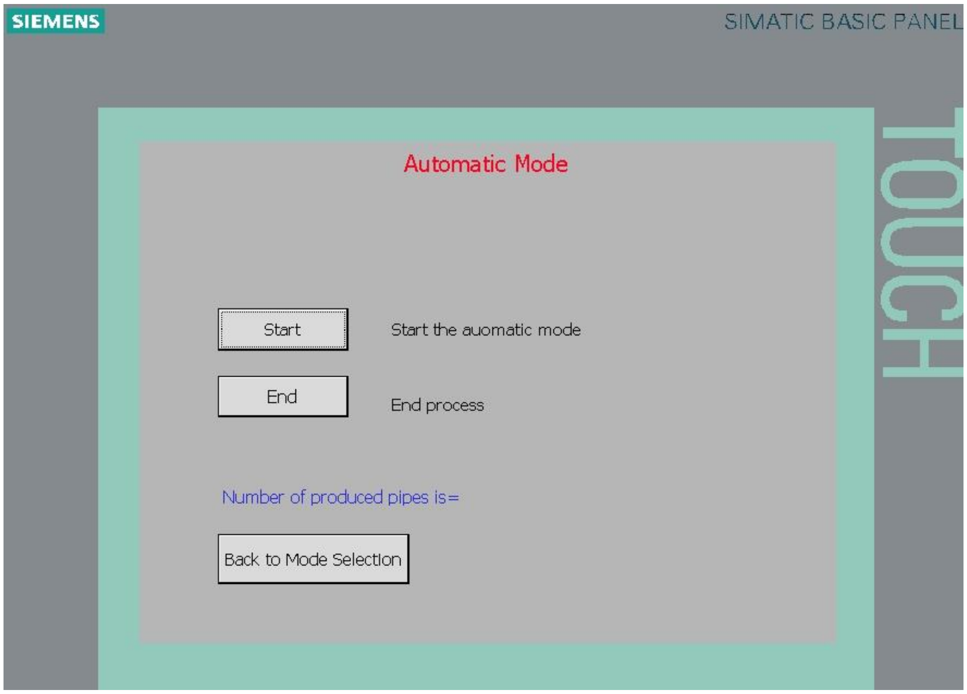

Figure 6.18 : The automatic mode touch screen page.

6.4.4 Manual mode page

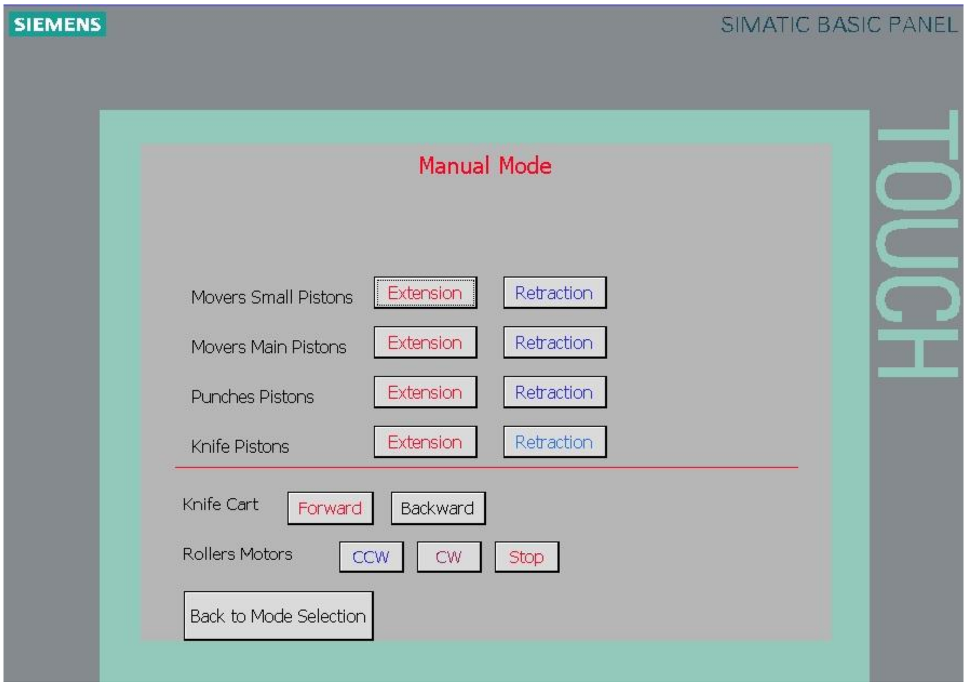

Figure 6.19: The manual mode touch screen page.

This page will appear if the manual operation mode is selected, as it can be seen the operator is allowed to control each actuator separately.

6.4.5 Fine Adjustment page

This page allows the operator, to adjust some parameters of the machine the knife cart case one position, and the PID of the second case parameters, if the PID tuning were chosen, a new page will appear (explained in section.6.4.6).

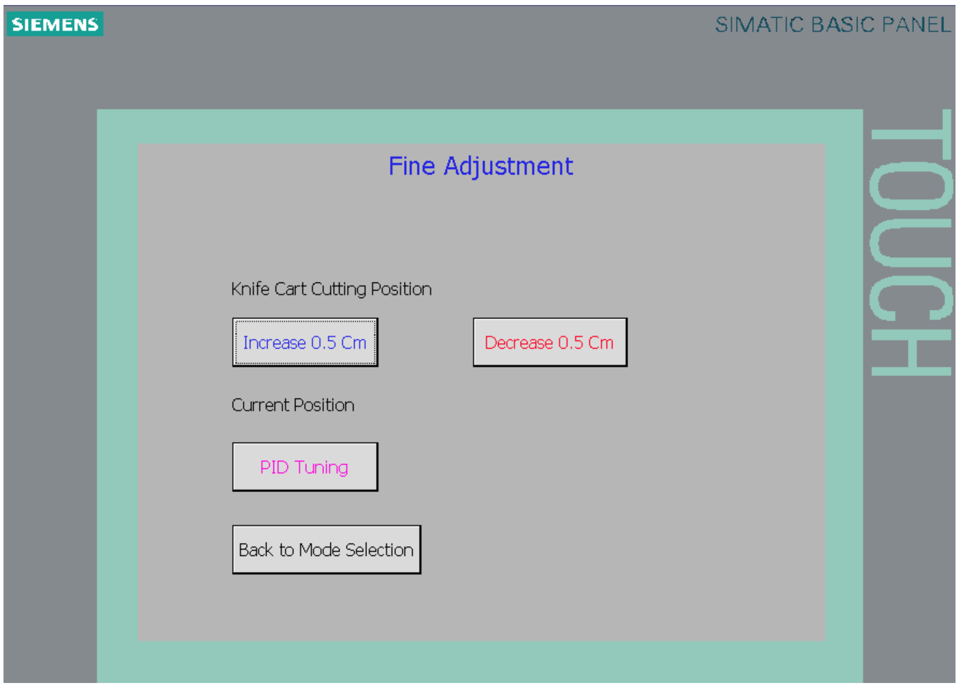

Figure 6.20: Fine adjustment touch screen page.

6.4.6 PID tuning page

This page allows the operator to adjust the PID parameters to enhance the response of the system as it was explained in section.6.3.4.2. see Fig.6.21 for the design of the page.

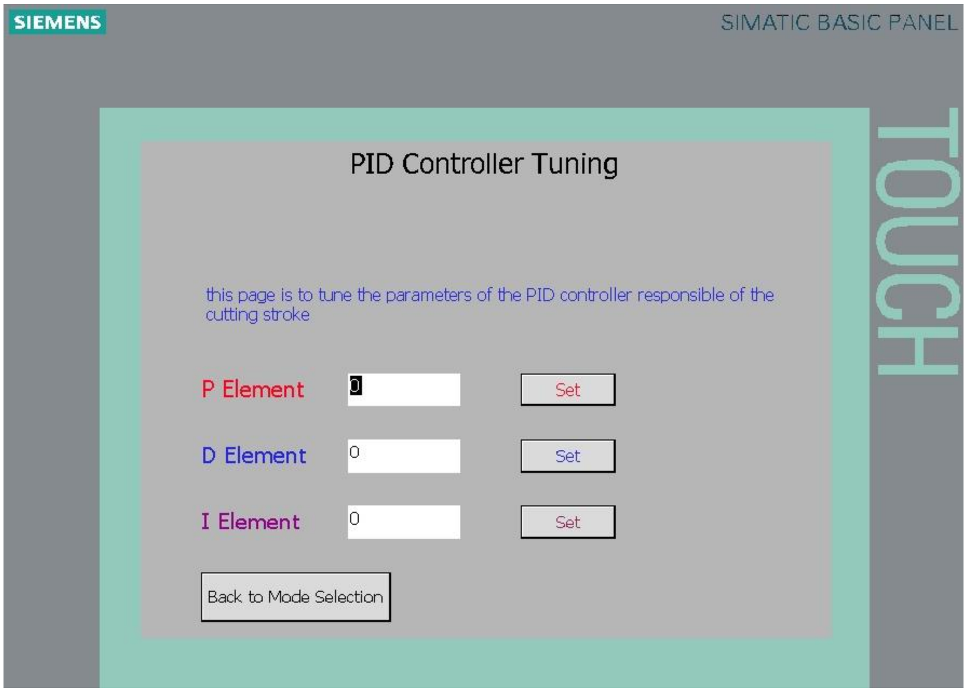

Figure 6.21: The PID tuning touch screen page.

6.4 Wiring diagrams

This section shows wiring diagram for all the hardware components, in the design, but it was divided in subsection for each type of components, as follows:

6.4.1 PLC input and out modules

Fig.6.22, shows the input and output modules of PLC, each terminal has a unique name, to indicates the component connected to the module.

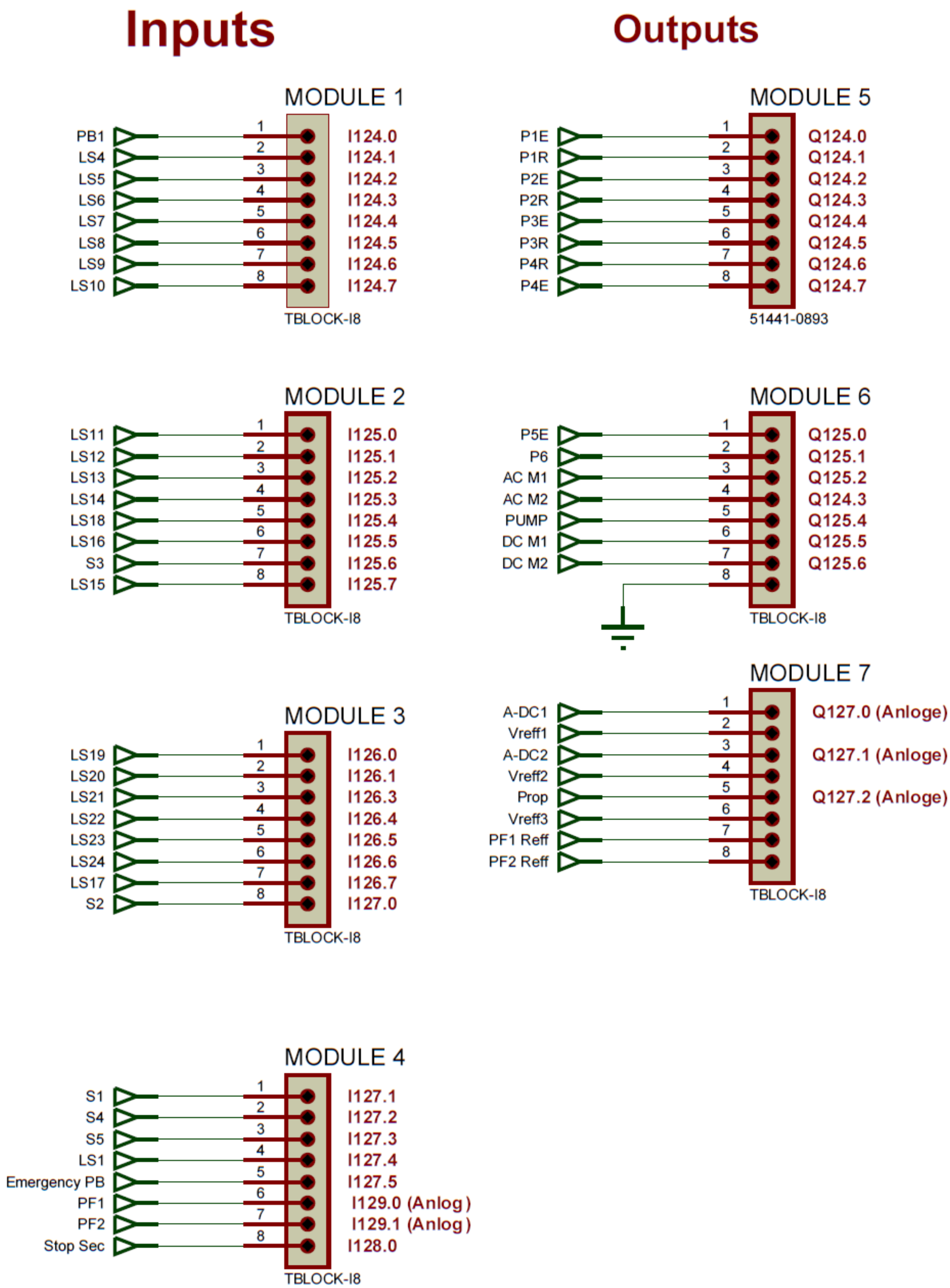

Figure 6.22: PLC input and output modules wiring diagram.

6.4.2 Limit switches.

Table.6.5 lists all the limit switches in the machine; They are directly connected to PLC, without condition circuits.

Sensor name	Description
LS1	1st limit switch to detect pipe on the slider
LS2	2nd limit switch to detect pipe on the slider
LS3	3rd limit switch to detect pipe on the slider
LS4	4th limit switch to detect pipe on the slider
LS5	Mover #1 maximum stroke limit switch
LS6	Mover #1 minimum stroke limit switch
LS7	Mover #1 maximum stroke limit switch
LS8	Mover #1 minimum stroke limit switch
LS9	Mover #2 maximum stroke limit switch
LS10	Mover #2 minimum stroke limit switch
LS11	Mover #2 maximum stroke limit switch
LS12	Mover #2 minimum stroke limit switch
LS13	Mover #1 minimum stroke limit switch
LS14	Mover #1 track maximum stroke limit switch
LS15	Mover #2 track minimum stroke limit switch
LS16	Mover #1 track maximum stroke limit switch
LS17	Punch#1 track minimum position
LS18	Punch#1 track maximum position
LS19	Punch#2 track minimum position
LS20	Punch#2 track maximum position
LS21	Cutting tool cart #1 full stroke
LS22	Cutting tool cart #1 minimum stroke
LS23	Cutting tool cart #2 minimum stroke
LS24	Cutting tool cart #2 full stroke

Table 6.5: List of the limits switches and their description.

6.4.3 Laser sensors

Fig.6.23, shows that the laser sensors are connected directly to the plc without conditioning circuit.

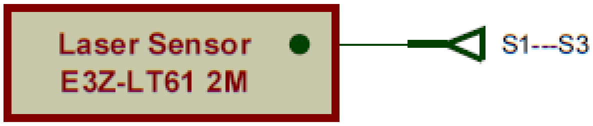

Figure 6.23: Wiring diagram of Laser sensors.

6.44 LDR (light dependent resistance) circuit

Table.6.6 shows describes the position of both LDR sensors.

Sensor name	Description
S4	LDR sensor 1 to detect the pipe on punch #1
S5	LDR sensor 1 to detect the pipe on punch #2

Table 6.6: list of LDR sensors

Fig6.24 shows the wiring circuit of the LDR sensor, there are two LDR sensors in the machine, it can be seen from the figure they are connected to S4 and S5 terminal of the PLC input module.

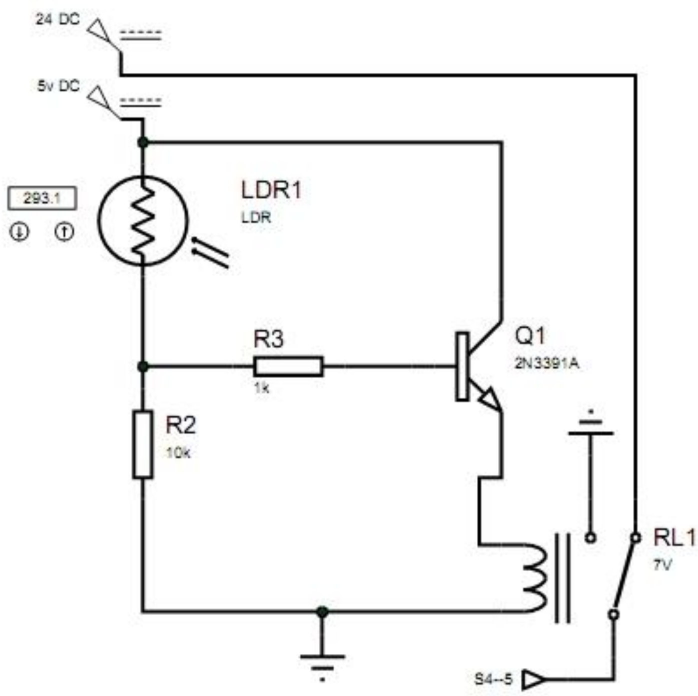

Figure 6.24: LDR circuit and wiring diagram.

6.4.5 Hydraulic valves wiring diagram

Fig.6.25 shows the connection terminal name for each of the hydraulic valves, it worth noting that there wasn't a need for conditioning circuit, and the valves can be connected directly to PLC.

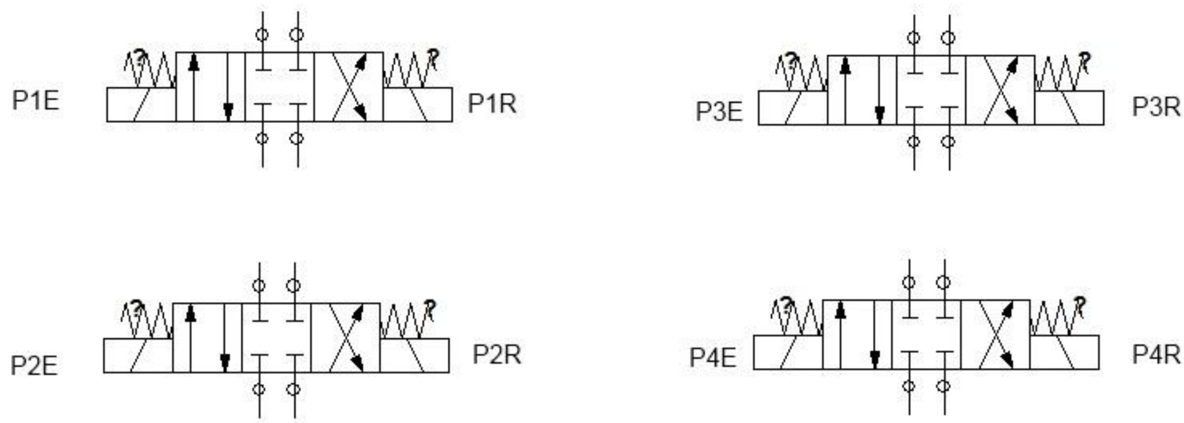

Figure 6.25: Hydraulic valves wiring diagram.

6.4.6 Pneumatic valves wiring diagram

Fig6.26 shows the connection terminal name of the pneumatic valve, it can be seen from the figure that there wasn't a need for conditioning circuit, and the valve can be directly connected to the PLC.

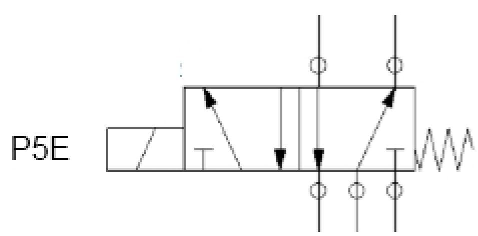

Figure 6.26: Pneumatic valve wiring diagram.

6.4.7 DC motor driving circuit and wiring diagram

Fig.6.27, shows that the driving circuit of the DC motor, the amplifier is the main driving component, it allows for reversing the direction of rotation, and also amplifies the signal to higher power level to drive the motor, the input terminal to this block is A-DC1, but there is a second motor and its input terminal is called A-DC2 as well.

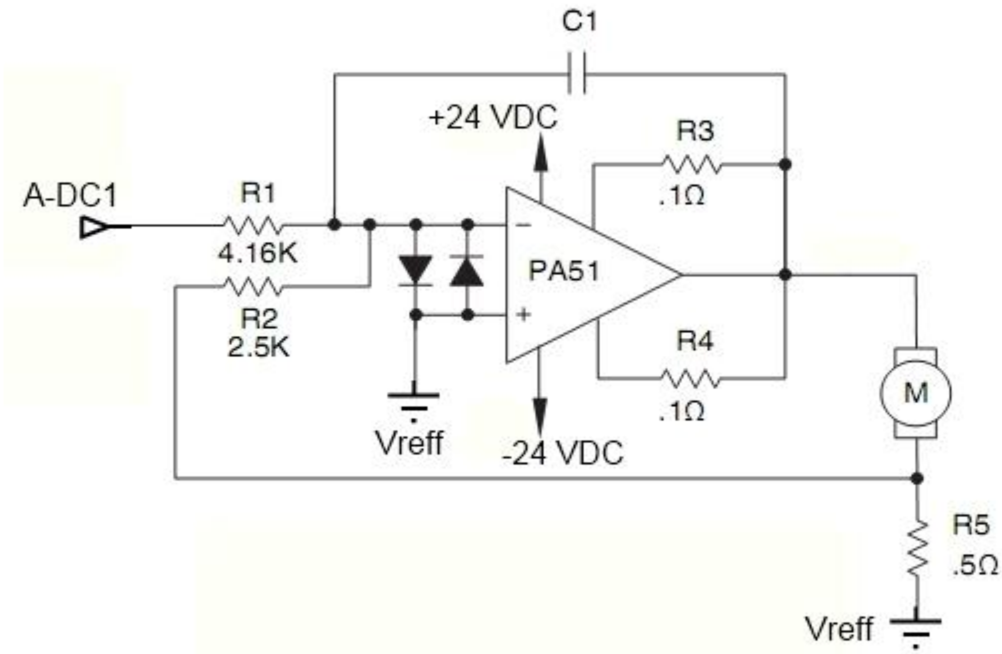

Figure 6.27: The DC motor Driving circuit.

6.4.8 AC motor driving circuit and wiring diagram

There are two AC motor to drive the Rollers, Fig6.28 shows the driving circuit of these motors, it consist of a 3 phase relay and overloads.

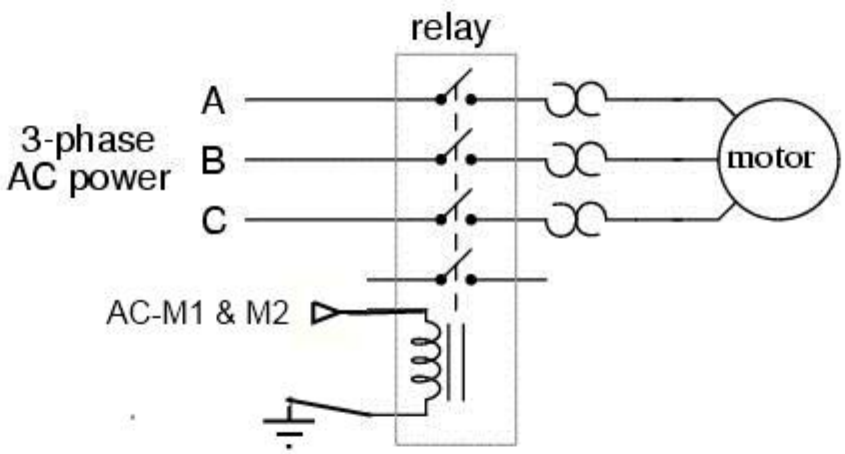

Figure 6.28: The driving circuit of the AC motor.

Recommendations

The designing process of any machine goes through a number of stages, starting from concepts to prototyping, running and optimizing the machine, in this thesis the latest stages was unreachable because of, financial, capabilities, and time limitation.

So all of the recommendation will be pouring on the same direction, which is in other words, completing the designing process of the machine.

1. Some parts of the machine weren't designed on accurate theories, and included a number of assumption, which was going to be compensated by experimental tuning, such as the Punch heads pressure, and the reflected force on the cutting tool, it is recommended to build models to find the actual values.
2. In case slippage occurred in turning the pipe on the roller, it is recommended to design a fixing mechanism that adds normal force to the pipe.
3. Reconsider designing the PID controller responsible of moving the cutting tool cart at the retraction phase.
4. Redesign the mechanical structure using forward analysis methods, instead of the reverse analysis which was followed in designing the mechanical structure of the machine.
5. Increasing the intelligence of the machine, by adding advanced control system and methodologies.

References

Books

[1] Anthony Esposito, *FLUID POWER AND ITS APPLICATION*, 4th edition

[2] NORMAN S. NISE, *Control Systems Engineering*, Sixth Edition

[4] Robert H. Bishopm, *THE MECHATRONICS HANDBOOK*.

[3] Budynas Nisbett, *Mechanical Engineering Design*, 8th Edition

Internet documents

[1] http://www.fer.unizg.hr/download/repository/S7pidcob.pdf (5/21/2012).

Appendix A

Datasheets

- Hydraulic pistons
- Hydraulic hose
- Directional valves
- Laser sensor
- Hydraulic filter
- Flow divider valve
- Jack screw
- Pressure temperature compensated flow control valve
- Hydraulic pump
- Proportional pressure reducing valve
- Potentiometer

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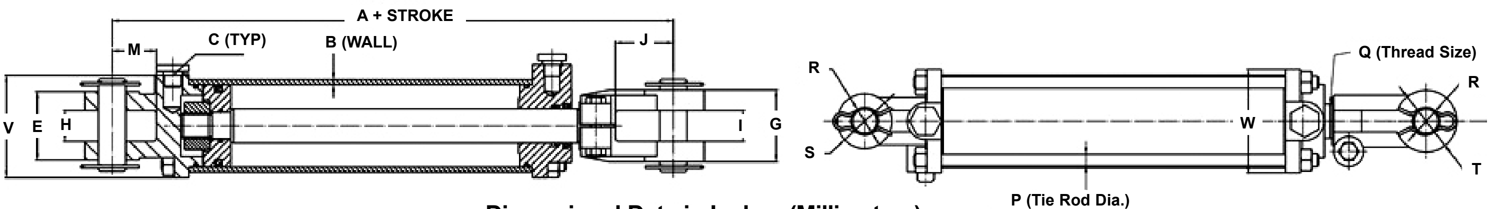

Dimensional Data in Inches (Millimeters)

BORE	DIMENSIONS A*	B	C	E	G	H	I	J	M	P	Q	R**	S	T	V	W
2.000 (50.8)	10.250 (260.4)	0.189 (4.80)	3/8" NPT	2.500 (63.5)	2.500 (63.5)	1.125 (28.6)	1.125 (28.6)	2.125 (54.0)	1.50 (38.1)	0.394 (10)	1 1/8-12 UNF	1.000 (25.4)	2.000 (50.8)	2.000 (50.8)	2.795 (71.0)	2.835 (72.0)
2.500 (63.5)	10.250 (260.4)	0.189 (4.80)	3/8" NPT	2.500 (63.5)	2.500 (63.5)	1.125 (28.6)	1.125 (28.6)	2.125 (54.0)	1.50 (38.1)	0.394 (10)	1 1/8-12 UNF	1.000 (25.4)	2.000 (50.8)	2.000 (50.8)	3.110 (79.0)	3.150 (80.0)
3.000 (76.2)	10.250 (260.4)	0.189 (4.80)	1/2" NPT	2.500 (63.5)	2.625 (66.7)	1.125 (28.6)	1.125 (28.6)	2.125 (54.0)	1.50 (38.1)	0.472 (12)	1 1/4-12 UNF	1.000 (25.4)	2.000 (50.8)	2.250 (57.2)	3.740 (95.0)	3.780 (96.0)
3.500 (88.9)	10.250 (260.4)	0.218 (5.53)	1/2" NPT	2.500 (63.5)	2.625 (66.7)	1.125 (28.6)	1.125 (28.6)	2.125 (54.0)	1.50 (38.1)	0.551 (14)	1 1/4-12 UNF	1.000 (25.4)	2.250 (57.2)	2.250 (57.2)	4.213 (107.0)	4.250 (108.0)
4.000 (101.6)	10.250 (260.4)	0.244 (6.20)	1/2" NPT	2.625 (66.7)	2.625 (66.7)	1.125 (28.6)	1.125 (28.6)	2.125 (54.0)	1.50 (38.1)	0.630 (16)	1 1/4-12 UNF	1.000 (25.4)	2.250 (57.2)	2.250 (57.2)	4.882 (124.0)	4.920 (125.0)

A* 12.25" (311.2) for 8" (203.2) stroke ASAE cylinders and 15.50" (393.7) for 16" (406.4) stroke ASAE cylinders. **(Pin diameter): 1.25 (31.75) for 16" (406.4) stroke ASAE cylinders from 3" to 4" bore.

BAILEY NO.	STROKE	ROD DIAMETER	DIMENSIONS RETRACTED	DIMENSIONS EXTENDED	COLUMN LOAD	PORT SIZE	PIN DIAMETER	SHIP WT.	PRICE EACH 1-9	PRICE EACH 10-UP
2" Bore • 2500 PSI										
218-297	4"	1 1/8"	14 1/4"	18 1/4"	7,850 lbs.	3/8" NPTF	1"	16	**54.00**	**51.00**
218-298	6"	1 1/8"	16 1/4"	22 1/4"	7,850 lbs.	3/8" NPTF	1"	17	**59.00**	**56.00**
218-299	8"	1 1/8"	18 1/4"	26 1/4"	7,850 lbs.	3/8" NPTF	1"	18	**60.00**	**57.00**
218-300	8" ASAE	1 1/8"	20 1/4"	28 1/4"	7,850 lbs.	3/8" NPTF	1"	19	**59.00**	**59.00**
218-306	10"	1 1/8"	20 1/4"	30 1/4"	7,850 lbs.	3/8" NPTF	1"	20	**68.00**	**63.00**
218-307	12"	1 1/8"	22 1/4"	34 1/4"	7,850 lbs.	3/8" NPTF	1"	21	**70.00**	**65.00**
218-308	14"	1 1/8"	24 1/4"	38 1/4"	7,850 lbs.	3/8" NPTF	1"	22	**74.00**	**70.00**
218-309	16"	1 1/8"	26 1/4"	42 1/4"	7,850 lbs.	3/8" NPTF	1"	23	**75.00**	**71.00**
218-310	18"	1 1/8"	28 1/4"	46 1/4"	7,850 lbs.	3/8" NPTF	1"	24	**81.00**	**75.00**
218-311	20"	1 1/8"	30 1/4"	50 1/4"	6,950 lbs.	3/8" NPTF	1"	25	**85.00**	**79.00**
218-312	24"	1 1/8"	34 1/4"	58 1/4"	5,180 lbs.	3/8" NPTF	1"	27	**92.00**	**86.00**
218-313	30"	1 1/8"	40 1/4"	70 1/4"	3,570 lbs.	3/8" NPTF	1"	35	**110.00**	**109.00**
218-314	36"	1 1/8"	46 1/4"	82 1/4"	2,610 lbs.	3/8" NPTF	1"	40	**126.00**	**124.00**
218-315	48"	1 1/8"	58 1/4"	106 1/4"	1,570 lbs.	3/8" NPTF	1"	50	**163.00**	**161.00**
204-500		1 1/8"	Packing Kit						**16.00**	-

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BAILEY NO.	STROKE	ROD DIAMETER	DIMENSIONS RETRACTED	DIMENSIONS EXTENDED	COLUMN LOAD	PORT SIZE	PIN DIAMETER	SHIP WT.	PRICE EACH 1-9	PRICE EACH 10-UP
2 1/2" Bore • 2500 PSI										
218-316	4"	1 1/8"	14 1/4"	18 1/4"	12,270 lbs.	3/8" NPTF	1"	18	**63.00**	**58.00**
218-317	6"	1 1/8"	16 1/4"	22 1/4"	12,270 lbs.	3/8" NPTF	1"	19	**63.00**	**58.00**
218-318	8"	1 1/8"	18 1/4"	26 1/4"	12,270 lbs.	3/8" NPTF	1"	20	**65.00**	**61.00**
218-301	8" ASAE	1 1/8"	20 1/4"	28 1/4"	12,270 lbs.	3/8" NPTF	1"	22	**68.00**	**61.00**
218-319	10"	1 1/8"	20 1/4"	30 1/4"	12,270 lbs.	3/8" NPTF	1"	22	**73.00**	**68.00**
218-320	12"	1 1/8"	22 1/4"	34 1/4"	12,270 lbs.	3/8" NPTF	1"	24	**82.00**	**76.00**
218-321	14"	1 1/8"	24 1/4"	38 1/4"	12,170 lbs.	3/8" NPTF	1"	25	**87.00**	**81.00**
218-322	16"	1 1/8"	26 1/4"	42 1/4"	10,000 lbs.	3/8" NPTF	1"	27	**90.00**	**84.00**
218-323	18"	1 1/8"	28 1/4"	46 1/4"	8,370 lbs.	3/8" NPTF	1"	28	**94.00**	**87.00**
218-324	20"	1 1/8"	30 1/4"	50 1/4"	7,100 lbs.	3/8" NPTF	1"	30	**96.00**	**91.00**
218-325	24"	1 1/8"	34 1/4"	58 1/4"	5,300 lbs.	3/8" NPTF	1"	33	**106.00**	**99.00**
218-329	30"	1 1/4"	40 1/4"	70 1/4"	5,500 lbs.	3/8" NPTF	1"	45	**128.00**	**128.00**
218-330	36"	1 1/4"	46 1/4"	82 1/4"	4,020 lbs.	3/8" NPTF	1"	56	**148.00**	**148.00**
218-331	48"	1 1/4"	58 1/4"	106 1/4"	2,410 lbs.	3/8" NPTF	1"	58	**191.00**	**190.00**
204-501		1 1/8"		Packing Kit					**19.00**	**-**
204-502		1 1/4"		Packing Kit					**19.00**	**-**
3" Bore • 2500 PSI										
218-333	4"	1 1/4"	14 1/4"	18 1/4"	17,670 lbs.	1/2" NPTF	1"	23	**72.00**	**67.00**
218-334	6"	1 1/4"	16 1/4"	22 1/4"	17,670 lbs.	1/2" NPTF	1"	24	**72.00**	**67.00**
218-335	8"	1 1/4"	18 1/4"	26 1/4"	17,670 lbs.	1/2" NPTF	1"	26	**73.00**	**68.00**
218-302	8" ASAE	1 1/4"	20 1/4"	28 1/4"	17,670 lbs.	1/2" NPTF	1"	29	**72.00**	**72.00**
218-336	10"	1 1/4"	20 1/4"	30 1/4"	17,670 lbs.	1/2" NPTF	1"	28	**83.00**	**76.00**
218-337	12"	1 1/4"	22 1/4"	34 1/4"	17,670 lbs.	1/2" NPTF	1"	29	**90.00**	**84.00**
218-338	14"	1 1/4"	24 1/4"	38 1/4"	17,670 lbs.	1/2" NPTF	1"	31	**94.00**	**87.00**
218-339	16"	1 1/4"	26 1/4"	42 1/4"	17,670 lbs.	1/2" NPTF	1"	34	**98.00**	**94.00**
218-340	16" ASAE	1 1/4"	31 1/2"	47 1/2"	17,670 lbs.	1/2" NPTF	1 1/4"	34	**109.00**	**96.00**
218-395	18"	1 1/4"	28 1/4"	46 1/4"	12,690 lbs.	SAE 8	1"	35	**102.00**	**94.00**
218-341	18"	1 1/4"	28 1/4"	46 1/4"	12,690 lbs.	1/2" NPTF	1"	35	**102.00**	**94.00**
218-342	20"	1 1/4"	30 1/4"	50 1/4"	10,780 lbs.	1/2" NPTF	1"	37	**114.00**	**106.00**
218-343	24"	1 1/4"	34 1/4"	58 1/4"	8,050 lbs.	1/2" NPTF	1"	41	**124.00**	**116.00**
218-344	30"	1 1/2"	40 1/4"	70 1/4"	11,240 lbs.	1/2" NPTF	1"	59	**148.00**	**138.00**
218-345	36"	1 1/2"	46 1/4"	82 1/4"	8,220 lbs.	1/2" NPTF	1"	68	**164.00**	**162.00**
218-346	48"	1 1/2"	58 1/4"	106 1/4"	4,950 lbs.	1/2" NPTF	1"	81	**208.00**	**205.00**
204-503		1 1/4"		Packing Kit					**20.00**	**-**
204-504		1 1/2"		Packing Kit					**20.00**	**-**
3 1/2" Bore • 2500 PSI										
218-347	4"	1 1/4"	14 1/4"	18 1/4"	24,050 lbs.	1/2" NPTF	1"	24	**75.00**	**71.00**
218-348	6"	1 1/4"	16 1/4"	22 1/4"	24,050 lbs.	1/2" NPTF	1"	26	**86.00**	**80.00**
218-349	8"	1 1/4"	18 1/4"	26 1/4"	24,050 lbs.	1/2" NPTF	1"	28	**87.00**	**81.00**
218-303	8" ASAE	1 1/4"	20 1/4"	28 1/4"	24,050 lbs.	1/2" NPTF	1"	32	**88.00**	**82.00**
218-350	10"	1 1/4"	20 1/4"	30 1/4"	24,050 lbs.	1/2" NPTF	1"	30	**94.00**	**87.00**
218-351	12"	1 1/4"	22 1/4"	34 1/4"	24,050 lbs.	1/2" NPTF	1"	33	**99.00**	**93.00**
218-352	14"	1 1/4"	24 1/4"	38 1/4"	18,730 lbs.	1/2" NPTF	1"	35	**107.00**	**101.00**
218-353	16"	1 1/4"	26 1/4"	42 1/4"	15,390 lbs.	1/2" NPTF	1"	36	**113.00**	**105.00**
218-354	16" ASAE	1 1/2"	31 1/2"	47 1/2"	22,050 lbs.	1/2" NPTF	1 1/4"	37	**123.00**	**114.00**
218-355	18"	1 1/4"	28 1/4"	46 1/4"	12,870 lbs.	1/2" NPTF	1"	40	**118.00**	**111.00**
218-356	20"	1 1/4"	30 1/4"	50 1/4"	10,920 lbs.	1/2" NPTF	1"	42	**126.00**	**117.00**
218-326	24"	1 1/2"	34 1/4"	58 1/4"	16,650 lbs.	1/2" NPTF	1"	51	**145.00**	**135.00**
218-327	30"	1 1/2"	40 1/4"	70 1/4"	11,480 lbs.	1/2" NPTF	1"	61	**193.00**	**180.00**
218-328	36"	1 1/2".	46 1/4"	82 1/4"	8,390 lbs.	1/2" NPTF	1"	69	**217.00**	**201.00**
218-357	48"	1 1/2".	58 1/4"	106 1/4"	5,040 lbs.	1/2" NPTF	1"	84	**244.00**	**229.00**
204-505		1 1/4"		Packing Kit					**21.00**	**-**
204-506		1 1/2"		Packing Kit					**21.00**	**-**
4" Bore • 2500 PSI										
218-360	8"	1 1/2"	18 1/4"	26 1/4"	31,410 lbs.	1/2" NPTF	1"	34	**105.00**	**98.00**
218-393	8" ASAE	1 1/2"	20 1/4"	28 1/4"	31,410 lbs.	SAE 8	1"	39	**112.00**	**104.00**
218-304	8" ASAE	1 1/2"	20 1/4"	28 1/4"	31,410 lbs.	1/2" NPTF	1"	39	**112.00**	**104.00**
218-361	10"	1 1/2"	20 1/4"	30 1/4"	31,410 lbs.	1/2" NPTF	1"	37	**123.00**	**114.00**
218-362	12"	1 1/2"	22 1/4"	34 1/4"	31,410 lbs.	1/2" NPTF	1"	40	**130.00**	**121.00**
218-363	14"	1 1/2"	24 1/4"	38 1/4"	31,410 lbs.	1/2" NPTF	1"	43	**140.00**	**131.00**
218-364	16"	1 1/2"	26 1/4"	42 1/4"	31,410 lbs.	1/2" NPTF	1"	45	**146.00**	**136.00**
218-365	16" ASAE	2"	31 1/2"	47 1/2"	31,410 lbs.	1/2" NPTF	1 1/4"	46	**138.00**	**129.00**
218-366	18"	1 1/2"	28 1/4"	46 1/4"	31,410 lbs.	1/2" NPTF	1"	49	**152.00**	**141.00**
218-367	20"	1 1/2"	30 1/4"	50 1/4"	22,600 lbs.	1/2" NPTF	1"	53	**158.00**	**148.00**
218-305	24"	1 1/2"	34 1/4"	58 1/4"	16,870 lbs.	1/2" NPTF	1"	61	**170.00**	**157.00**
218-332	24"	2"	34 1/4"	58 1/4"	31,410 lbs.	1/2" NPTF	1"	65	**180.00**	**170.00**
218-368	30"	2"	40 1/4"	70 1/4"	31,410 lbs.	1/2" NPTF	1"	87	**218.00**	**202.00**
218-369	36"	2"	46 1/4"	82 1/4"	25,890 lbs.	1/2" NPTF	1"	98	**244.00**	**228.00**
218-390	40"	2"	50 1/4"	90 1/4"	21,530 lbs.	1/2" NPTF	1"	101	**254.00**	**240.00**
218-370	48"	2"	58 1/4"	106 1/4"	15,560 lbs.	1/2" NPTF	1"	123	**265.00**	**248.00**
204-507		1 1/2"		Packing Kit					**23.00**	**-**
204-508		2"		Packing Kit					**23.00**	**-**

SPECIAL PRICING AVAILABLE ON LARGER VOLUME PURCHASES. CALL FOR A FREE QUOTE.

MIX & MATCH

Mix and match within this product group to obtain volume discounts.

Similar Items

Our **CHIEF TC** tie-rod cylinders on pages 4-5 feature a 2500 PSI rating.

Related Items

Hose Products	p.80-85
Stroke Controls	p.36
Directional Control Valves	p.62-67
Filters and Strainers	p.59-61
Pressure Gauges	p.58,61

Also Available

SAE Porting

Technical Information

Column Load is the maximum recommended push load (lb) to maintain at minimum a 2:1 column safety factor. The column load is a calculated value based on pin-pin mounting.

Common 3/8" NPT Adapters

470-007 06MP-08FPS STRAIGHT SWIVEL
470-003 06MP-06FPS STRAIGHT SWIVEL

Common 1/2" NPT Adapters

470-005 08MP-06FPS STRAIGHT SWIVEL
470-009 08MP-08FPS STRAIGHT SWIVEL
471-059 08MP-06FP REDUCER BUSHING

Fittings on page 82-83

hardy spicer
• HOSE • FITTINGS • DRIVESHAFTS

Hydraulic Hose

Extremely High Pressure — EFG6K Spiral Wire Hose - SAE 100R15

For Biodegradable Hydraulic Fluids

(Meets Flame Resistance Acceptance Designation "US. MSHA2G")

Recommended For: Extremely high pressure, high impulse applications such as hydrostatic transmissions. EFG6K is designed to meet all requirements of SAE 100R15 specifications and performance requirements of EN 856 (-6, -8, -10, and -12) and EN 8564SH (-12, -16, and -20). **Compatible with biodegradable hydraulic fluids like polyolester, polyglycol and vegetable oil as well as standard petroleum based fluids.** Available in 36M and 60M coils.

Tube: Black, oil-resistant synthetic rubber (Nitrile-Type C)

Reinforcement: Four (six for -20) alternating layers of spiraled, high tensile steel.

Cover: Black, oil resistant, synthetic rubber (Neoprene Type A). Blue stripe with gold print layline. Available with unique abrasion-resistant MegaTuff® cover.

Temperature Range: -40°C to +121°C

Fittings: (see crimp manuals for specifics):
GS Fittings up to -20
GSH Fittings for -24

SPECIFICATIONS

Hardy Spicer Part Number	Product No. (Bulk Carton)	Hose I.D. (inch)	Hose O.D. (inch)	Working Pressure (psi / bar)	Min. Burst Pressure (psi / bar)	Min. Bend Radius (inch / mm)	Approx. Bulk Carton Length (ft / m)
EFG6K-06	4651-1396	3/8	0.800	6000 / 413	24000 / 1654	5.000 / 127	100 / 30
EFG6K-08	4651-1371	1/2	0.950	6000 / 413	24000 / 1654	7.000 / 178	100 / 30
EFG6K-10	4651-1368	5/8	1.090	6000 / 413	24000 / 1654	8.000 / 203	100 / 30
EFG6K-12	4651-1288	3/4	1.240	6000 / 413	24000 / 1654	9.500 / 241	100 / 30
EFG6K-16	4651-1289	1	1.530	6000 / 413	24000 / 1654	12.000 / 305	100 / 30
EFG6K-20	4651-1290	1 1/4	1.970	6000 / 413	24000 / 1654	16.500 / 419	50 / 15
EFG6K-24	4651-1531	1 1/2	2.260	6000 / 413	24000 / 1654	10.000 / 254	50 / 15

MEGATUFF® COVER SPECIFICATIONS

Megatuff® hose lasts up to 300 times longer than standard hose during hose-to-hose amd hose-to-metal abrasion tests per ISO 6945

EFG6K-08-MTF ¥	4651-1609	1/2	0.950	6000 / 413	24000 / 1654	7.000 / 178	100 / 30
EFG6K-10-MTF ¥	4651-1416	5/8	1.090	6000 / 413	24000 / 1654	8.000 / 203	100 / 30
EFG6K-12-MTF ¥	4651-1606	3/4	1.240	6000 / 413	24000 / 1654	9.500 / 241	100 / 30
EFG6K-16-MTF ¥	4651-1604	1	1.530	6000 / 413	24000 / 1654	12.000 / 305	100 / 30
EFG6K-20-MTF ¥	4651-1601	1 1/4	1.970	6000 / 413	24000 / 1654	16.500 / 419	50 / 15

Extremely High Pressure — Global G6K Spiral Wire Hose - SAE 100R15

(Meets Flame Resistance Acceptance Designation "US. MSHA 2G")

Recommended For: Extremely high pressure, high impulse applications such as hydrostatic transmissions. G6K is designed to meet all requirements of SAE 100R15 specifications and performance requirements of EN 856 4SH (-24).

Revolutionary design: Makes designing and plumbing of extremely high-pressure hydraulic systems easy and efficient. 1-1/2" sizes are available in 40m and 60m continuous lengths.

Tube: Black, oil-resistant synthetic rubber (Nitrile-Type A)

Reinforcement: Six for -24 alternating layers of spiraled, high tensile steel.

Cover: Black, oil resistant, synthetic rubber (Neoprene). Dual gold stripe layline.

Temperature Range: -40°C to +121°C

Fittings: (see crimp manuals for specifics):
Permanent PCM Fittings
Skiving required for PCM fittings

SPECIFICATIONS

Hardy Spicer Part Number	Product No. (Bulk Carton)	Hose I.D. (inch)	Hose O.D. (inch)	Working Pressure (psi / bar)	Min. Burst Pressure (psi / bar)	Min. Bend Radius (inch / mm)	Approx. Bulk Carton Length (ft / m)
G6K-24 ^	4651-0673	1-1/2	2.260	6000 / 413	24000 / 1654	20.000 / 508	50 / 15

^ Available while stock lasts. Superseded to EFG6K-24
¥ Pricing & availability on request. Minimum purchase quantity may apply.

www.hardyspicer.com.au

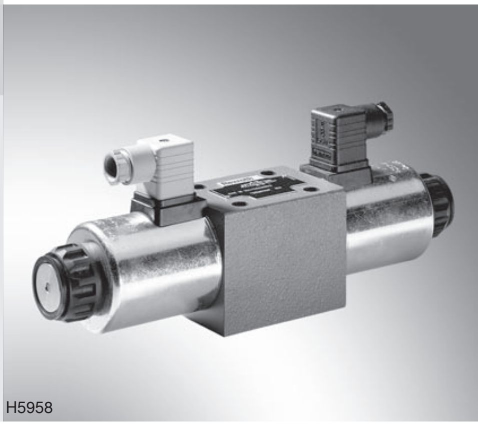
Document No:	HSHYDCAT
Issue:	5
Issue Date:	01/02/11

4/3, 4/2 and 3/2 directional valve with wet-pin AC or DC solenoids

RE 23327/08.08
Replaces: 02.03

Type WE

Size 10
Component series 3X; 4X
Maximum operating pressure 315 bar *[4569 psi]*
Maximum flow 120 l/min *[31.7 US gpm]*



H5958

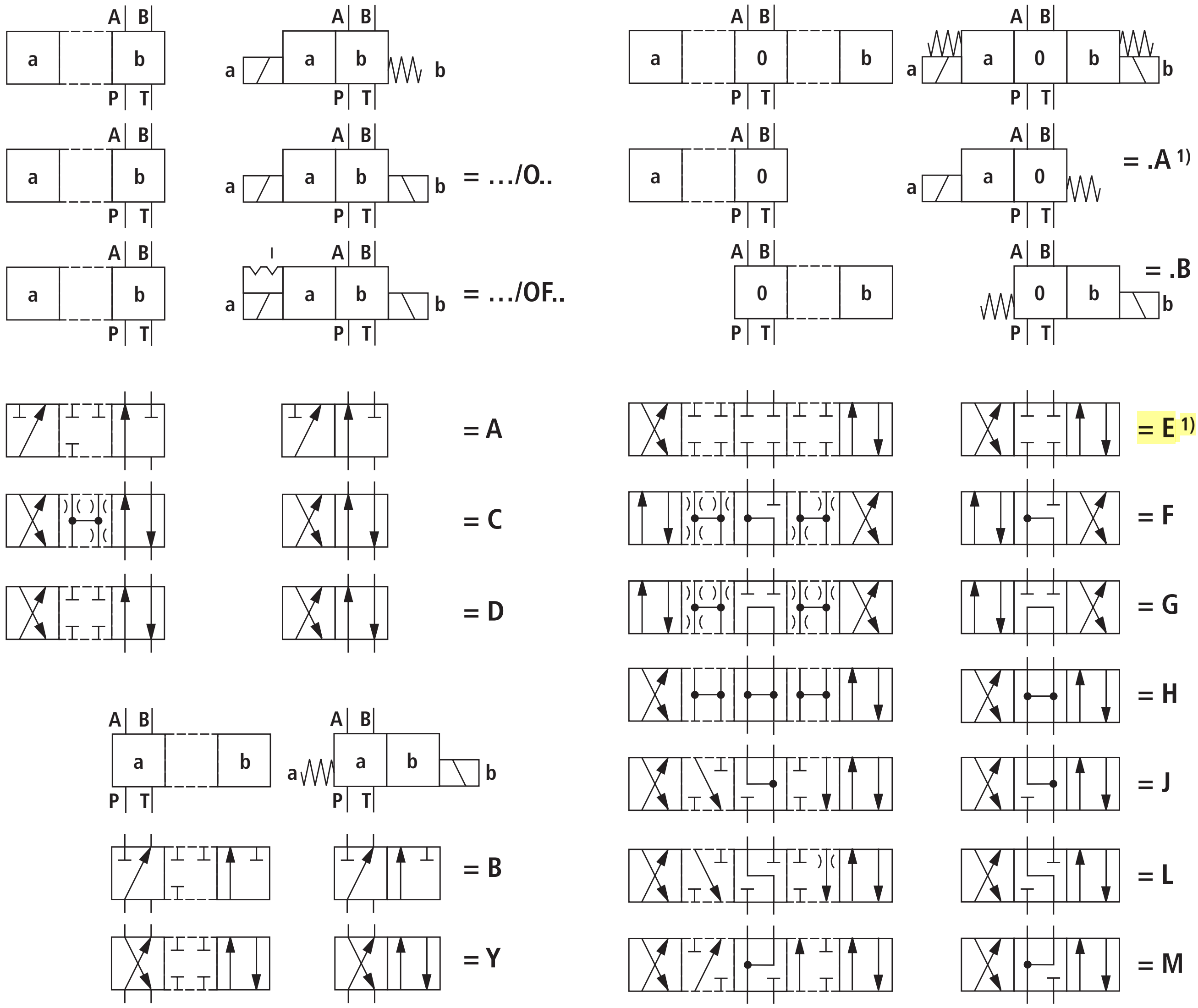
Table of contents

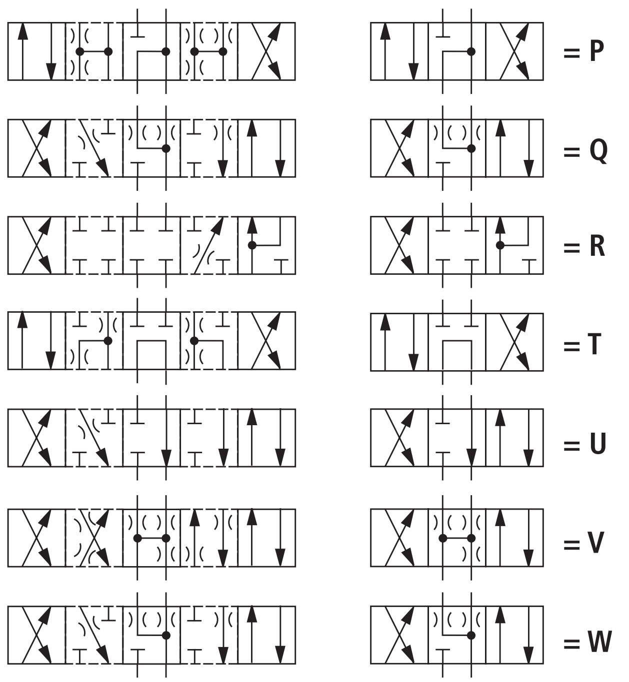
Features

- Direct operated directional spool valve with solenoid actuation in heavy-duty design
- Porting pattern to ISO 4401-05-04-0-05 and NFPA T3.5.1 R2-2002 D05
- Subplates, see data sheet RE 45054 (separate order)
- Wet-pin DC or AC solenoids with detachable coil
- Solenoid coil can be rotated 90°
- The pressure-tight chamber needs not to be opened for changing the coil
- Electrical connection as individual or central connection
- Manual override, optional
- Smoothly switching version, see RE 23183
- Inductive position switches and proximity sensors (contactless), see RE 24830
- For further electrical connections, see RE 08010

Notes on available spare parts:
www.boschrexroth.com/spc

Spool symbols





1) **Example:**
Spool symbol E with spool position "a", ordering code ..**EA**..

Technical data (for applications outside these parameters, please consult us!)

General

			Individual connection	Central connection
Weight	– Valve with one solenoid	kg *[lbs]*	4.4 *[9.7]* (DC); 3.6 *[7.9]* (AC)	4.3 *[9.5]* (DC); 3.5 *[7.7]* (AC)
	– Valve with two solenoids	kg *[lbs]*	6.0 *[13.2]* (DC); 4.4 *[9.7]* (AC)	5.9 *[13.0]* (DC); 4.3 *[9.5]* (AC)
Installation position			Optional	
Ambient temperature range		°C *[°F]*	–30 to +50 *[–22 to +122]* (NBR seals) –20 to +50 *[–4 to +122]* (FKM seals)	

Hydraulic

Maximum operating pressure	– Ports A, B, P	bar *[psi]*	315 *[4569]*
	– Port T	bar *[psi]*	210 *[3050]* (DC); 160 *[2320]* (AC) With symbols A and B, port T must be used as leakage oil port, if the operating pressure is higher than the tank pressure.
Maximum flow		l/min *[US gpm]*	120 *[31.7]*
Flow cross-section (spool position 0)	– Spool symbol V	mm^2 *[$inch^2$]*	11 *[0.017]* (A/B to T); 10,3 *[0.016]* (P to A/B)
	– Spool symbol W	mm^2 *[$inch^2$]*	2.5 *[0.004]* (A/B to T)
	– Spool symbol Q	mm^2 *[$inch^2$]*	5.5 *[0.009]* (A/B to T)
Hydraulic fluid [1]			Mineral oil (HL, HLP) to DIN 51524 [2]; fast bio-degradable hydraulic fluids to VDMA 24568 (see also RE 90221); HETG (rape seed oil) [2]; HEPG (polyglycols) [3]; HEES (synthetic esters) [3]; other hydraulic fluids on request
Hydraulic fluid temperature range		°C *[°F]*	–30 to +80 *[–22 to +176]* (NBR seals) –20 to +80 *[–4 to +176]* (FKM seals)
Viscosity range		mm^2/s *[SUS]*	2.8 to 500 *[35 to 2320]*
Permissible max. degree of contamination of the hydraulic fluid - cleanliness class to ISO 4406 (c)			Class 20/18/15 [4]

[1] The ignition temperature of the process and operating medium used must be higher than the maximum solenoid surface temperature.

[2] Suitable for NBR and FKM seals

[3] Suitable only for FKM seals

[4] The cleanliness classes specified for components must be adhered to in hydraulic systems. Effective filtration prevents malfunction and, at the same time, prolongs the service life of components.

For the selection of filters, see data sheets RE 50070, RE 50076, RE 50081, RE 50086, RE 50087 and RE 50088.

Technical data (for applications outside these parameters, please consult us!)

Electrical

Type of voltage			DC voltage	AC voltage 50/60 Hz
Available voltages [5] (Ordering code for AC solenoids, see below)		V	12, 24, 42, 60, 96, 110, 180, 205, 220	42, 110, 230
Voltage tolerance (nominal voltage)		%	±10	
Power consumption		W	35	–
Holding power		VA	–	90
Making capacity		VA	–	550
Duty cycle		%	100	
Switching time to ISO 6403	– ON	ms	45 to 60	15 to 25
	– OFF	ms	20 to 30	20 to 30
Maximum switching frequency		1/h	15000	7200
Maximum coil temperature [6]		°C *[°F]*	150 *[302]*	180 *[356]*
Type of protection to DIN EN 60529			IP 65 with mating connector mounted and locked	
Insulation class VDE 0580			F	H
Electrical protection			Each solenoid must be protected separately with a suitable fuse with tripping characteristic K (inductive loads).	
Behavior in the event of a fault (solenoid is not enabled)			The solenoid surface temperature can be exceeded.	

[5] Special voltages on request

[6] Due to the surface temperatures of the solenoid coils, observe standards ISO 13732-1 and EN 982!

Notes!

- The manual override can only be operated up to a tank pressure of ca. 50 bar. Avoid damage to the bore for the manual override! (Special tool for operation, separate order, Material no. **R900024943**). When the manual override is blocked, the operation of the opposite solenoid must be ruled out!
- The simultaneous operation of the solenoids must be ruled out!

Note!

AC solenoids can be used for 2 or 3 mains;
e.g. solenoid type **W110** for:
110 V, 50 Hz; 110 V, 60 Hz; 120 V, 60 Hz

Ordering code	Mains
W42	42 V, 50 Hz 42 V, 60 Hz
W110	110 V, 50 Hz 110 V, 60 Hz 120 V, 60 Hz
W230	230 V, 50 Hz 230 V, 60 Hz

When establishing the electrical connection, properly connect the protective earth conductor (PE ⏚).

Laser Photoelectric Sensor with Built-in Amplifier
E3Z-LT/LR/LL

CSM_E3Z-LT_LR_LL_DS_E_4_2

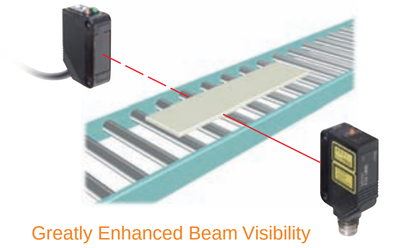
The Most Compact Laser Sensor
The Most Reliable E3Z

- Excellent quality of E3Z such as the maximum ambient operating temperate of 55°C, IP67 degree of protection is inherited.
- Safe and reliable class 1 (JIS/IEC) laser used
- Excellent detection performance supporting long distance and low hysteresis
- Complete Compliance with RoHS
- Spot diameters can be customized.
  Increasing the spot diameter makes optical axis adjustment easier.

⚠ Be sure to read *Safety Precautions* on page 9.

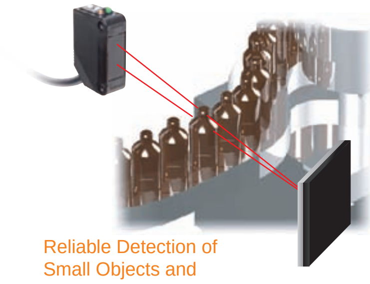
Applications

Detect the sides of large tiles.



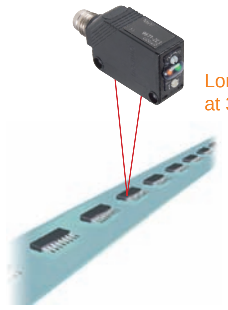
Greatly Enhanced Beam Visibility
for Easier Optical Axis Adjustment of Sensors

Count bottles.



Reliable Detection of
Small Objects and
Narrow Gaps with the Small Spot

Detect chip components on tape.



Long-distance Sensing
at 300 mm (White Paper)

Detect protruding straws.

A Low Black/White Error for
Applications with Mixed Colors

Ordering Information

Sensors (Refer to *Dimensions* on page 11.)

Red light

Sensing method	Appearance	Connection method	Response time	Sensing distance	Model	
					NPN output	PNP output
Through-beam (Emitter + Receiver) *4		Pre-wired (2 m)*3	1 ms	60 m	E3Z-LT61 2M	E3Z-LT81 2M
		Connector (M8, 4 pins)			E3Z-LT66	E3Z-LT86
Retro-reflective with MSR function	*1	Pre-wired (2 m)*3		*2 15 m (300 mm) (Using E39-R1); 7 m (200 mm) (Using E39-R12); 7 m (200 mm) (Using E39-R6)	E3Z-LR61 2M	E3Z-LR81 2M
		Connector (M8, 4 pins)			E3Z-LR66	E3Z-LR86
Distance-settable (BGS Models)		Pre-wired (2 m)*3		20 to 40 mm (Min. distance set); 20 to 300 mm (Max. distance set)	E3Z-LL61 2M	E3Z-LL81 2M
		Connector (M8, 4 pins)			E3Z-LL66	E3Z-LL86
		Pre-wired (2 m)*3	0.5 ms	25 to 40 mm (Min. distance set); 25 to 300 mm (Max. distance set)	E3Z-LL63 2M	E3Z-LL83 2M
		Connector (M8, 4 pins)			E3Z-LL68	E3Z-LL88

*1. The Reflector is sold separately. Select the Reflector model most suited to the application.
*2. Values in parentheses indicate the minimum required distance between the Sensor and Reflector.
*3. Pre-wired Models with a 0.5-m cable are also available for these products. When ordering, specify the cable length by adding “0.5M” to the end of the model number (e.g., E3Z-LT61 0.5M).
M12 Pre-wired Connector Models are also available. When ordering, add “-M1J” to the end of the model number (e.g., E3Z-LT61-M1J). The cable is 0.3 m long.
Also, the following connection forms can be manufactured. Ask your OMRON representative for details.
• Pre-wired Models with 1-m or 5-m cables
• Pre-wired Connector Models with M8 4-pin connectors or M8 3-pin connectors.
*4. The model number of the Emitter is expressed by adding an "L" to the set model number in the table. Example: E3Z-LT61-L 2M
The model number of the receiver is expressed by adding a "D" to the set model number in the table. Example: E3Z-LT61-D 2M
Orders for individual Emitters and Receivers are accepted. (Modifications are required for some models.)

Accessories

Slits (for E3Z-LT☐☐) (Refer to *Dimensions* on page 14.)

Slit width	Sensing distance	Minimum detectable object (typical)	Model	Contents
0.5 mm dia.	3 m	0.1 mm dia.	**E39-S65A**	One set (contains Slits for both the Emitter and Receiver)

Reflectors (for E3Z-LR☐☐) (Refer to *Dimensions* on page 14.)

Name	Sensing distance (typical)	Model	Remarks
Reflector	15 m (300 mm)	**E39-R1**	• Retro-reflective models are not provided with Reflectors. • Separate the Sensor and the Reflector by at least the distance given in parentheses. • The MSR function is enabled.
	7 m (200 mm)	**E39-R12**	
	7 m (200 mm)	**E39-R6**	

Ratings and Specifications

Item		Through-beam	Retro-reflective with MSR function	Distance-settable (BGS models)	
Response		Standard response			High-speed response
Model	NPN output	E3Z-LT61/-LT66	E3Z-LR61/-LR66	E3Z-LL61/-LL66	E3Z-LL63/-LL68
	PNP output	E3Z-LT81/-LT86	E3Z-LR81/-LR86	E3Z-LL81/-LL86	E3Z-LL83/-LL88
Sensing distance		60 m	0.3 to 15 m (when using E39-R1) 0.2 to 7 m (when using E39-R12) 0.2 to 7 m (when using E39-R6)	White paper (100 × 100 mm): 20 to 300 mm Black paper (100 × 100 mm): 20 to 160 mm	White paper (100 × 100 mm): 25 to 300 mm Black paper (100 × 100 mm): 25 to 100 mm
Set distance range		---		White paper (100 × 100 mm): 40 to 300 mm Black paper (100 × 100 mm): 40 to 160 mm	White paper (100 × 100 mm): 40 to 300 mm Black paper (100 × 100 mm): 40 to 100 mm
Spot diameter (typical)		5-mm dia. at 3 m		0.5-mm dia. at 300 mm	
Standard sensing object		Opaque: 12-mm dia. min.	Opaque: 75-mm dia. min.	---	
Minimum detectable object (typical)		6-mm-dia. opaque object at 3 m		0.2-mm-dia. stainless-steel pin gauge at 300 mm	
Differential travel		---		5% max. of set distance	
Black/white error		---		5% at 160 mm	5% at 100 mm
Directional angle		Receiver: 3 to 15°	---		
Light source (wavelength)		Red LD (655 nm), JIS CLass 1, IEC Class 1, FDA Class II			
Power supply voltage		12 to 24 VDC±10%, ripple (p-p): 10% max.			
Current consumption		35 mA (Emitter 15 mA, Receiver 20 mA)	30 mA max.		
Control output		Load power supply voltage: 26.4 VDC max., Load current: 100 mA max., Open collector output			
Residual output voltage		Load current of less than 10 mA: 1 V max. Load current of 10 to 100 mA: 2 V max.			
Output mode switching		Switch to change between light-ON and dark-ON			
Protection circuits		Reversed power supply polarity protection, Output short-circuit protection, and Reversed output polarity protection	Reversed power supply polarity protection, Output short-circuit protection, Mutual interference prevention, and Reversed output polarity protection		
Response time		Operate or reset: 1 ms max.			Operate or reset: 0.5 ms max.
Sensitivity adjustment		One-turn adjuster		Five-turn endless adjuster	
Ambient illumination (Receiver side)		Incandescent lamp: 3,000 lx max. Sunlight: 10,000 lx max.			
Ambient temperature range		Operating: –10 to 55°C, Storage: –25 to 70°C (with no icing or condensation)			
Ambient humidity range		Operating: 35% to 85%, Storage: 35% to 95% (with no icing or condensation)			
Insulation resistance		20 MΩ min. at 500 VDC			
Dielectric strength		1,000 VAC, 50/60 Hz for 1 min			
Vibration resistance		Destruction: 10 to 55 Hz, 1.5-mm double amplitude for 2 hours each in X, Y, and Z directions			
Shock resistance		Destruction: 500 m/s² 3 times each in X, Y, and Z directions			
Degree of protection		IP67 (IEC 60529)			
Connection method		Pre-wired cable (standard length: 2 m): E3Z-L□□1/-L□□3 Standard M8 Connector: E3Z-L□□6/-L□□8			
Indicator		Operation indicator (orange) Stability indicator (green) Emitter for Through-bream Models has power indicator (orange) only.			
Weight (packed state)	Pre-wired cable (2 m)	Approx. 120 g	Approx. 65 g		
	Standard Connector	Approx. 30 g	Approx. 20 g		
Material	Case	PBT (polybutylene terephthalate)			
	Lens	Modified polyarylate resin	Methacrylic resin	Modified polyarylate resin	
Accessories		Instruction manual (Neither Reflectors nor Mounting Brackets are provided with any of the above models.)			

Standard types

Tank mounted return line filter, filter rating 3 µm, 10 µm and 20 µm

Filter type	Flow in l/min *[gpm]* with ν = 30 mm²/s *[142 SUS]* and Δp = 0.5 bar *[7.25 psi]*	Port/Material no.			
10TEN0040-H20XLA00-P2,2-M-…	62 *[16.4]*	..R3	**R928041199**	..U4	**R928041200**
10TEN0063-H20XLA00-P2,2-M-…	80 *[21.1]*	..R4	**R928041201**	..U9	**R928041202**
10TEN0100-H20XLA00-P2,2-M-…	95 *[25.1]*	..R4	**R928041203**	..U9	**R928041204**
10TEN0160-H20XLA00-P2,2-M-…	260 *[68.7]*	..R5	**R928041205**	..S5	**R928041206**
10TEN0250-H20XLA00-P2,2-M-…	320 *[84.5]*	..R6	**R928041208**	..S6	**R928041209**
10TEN0400-H20XLA00-P2,2-M-…	560 *[147.9]*	..S8	**R928041210**	..S9	**R928041211**
10TEN0630-H20XLA00-P2,2-M-…	630 *[166.4]*	..S9	**R928041223**	..S8	**R928041224**
10TEN1000-H20XLA00-P2,2-M-…	1270 *[335.5]*	..S10	**R928041225**	..S12	**R928041226**
10TE2000-H20XLA00-P2,2-M-…	1600 *[422.7]*	..S12	**R928041228**	..S10	**R928041229**
10TE2500-H20XLA00-P2,2-M-…	1680 *[443.8]*	..S12	**R928041230**	..S10	**R928041231**
10TEN0040-H10XLA00-P2,2-M-…	43 *[11.3]*	..R3	**R928041271**	..U4	**R928041272**
10TEN0063-H10XLA00-P2,2-M-…	62 *[16.4]*	..R4	**R928041273**	..U9	**R928041274**
10TEN0100-H10XLA00-P2,2-M-…	80 *[21.1]*	..R4	**R928041275**	..U9	**R928041276**
10TEN0160-H10XLA00-P2,2-M-…	190 *[50.2]*	..R5	**R928041277**	..S5	**R928041278**
10TEN0250-H10XLA00-P2,2-M-…	260 *[68.7]*	..R6	**R928041279**	..S6	**R928041280**
10TEN0400-H10XLA00-P2,2-M-…	460 *[121.5]*	..S8	**R928041281**	..S9	**R928041282**
10TEN0630-H10XLA00-P2,2-M-…	560 *[147.9]*	..S9	**R928041283**	..S8	**R928041284**
10TEN1000-H10XLA00-P2,2-M-…	970 *[256.2]*	..S10	**R928041285**	..S12	**R928041286**
10TE2000-H10XLA00-P2,2-M-…	1350 *[356.6]*	..S12	**R928041288**	..S10	**R928041289**
10TE2500-H10XLA00-P2,2-M-…	1450 *[383.0]*	..S12	**R928041290**	..S10	**R928041291**
10TEN0040-H3XLA00-P2,2-M-…	23 *[6.1]*	..R3	**R928041292**	..U4	**R928041293**
10TEN0063-H3XLA00-P2,2-M-…	35 *[9.2]*	..R4	**R928041294**	..U9	**R928041295**
10TEN0100-H3XLA00-P2,2-M-…	52 *[13.7]*	..R4	**R928041296**	..U9	**R928041297**
10TEN0160-H3XLA00-P2,2-M-…	105 *[27.7]*	..R5	**R928041298**	..S5	**R928041299**
10TEN0250-H3XLA00-P2,2-M-…	160 *[42.3]*	..R6	**R928041300**	..S6	**R928041301**
10TEN0400-H3XLA00-P2,2-M-…	290 *[76.6]*	..S8	**R928041302**	..S9	**R928041303**
10TEN0630-H3XLA00-P2,2-M-…	410 *[108.3]*	..S9	**R928041304**	..S8	**R928041305**
10TEN1000-H3XLA00-P2,2-M-…	560 *[147.9]*	..S10	**R928041306**	..S12	**R928041307**
10TE2000-H3XLA00-P2,2-M-…	900 *[237.7]*	..S12	**R928041308**	..S10	**R928041309**
10TE2500-H3XLA00-P2,2-M-…	1100 *[290.6]*	..S12	**R928041310**	..S10	**R928041311**

GENERAL FEATURES

p_1 Max continuous pressure	p_2 Max peak pressure

Type	Displacement		Max. outlet pressure				Max. outlet Δp		Speed		Flow per section		Flow per section	
			p_1	p_2	p_1	p_2	between sections		min.	max.	min.	max.	min.	max.
	cm^3/rev	cu.in./rev	bar	bar	psi	psi	bar	psi	min^{-1}		l/min		gpm	
2DRE - 3.2*	3.20	0.19	250	280	3600	4000	50	725	1250	4000	4.21	13.47	1.11	3.55
2DRE - 3.9*	3.90	0.24	250	280	3600	4000	50	725	1250	4000	5.13	16.42	1.35	4.32
2DRE - 4,5	4.60	0.27	250	280	3600	4000	50	725	1250	3900	6.05	18.88	1.59	4.97
2DRE - 6,2	6.50	0.40	250	280	3600	4000	50	725	1250	3750	8.55	25.66	2.25	6.75
2DRE - 8,3	8.20	0.50	250	280	3600	4000	50	725	1200	3600	10.36	31.07	2.73	8.18
2DRE - 10,5*	10.60	0.65	250	280	3600	4000	50	725	1200	3500	13.39	39.05	3.52	10.28
2DRE - 11,3	11.50	0.68	250	280	3600	4000	50	725	1200	3500	14.53	42.37	3.82	11.15
2DRE - 12,5*	12.70	0.77	250	280	3600	4000	50	725	1200	3400	16.04	45.45	4.22	11.96
2DRE - 13,8	13.80	0.84	250	280	3600	4000	50	725	1200	3400	17.43	49.39	4.59	13.00
2DRE - 16	16.60	1.01	250	280	3600	4000	50	725	1100	3200	19.22	55.92	5.06	14.71
2DRE - 19	19.40	1.15	220	240	3150	3450	50	725	1100	3200	22.46	65.35	5.91	17.20
2DRE - 22,5	22.90	1.37	220	240	3150	3450	50	725	1100	3000	26.52	72.32	6.98	19.03
2DRE - 26	25.80	1.58	200	220	2900	3150	50	725	1100	2850	29.87	77.40	7.86	20.37
2DRE - 30*	30.10	1.84	200	220	2900	3150	50	725	1100	2700	34.85	85.55	9.17	22.51

These displacements are not commonly in production, for this reason we can sell them only for quantity.

Max. flow for each inlet section
When the inlet flow exceed the 80 l/min, please get in touch with our technical dept.

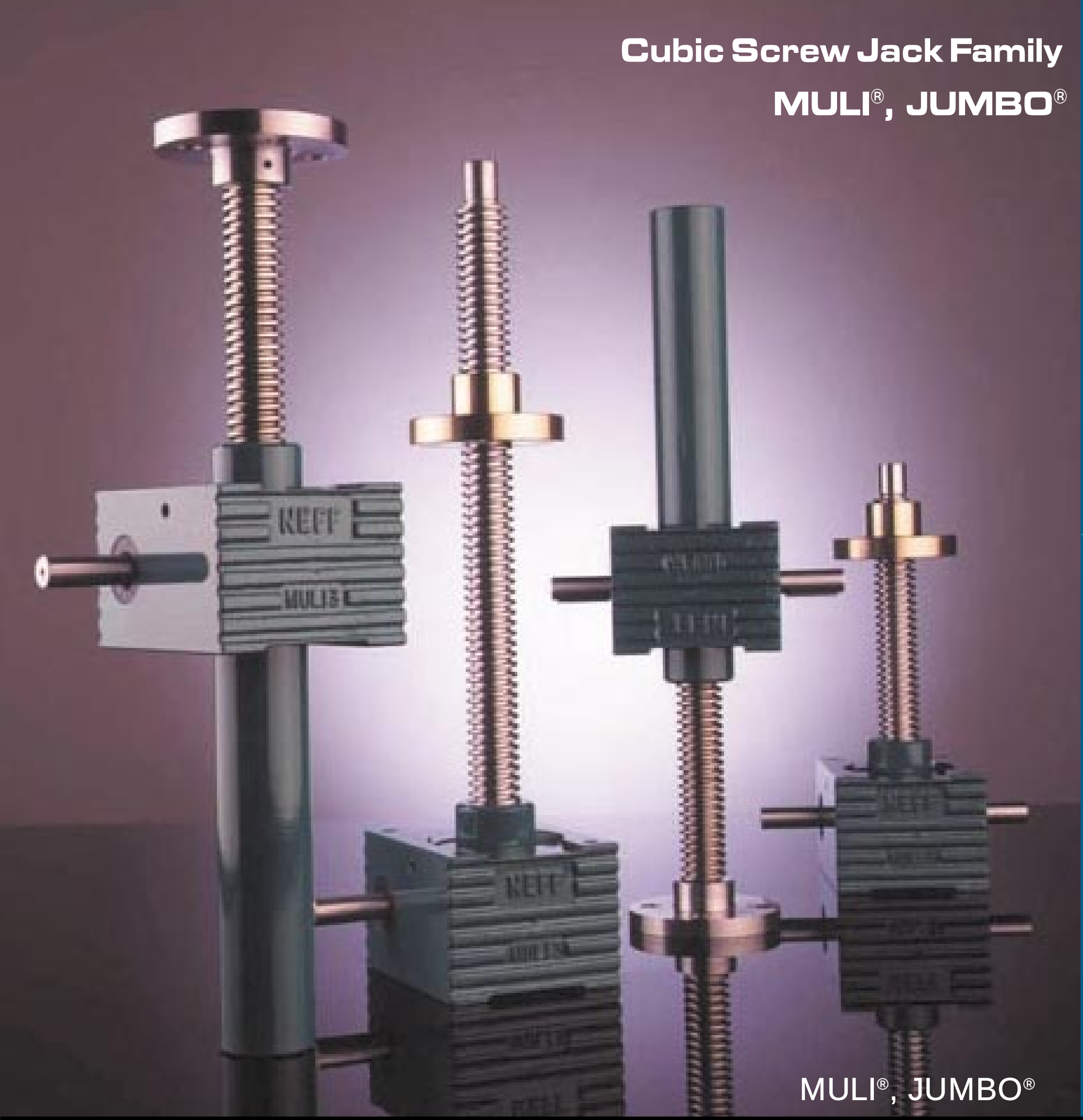
- When the flow divider is used as pressure intensifier, the pressure between sections can be higher.
- For different working conditions, please get in touch with our technical department.

WORKING CONDITIONS

- Minimum operating fluid viscosity	12 mm^2 / sec
- Max starting viscosity	800 mm^2 / sec
- Suggested fluid viscosity range	17 - 65 mm^2 / sec
- Fluid operating temperature range	-15 to +85 °C
- Hydraulic fluid	mineral oil

FILTRATION INDEX

Working pressure	**> 200 bar / *2900 psi***	**< 200 bar / *2900 psi***
Contamination class NAS 1638	9	10
Contamination class ISO 4406	18/15	19/16
Achieved with filter $ß_x$ =75	15 µm	25 µm



Lifting >> Tilting >> Lowering >> Feeding

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click for Trapezoidal Rod/Screwjacks page index

Technical data

Trapezoidal screws and ball screws

Trapezoidal screws

		MULI 1	MULI 2	MULI 3	MULI 4	MULI 5	JUMBO 1	JUMBO 2	JUMBO 3	JUMBO 4	JUMBO 5
Maximum lifting capacity [kN][2]		5	10	25	50	100	150	200	250	350	500
Maximum lifting capacity [tons]		0.6	1.1	2.8	5.6	11.2	16.8	22.4	28.0	39.2	56.0
Screw diameter and pitch [mm]		18 x 4	20 x 4	30 x 6	40 x 7	55 x 9	60 x 9	70 x 10	80 x 10	100 x 10	120 x 14
Stroke in mm per full turn	Ratio H[1]	1	1	1	1	1	1	1	1	1	1
of the worm shaft	Ratio L[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Gear ratio	Ratio H[1]	4:1	4:1	6:1	7:1	9:1	9:1	10:1	10:1	10:1	14:1
	Ratio L[1]	16:1	16:1	24:1	28:1	36:1	36:1	40:1	40:1	40:1	56:1
Efficiency [%][3]	Ratio H[1]	31	29	29	26	24	23	22	20	19	19
	Ratio L[1]	25	23	23	21	19	18	17	15	15	15
Weight [kg] (zero stroke)		1.2	2.1	6.0	17.0	32.0	41.0	57.0	57.0	85.0	160.0
Weight [kg per 100 mm stroke]		0.26	0.42	1.14	1.67	3.04	3.1	4.45	6.13	7.9	11.5
Idling torque [Nm]	H	0.04	0.11	0.15	0.35	0.84	0.88	1.28	1.32	1.62	1.98
	L	0.03	0.10	0.12	0.25	0.51	0.57	0.92	0.97	1.10	1.42

Ball screws

		MULI 1	MULI 2	MULI 3	MULI 4		MULI 5	JUMBO 3
Maximum lifting capacity [kN][2]		5	10	12.5	22	42	65	78
Maximum lifting capacity [tons]		0.6	1.1	1.4	2.5	4.7	7.3	8.7
Screw diameter and pitch [mm]		1605	2005	2505	4005	4010	5010	8010
Stroke in mm per full turn	Ratio H[1]	1.25	1.25	0.83	0.71	1.43	1.1	1
of the worm shaft	Ratio L[1]	0.31	0.31	0.21	0.18	0.36	0.28	0.25
Gear ratio	Ratio H[1]	4:1	4:1	6:1	7:1		9:1	10:1
	Ratio L[1]	16:1	16:1	24:1	28:1		36:1	40:1
Efficiency [%][3]	Ratio H[1]	57	56	55	53	56	47	45
	Ratio L[1]	46	44	43	43	45	37	34
Weight [kg] (zero stroke)		1.3	2.3	7.0	19.0		35.0	63.0
Weight [kg per 100 mm stroke]		0.26	0.42	1.14	1.67		3.04	6.13
Idling torque [Nm]	H	0.04	0.11	0.15	0.35		0.84	1.32
	L	0.03	0.10	0.12	0.25		0.51	0.97

1) H = High speed, L = Low speed

2) Depending on speed of travel, operating hours, etc.

3) The specified efficiencies are average values

Precision Potentiometric Output
Ranges: 0-3 to 0-30 inches [0-75 to 0-750 mm]
5K – 10K ohms • IP65

CLWG

CE

Specification Summary:

GENERAL

Full Stroke Ranges .... 0-3 to 0-30 in. (0-75 to 0-750 mm)
Output Signal .... voltage divider (potentiometer)
Linearity .... ± 0.04 to 0.1% full stroke, see ordercode
Repeatability .... < 0.01 mm
Resolution .... essentially infinite
Life Expectancy .... 50 million cycles
Enclosure Material .... aluminum
Sensor .... conductive plastic linear potentiometer
Operating Speed .... 200 inches (5 M) per second, max.

ELECTRICAL

Input Resistance .... 5K to 10K ohms (±20%), see ordercode
Recommended Maximum Input Voltage .... 25-30 V(AC or DC)
Recommended Operating Wiper Current .... ≤ 1 µA

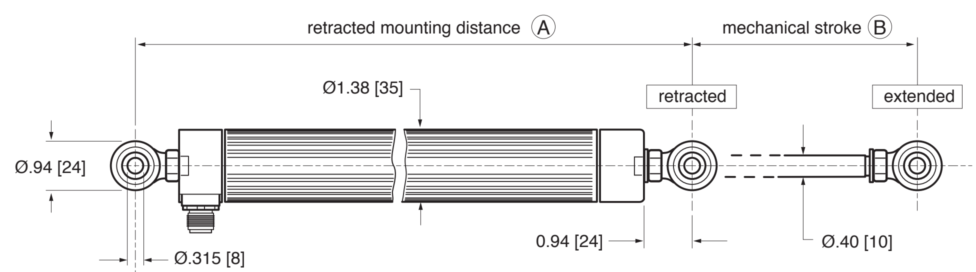
ENVIRONMENTAL

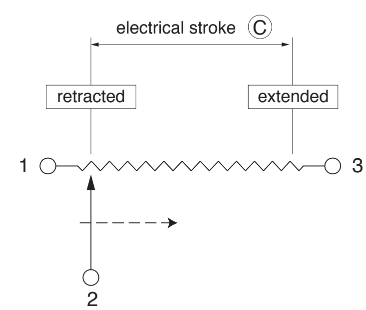
Enclosure Design IP65
Operating Temperature .... -22º to 212ºF
Vibration .... up to 10 G's to 2000 Hz maximum

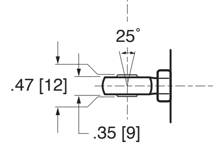
Developed specifically for a wide range of demanding applications, Celesco's CL series position transducers offer unrivalled performance in terms of accuracy, repeatability, life expectancy and ease of mounting. Such applications include industrial automation, automotive and robotics.

The CLWG uses a twin-bearing actuating rod, backlash-free pivot heads and a superior wiper system to provide outstanding linearity and performance.

Outline Drawing







All DIMENSIONS ARE IN INCHES [MM]

Measurement Range	3 75	4 100	6 150	9 225	12 300	14 360	18 450	20 500	24 600	30 750	in mm
Ⓐ	9.72 247	10.75 273	12.72 323	15.75 400	18.74 476	21.69 551	26.18 665	28.74 730	33.70 856	40.94 1040	in mm
Ⓑ	3.11 79	4.13 105	6.10 155	9.09 231	12.09 307	14.49 368	18.11 460	20.08 510	24.09 612	30.07 764	± 0.02 in ± 2 mm
Ⓒ	2.99 76	4.01 102	5.98 152	8.98 228	11.97 304	14.41 366	17.99 457	20.00 508	24.02 610	30.00 762	in mm

celesco
celesco.com • info@celesco.com

Celesco Transducer Products, Inc.
20630 Plummer Street • Chatsworth, CA 91311
tel: 800.423.5483 • +1.818.701.2750 • fax: +1.818.701.2799

Ordering Information:

Model Number:

CLWG - ______ - ______

order code: Ⓡ Ⓐ

Sample Model Number:

CLWG - 75 - NC4

Ⓡ range: 3 inches [75 mm]

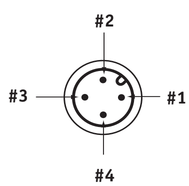
Ⓐ electrical connection: 4-pin, 90° M12 cordset

Full Stroke Range:

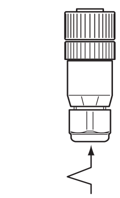
Ⓡ order code:	75	100	150	225	300	360	450	500	600	750
measurement range, in. [mm]:	3[75]	4[100]	6[150]	9[225]	12[300]	14[360]	18[450]	20[500]	24[600]	30[750]
resistance, (±20%):	3K	3K	5K	5K	5K	5K	5K	5K	5K	10K
linearity, %:	0.1%	0.1%	0.08%	0.07%	0.06%	0.05%	0.05%	0.05%	0.05%	0.04%

Electrical Connection:

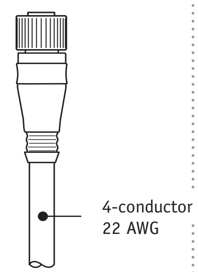
Ⓐ order code:	blank	MC4	SC4	NC4
	4-pin M12 connector *(no mating plug supplied)*	4-pin M12 connector w/ mating plug	4-pin M12 connector and 4 meter length cordset w/straight mating plug	4-pin M12 connector and 4 meter length cordset w/90° mating plug

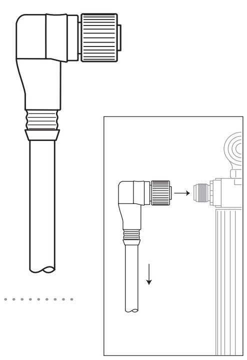


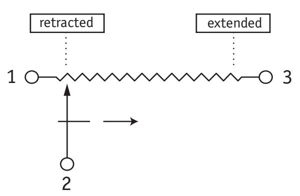
male receptacle
(contact view)



0.13" - 0.20" OD Cable
(4mm - 6mm)







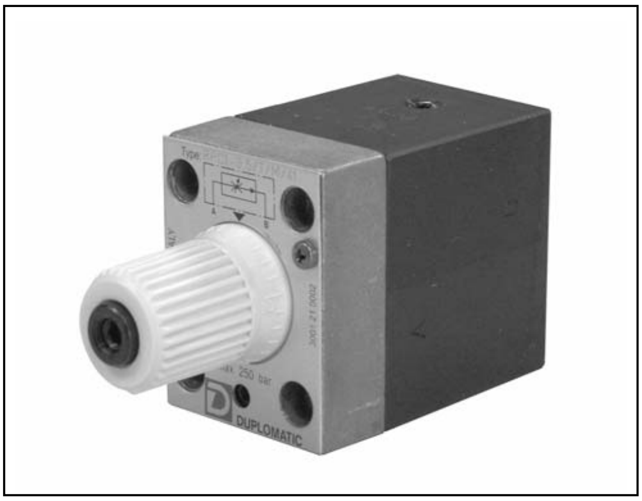
Pin#	Cordset Wire Color
1	BROWN
2	WHITE
3	BLUE
4	BLACK

version: **3.1** last updated: **April 9, 2009**

RPC1

PRESSURE AND TEMPERATURE COMPENSATED FLOW CONTROL VALVE

SERIES 41

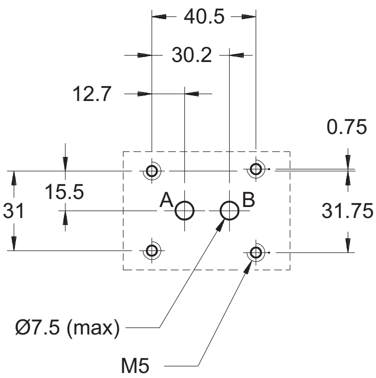


SUBPLATE MOUNTING
ISO 6263-03 (CETOP 03)

p max **250** bar
Q max (see table of performances)

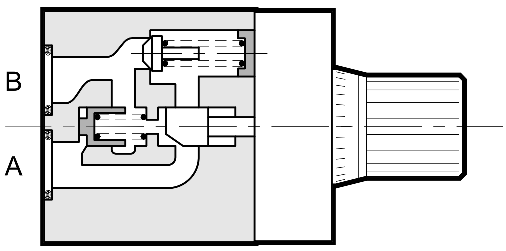
MOUNTING INTERFACE

ISO 6263-03-03-*-97
(CETOP 4.5.2-2-03-250)



NOTE: The RPCED1 mounting interface, with CETOP 03 holes, must not have P and T ports or must have the 0113388 subplate (see paragraph 9)

OPERATING PRINCIPLE

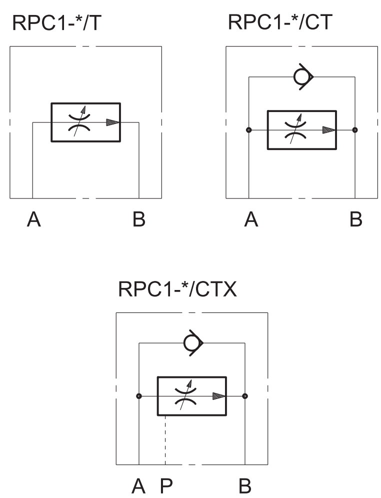


— The RPC1 valve is a pressure and temperature compensated flow control valve.
— The flow is adjusted by a calibrated knob that modulates the opening of the control gap and can be locked in any adjustment position. Adjustment is made with three turns, and upon request one-turn adjustment, RPC1*/M, is available.
— It is available in seven different flow rate adjustment ranges from 0,5 l/min up to 30 l/min.

PERFORMANCE RATINGS (obtained with mineral oil with viscosity of 36 cSt at 50°C)

Maximum operating pressure Minimum pressure difference between A and B Check valve cracking pressure	bar	250 10 0,5
Maximum controlled flow rates Minimum controlled flow rate (for 0,5-1 and 4 l/min) Maximum flow rate in free flow direction	l/min	0,5-1-4-10-16-22-30 0,025 40
Ambient temperature range	°C	-20 / +50
Fluid temperature range	°C	-20 / +80
Fluid viscosity range	cSt	10 ÷ 400
Fluid contamination degree Fluid contamination degree for flows < 0,5 l/min	According to ISO 4406:1999 class 20/18/15 According to ISO 4406:1999 class 18/16/13	
Recommended viscosity	cSt	25
Mass	kg	1,3
Number of adjustment knob turns	RPC1 RPC1-*/M	3 1

HYDRAULIC SYMBOLS



1 - IDENTIFICATION CODE

R P C 1 - [ ] / [ ] T [ ] / [ ] / 41 / [ ]

Pressure compensated flow control valve

Size ISO 6263-03 (CETOP 03)

Controlled flow
0,5 = 0,5 l/min
1 = 1 l/min
4 = 4 l/min
10 = 10 l/min
16 = 16 l/min
22 = 22 l/min
30 = 30 l/min

C = incorporated check valve
(omit if not required)

Temperature compensation

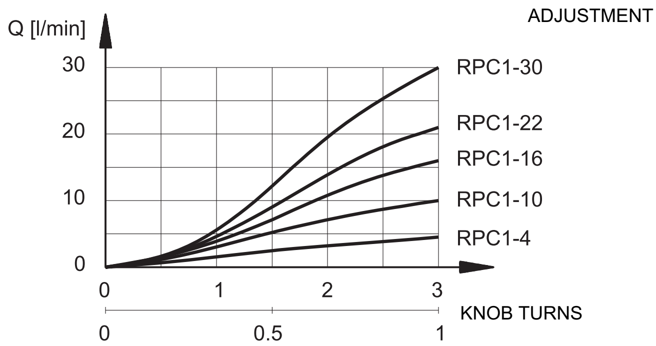
X = with speed anti-jump port P, available only in the check valve version
(Omit if not required)

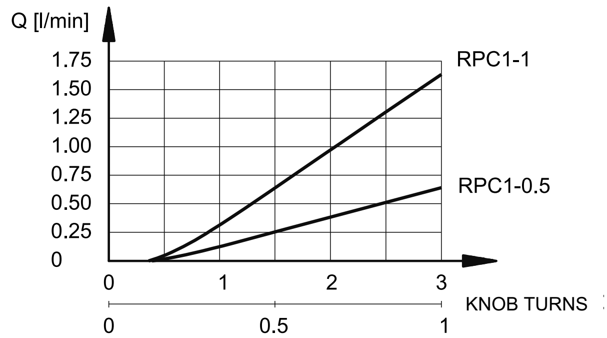
M = single-turn adjustment knob
(omit for three-turn adjustment)

Series No. (the overall and mounting dimensions remain unchanged from 40 to 49)

Seals: omit for mineral oils
V = viton for special fluids

2 - CHARACTERISTIC CURVES (values obtained with viscosity of 36 cSt at 50°C)





3 - HYDRAULIC FLUIDS

Use mineral oil-based hydraulic fluids HL or HM type, according to ISO 6743-4. For these fluids, use NBR seals. For fluids HFDR type (phosphate esters) use FPM seals (code V). For the use of other kinds of fluid such as HFA, HFB, HFC, please consult our technical department. Using fluids at temperatures higher than 80 °C causes a faster degradation of the fluid and of the seals characteristics.
The fluid must be preserved in its physical and chemical characteristics.

4 - PRESSURE COMPENSATION

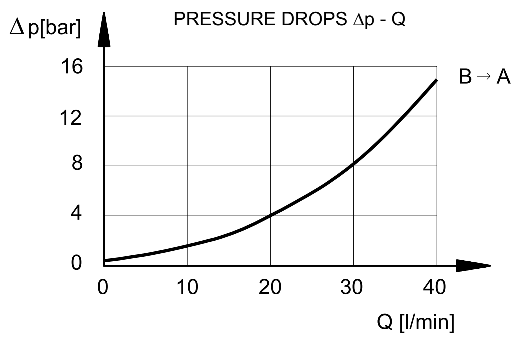
Two throttles in series are in the valve. The first is an opening regulated by the knob; the second, piloted by the pressure upstream and downstream of the first throttle, assures a constant pressure drop across the adjustable throttle. In these conditions, the set flow rate value stays constant within a tolerance range of ± 2% of the maximum flow controlled by the valve for maximum pressure variation between the intake and outlet chambers of the valve.

5 - TEMPERATURE COMPENSATION

The valve temperature compensation is obtained with the principle of fluid passage across a thin wall orifice in which the flow rate is not subtantially influenced by the oil viscosity fluctuations. For controlled flows of less than 0,5 l/min and with a temperature difference of 50 °C, flow is increased by about 13% of the set flow value. For higher flow rates, and with the same temperature difference, the flow increase is about 4% of the maximum flow controlled by the valve.

6 - REVERSE FREE FLOW

The RPC1 valve, upon request, is supplied with an incorporated check valve to allow free flow in the direction opposite to the controlled flow, B→A.
In this case the valve code becomes RPC1-*/**C**T.

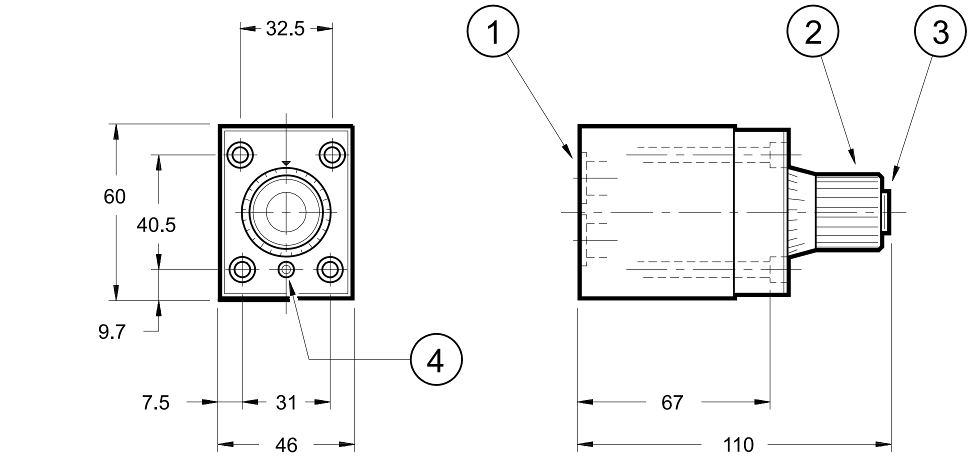


7 - RPC1-*/CTX

This valve is normally used for intake control and is positioned downstream of the directional valve.
The piloting connection "P" keeps the compensator in the closed position, thus avoiding the initial speed jump that occurs at the time the distributor sends oil to the valve (see the application diagram, paragraph 11).

8 - RPC1-* OVERALL AND MOUNTING DIMENSIONS

dimensions in mm

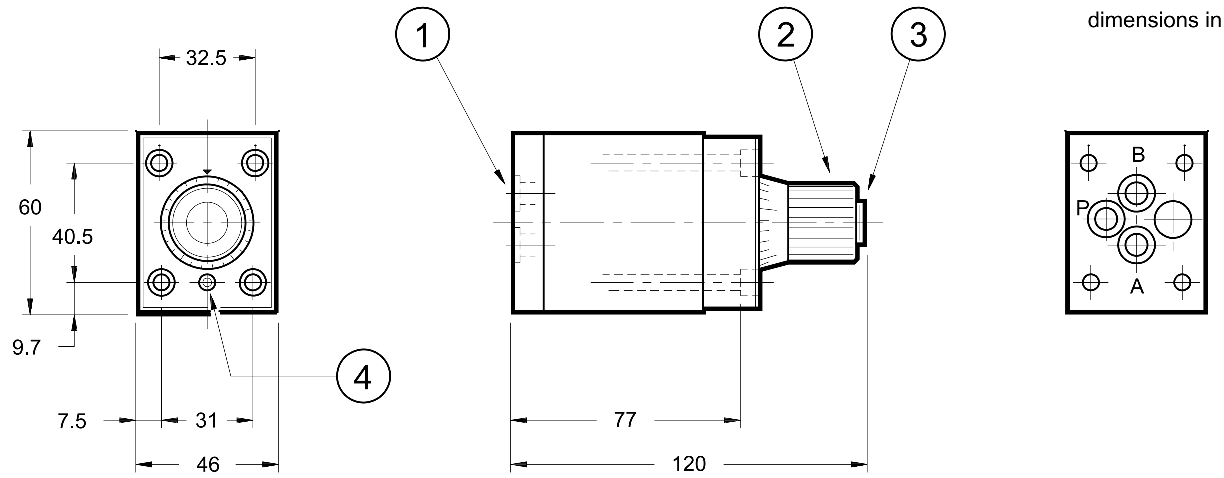


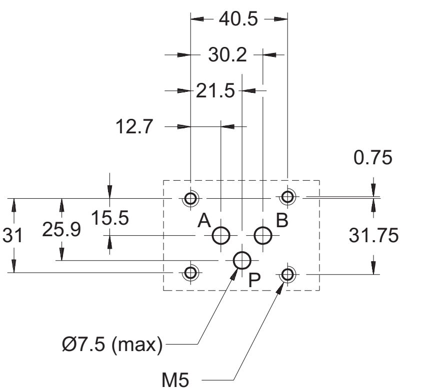
1	Mounting surface with sealing rings: 2 ORM - 0140 - 20 (14x2)
2	Adjustment knob. Anticlockwise rotation to increase flow.
3	Indicator of knob turns
4	Knob locking screw

FASTENING BOLTS
4 bolts M5x75
Tightening torque: 5 Nm

9 - RPC1-*/CTX OVERALL AND MOUNTING DIMENSIONS

dimensions in mm





Mounting surface: ISO 6263-03-03-*-97 (CETOP 4.5.2-2-03-250)

1	Subplate cod. 0113388. Mounting surface with sealing rings: 4 OR type 2037 (9.25x1.78) - 90 Shore)
2	Adjustment knob. Anticlockwise rotation to increase flow.
3	Indicator of knob turns
4	Knob locking screw

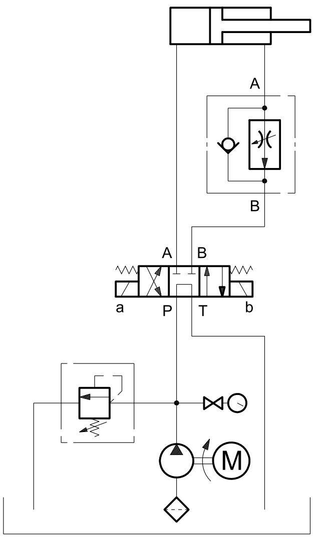
FASTENING BOLTS
4 bolts M5x85
Tightening torque: 5 Nm

10 - SUBPLATES (look at datasheet 51 000)

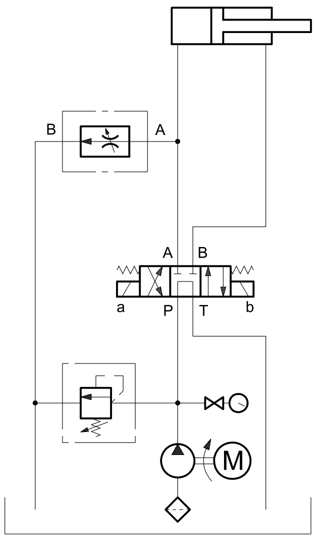
Type	PMRPC1-AI3G with rear ports PMRPC1-AL3G with side ports	
Type	PMMD-AI3G with rear ports, with user T plugged PMMD-AL3G with side ports, with user T plugged	only for valve RPC1-*/CTX
Port dimension	3/8” BSP	

11 - APPLICATION EXAMPLES

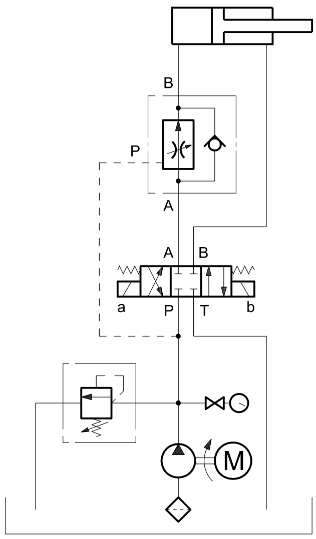
Meter-out control



Bleed-off control



Meter-in control with anti-jump device



DUPLOMATIC OLEODINAMICA
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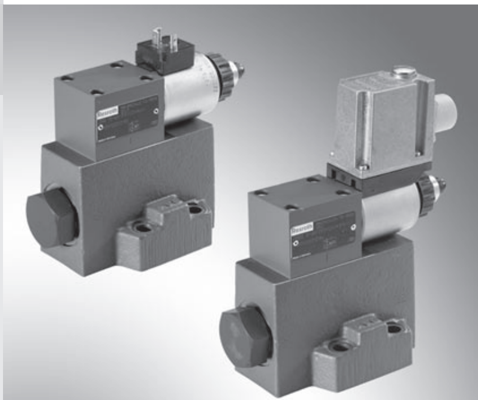
Fax +39 0331.895.339
www.duplomatic.com • e-mail: sales.exp@duplomatic.com

Rexroth
Bosch Group

Proportional pressure reducing valve, pilot operated

Type DRE and DREE


HAD 7655 + HAD 7656

Sizes 10 and 25 [1)]
Component series 6X

Maximum operating pressure	315 bar
Maximum flow	300 l/min

Table of contents

Features

- Valve for reducing an operating pressure
- Operation by means of proportional solenoids
- For subplate mounting:
  Porting pattern according to ISO 5781, subplates according to data sheet RE 45062 (separate order), see page 11
- Third path A to Y (Ø 7.5 mm)
- Minimum setting pressure 2 bar with command value zero
- Linearized command value-pressure characteristic curve
- Main spool closed from B to A in rest position
- Good transient response
- Optional check valve between A and B
- Type DREE with integrated electronics (OBE):
  - Low manufacturing tolerance of the command value-pressure characteristic curve

[1)] Size 32 see data sheet RE 29178

Information on available spare parts:
www.boschrexroth.com/spc

Technical data (For applications outside these parameters, please consult us!)

general

Size		Size	10	25
Weight	– DRE	kg	4.7	6.0
	– DREE	kg	4.8	6.1
Installation position			Any	
Storage temperature range		°C	–20 to +80	
Ambient temperature range	– DRE	°C	–20 to +70	
	– DREE	°C	–20 to +50	

hydraulic (measured with HLP 46, ϑ_{oil} = 40 °C ± 5 °C)

Size		Size	10	25
Max operating pressure	– Port A and B	bar	315	
	– Port Y		Separately and to the tank at zero pressure (internal pipe Ø ≥ 5 mm; pipe length < 2,500 mm)	
Max. setting pressure in channel A	– Pressure rating 50 bar	bar	50	
	– Pressure rating 100 bar	bar	100	
	– Pressure rating 200 bar	bar	200	
	– Pressure rating 315 bar	bar	315	
Min. setting pressure in channel A with command value zero		bar	2	
Max. flow of the main valve		L/min	200	300
Pilot flow		cm^3/min	800	
Hydraulic fluid			Mineral oil (HL, HLP) according to DIN 51524, other hydraulic fluids upon request	
Hydraulic fluid temperature range		°C	–20 to +80	
Viscosity range		mm^2/s	15 to 380	
Max. admissible degree of contamination of the hydraulic fluid cleanliness class according to ISO 4406 (c)			Class 20/18/15 [1]	
Hysteresis		%	±3.5 of the max. setting pressure	
Repeatability		%	< ±2 of the max. setting pressure	
Linearity		%	±2 of the max. setting pressure	
Manufacturing tolerance of the command value pressure characteristic curve,	– DRE	%	±3.5 of the max. setting pressure	
	– DREE	%	±1.5 of the max. setting pressure	
Related to the hysteresis characteristic curve, pressure increasing				
Step response $T_u + T_g$	10 → 90 %	ms	~130	Measured with standing hydraulic fluid column, 1 liter at port A
	90 → 10 %	ms	~160	
Step response $T_u + T_g$	10 → 90 %	ms	~150	Measured with standing hydraulic fluid column, 5 liters at port A
	90 → 10 %	ms	~150	

[1] The cleanliness classes specified for the components must be adhered to in hydraulic systems. Effective filtration prevents faults and at the same time increases the service life of the components.

For the selection of filters, see data sheets RE 50070, RE 50076, RE 50081, RE 50086 and RE 50088.

Technical data (For applications outside these parameters, please consult us!)

electrical

Minimum solenoid current		mA	≤ 100
Maximum solenoid current		mA	1,600 ± 10 %
Solenoid coil resistance	Cold value at 20 °C	Ω	5.5
	Max. hot value	Ω	8.05
Duty cycle		%	100

electrical, integrated electronics (OBE)

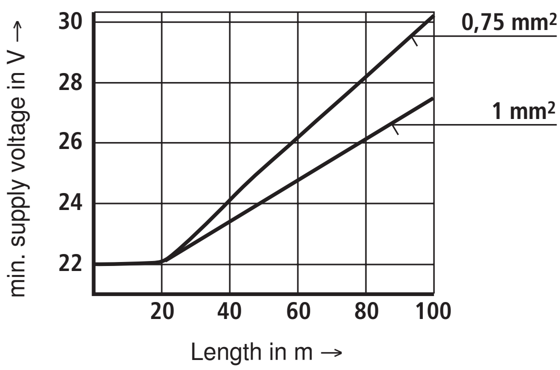
Supply voltage	Nominal voltage	VDC	24
	Lower limit value	VDC	21
	Upper limit value	VDC	35
Current consumption		A	≤ 1.5
Required fuse protection		A	2, time-lag
Inputs	Voltage	V	0 to 10
	Current	mA	4 to 20
Output	Actual current value	mV	1 m V ≙ 1mA
Protection class of the valve according to EN 60529			IP 65 with mating connector mounted and locked

Electrical connection

Connection cable for DREE

- Recommendation 6-wire, 0.75 or 1 mm^2 plus protective earthing conductor and screening
- Only connect the screening to PE on the supply side
- max. admissible length 100 m

The minimum supply voltage at the power supply unit depends on the length of the supply line (see diagram).



Integrated electronics (OBE) with Type DREE

Function

The electronics are supplied with voltage via ports A and B. The command value is applied to the differential amplifier ports D and E.

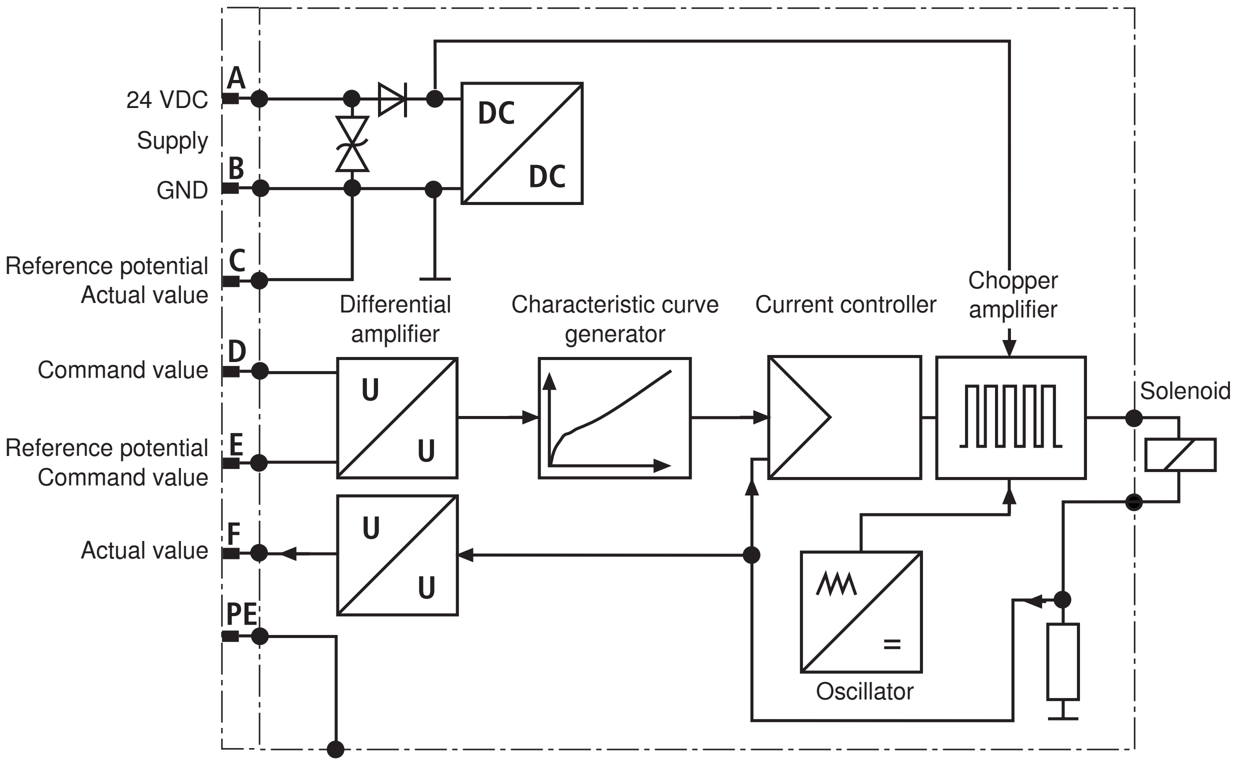
Via the characteristic curve generator, the command value solenoid current characteristic curve is adjusted to the valve so that non-linearities in the hydraulic system are compensated and thus, a linear command value pressure characteristic curve is created.

The current controller controls the solenoid current independent of the solenoid coil resistance.

The power stage of the electronics for controlling the proportional solenoid is a chopper amplifier with a cycle frequence of ca. 180 Hz to 400 Hz. The output signal is pulse-width modulated (PWM).

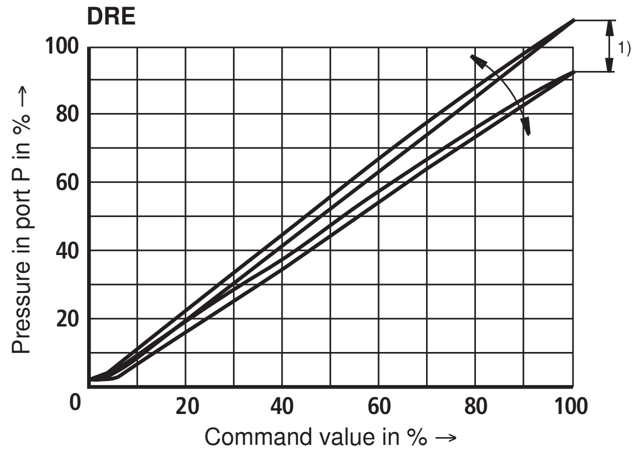
For checking the solenoid current, a voltage can be measured between pin F(+) and pin C(–) that is proportional to the solenoid current. **1 mV** corresponds to **1 mA** solenoid current.

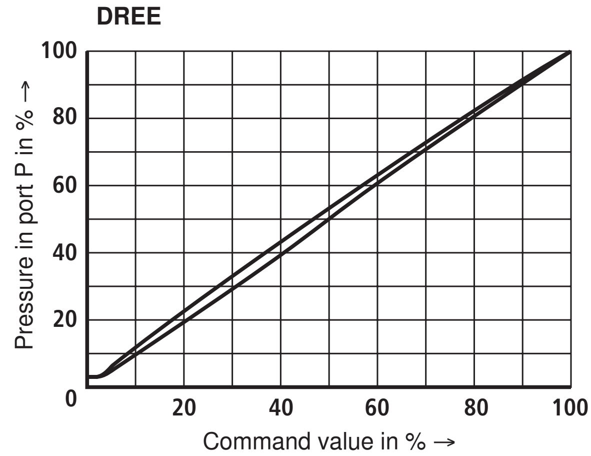
Block circuit diagram



Characteristic curves (measured with HLP46, ϑ_{oil} = 40 °C ± 5 °C)

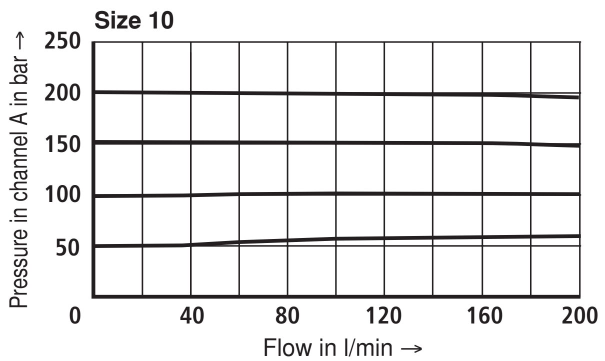
Pressure in port P depending on the command value (flow = 0.8 l/min)

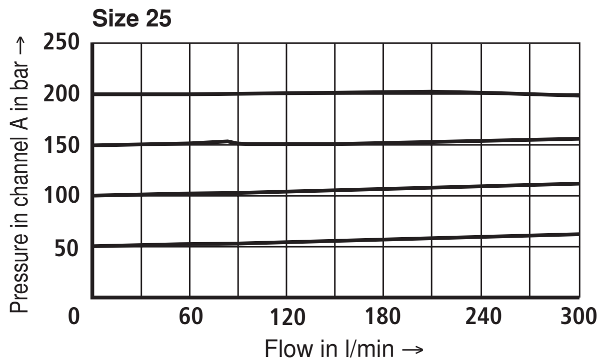




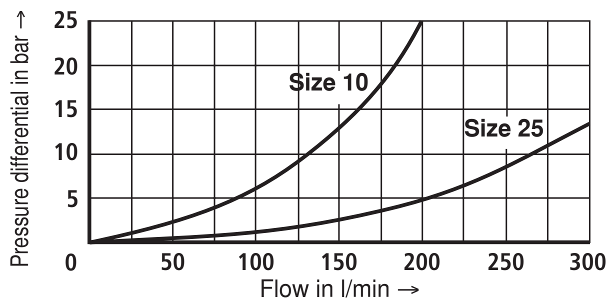
1) With valve DRE, the manufacturing tolerance at the **external amplifier** (type and data sheet see page 2) can be changed using the command value attenuator potentiometer "**Gw**". The digital amplifier is set using the parameter "Limit".
In this connection, the control current according to the technical data must not be exceeded.
In order to be able to adjust several valves to the same characteristic curve, don't set the pressure higher than the maximum setting pressure of the pressure rating with command value 100 %.

Pressure in channel A dependent on the flow q_v

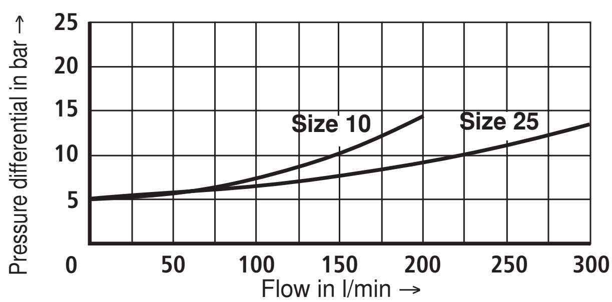




Pressure differential via the check valve from A to B



Pressure differential from B to A



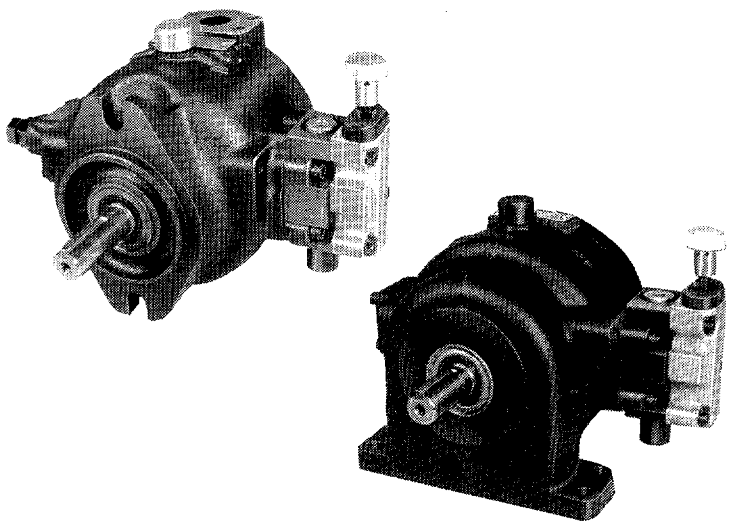
BOSCH

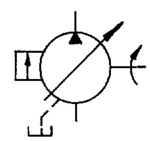
Engineering Data

VARIABLE VOLUME VANE PUMPS

MODEL SV-20
MODEL SV-25

FLANGE MOUNTED
SUBPLATE MOUNTED





SYMBOL

QUICK REFERENCE CHART

MODEL	GPM @ 100 PSI & 1800 RPM	MAXIMUM PRESSURE (PSI)	MAXIMUM RPM	PRESSURE COMPENSATING RANGE (PSI)	THEORETICAL DISPLACEMENT IN^3/REV	INPUT HP @ MAX PSI & 1800 RPM
STANDARD SV-20	15	2000	1800	375-2000	1.9	20
STANDARD SV-25	20	1500	1800	300-1000	2.56	20.3
LOW PRESSURE SV-20	15	750	1800	175- 750	1.9	7.25
LOW PRESSURE SV-25	20	750	1800	175- 750	2.56	9.75

STANDARD PUMP — The SV pump is a pressure compensated vane pump and is available in four basic displacements; one, two, four, and eight cubic inches. This bulletin covers the Model SV-20 (two cubic inch displacement) and variations of it all of which are dimensionally the same. The SV-25 is a modified SV-20 which uses a different ring to allow the ring to shift further and increase the displacement. By increasing the ring stroke, the vanes extend further and requires the maximum pressure rating to be reduced. Increasing the flow of the basic pump allows the design engineer to reduce circuit costs by using a smaller pump instead of selecting the next larger size provided the reduced pressure rating is adequate.

LOW PRESSURE PUMP — On some applications, such as grinders, the pump must compensate at very low pressures which are not within the normal compensating range of the standard pump. By making internal modifications to the standard pump, the compensating range can be reduced to create a "low pressure" pump for this kind of application.

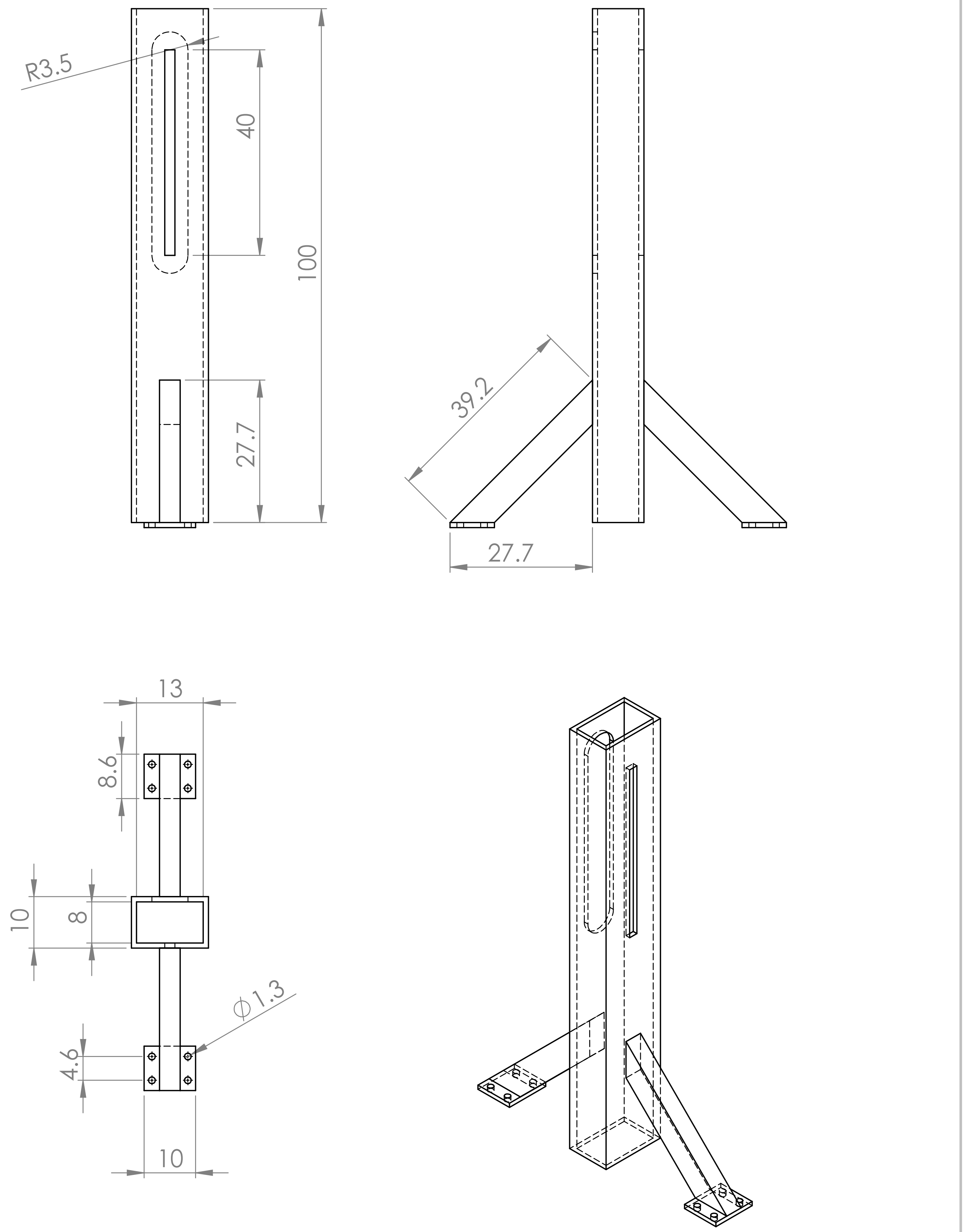
PUMP MODEL	SERVICE BULLETIN
STANDARD SV-20 & SV-25	HPUS RSB 003/13 US
LOW PRESSURE SV-25 & SV-25	HPUS RSB 003/14 US

FOR REPAIR PARTS, REFER TO THE SERVICE BULLETIN LISTED IN THE TABLE.

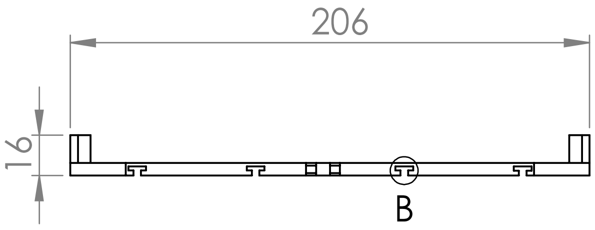
Appendix B

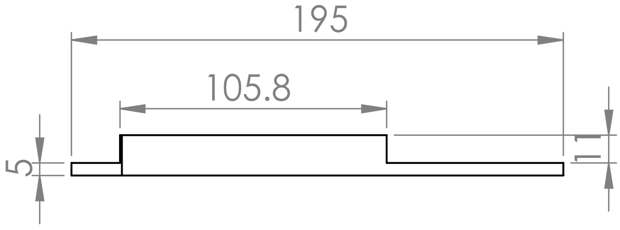
Machine dimensions

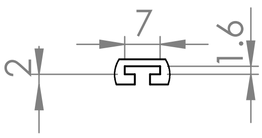
- Punch supporting frame
- Mover base
- Cutting tool cart
- Cutting tool supporting frame
- Cutting tool base frame
- Cutting tool
- ECM layout
- Head base
- Mover head
- The Mover
- Punch and Cutting Machine
- Punch base track
- Punch base
- Mover track
- Rollers



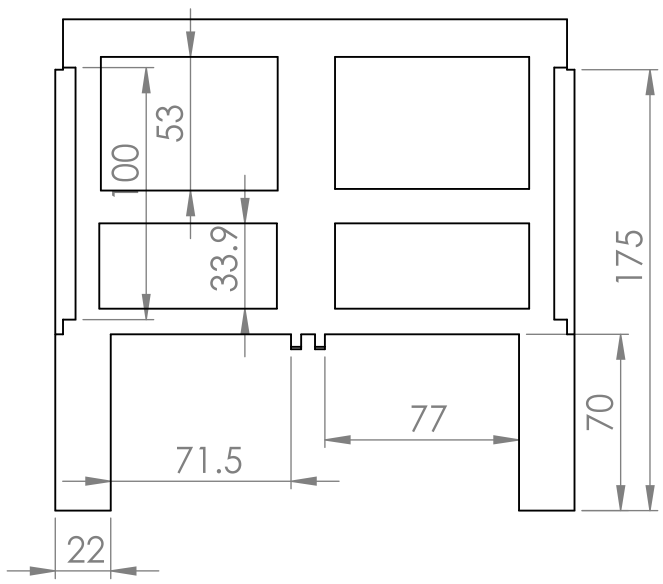
MATERIAL :Steel AISI 1020	SCALE:1:20	Title: Punch Supporting Frame
All dimensions in Cm		

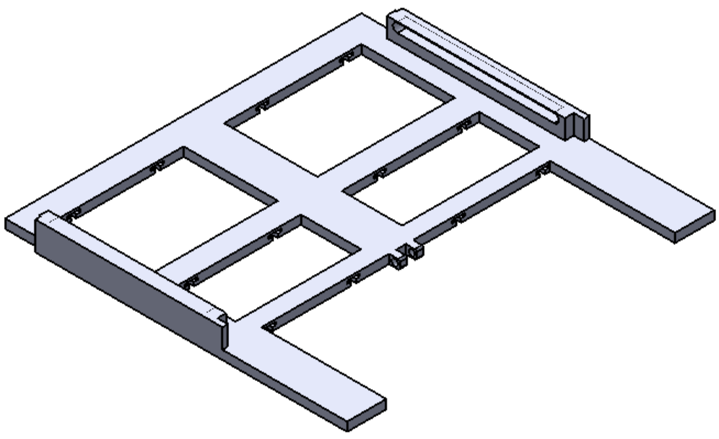




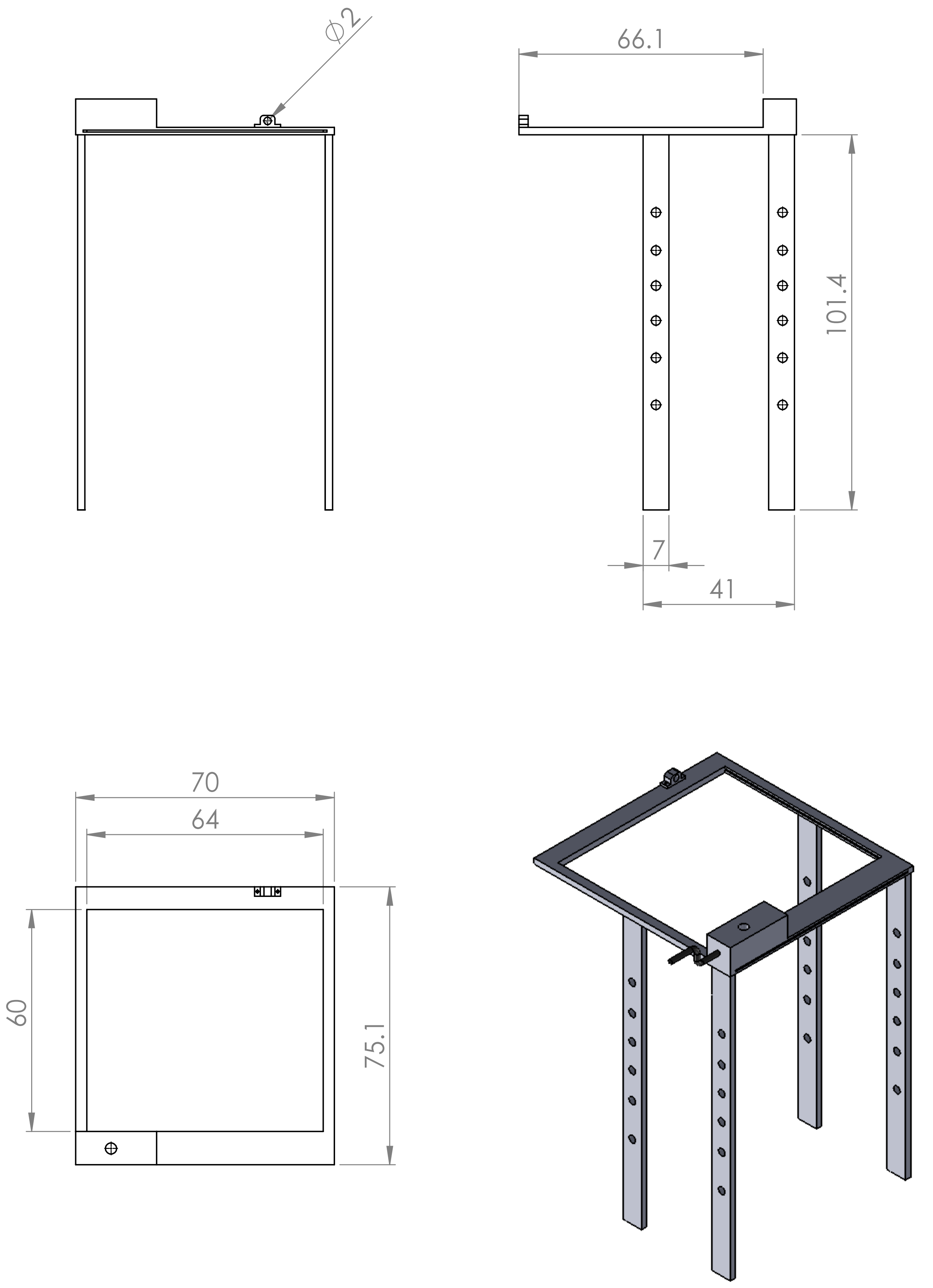


DETAIL B
SCALE 1 : 15

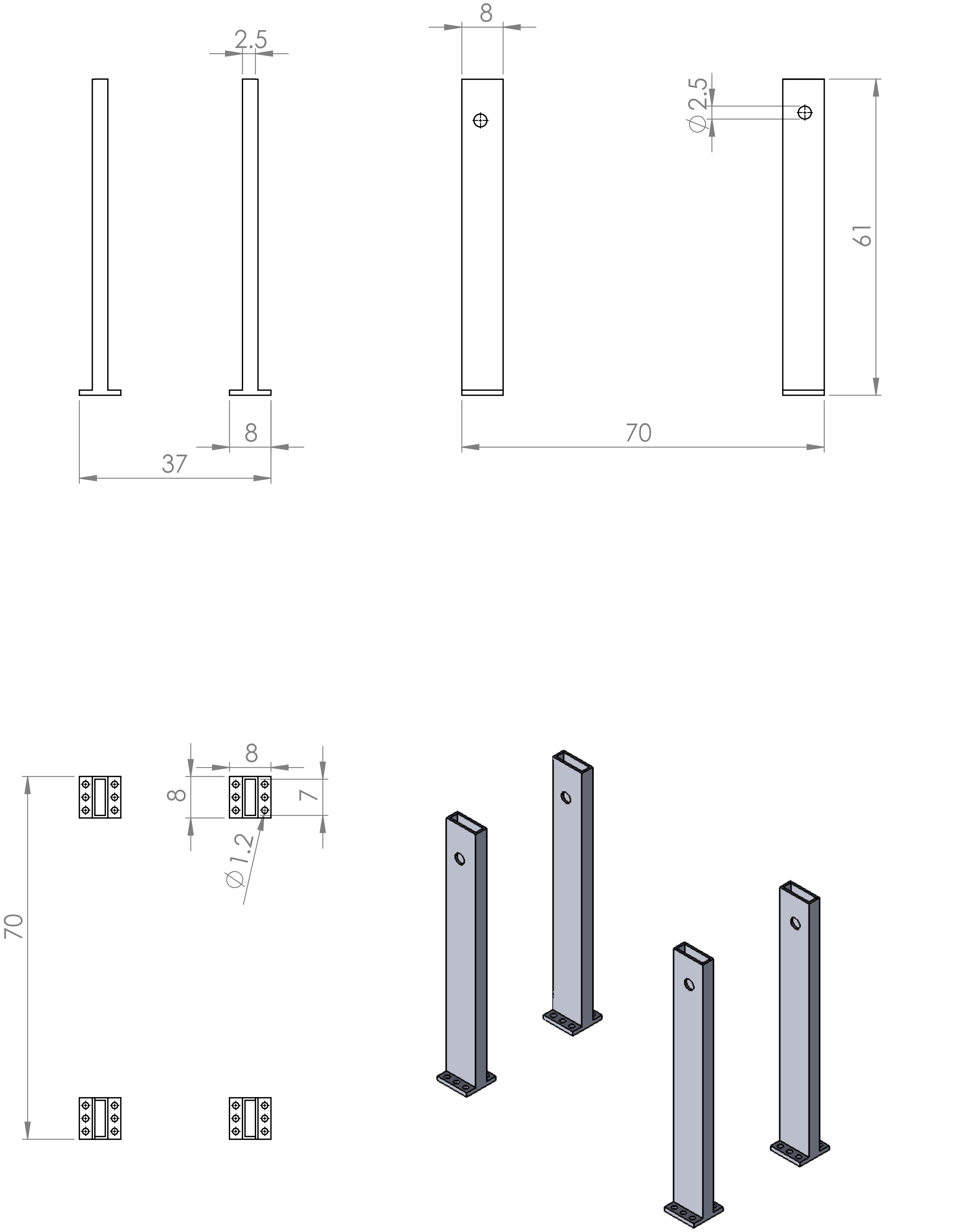




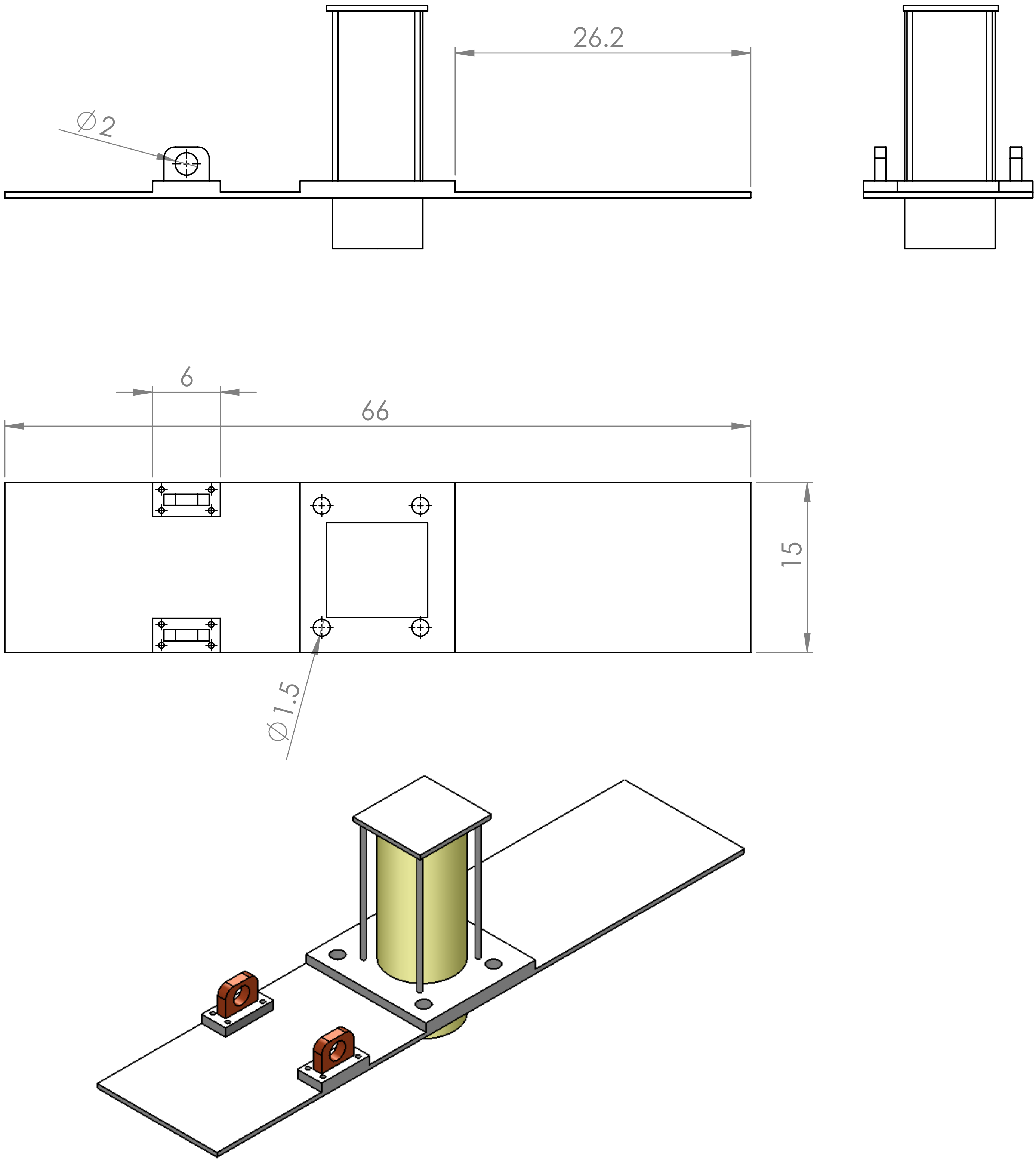
MATERIAL: Steel AISI 1020	SCALE: 1 : 30	TITLE:	Mover base
All dimensions are in Cm			



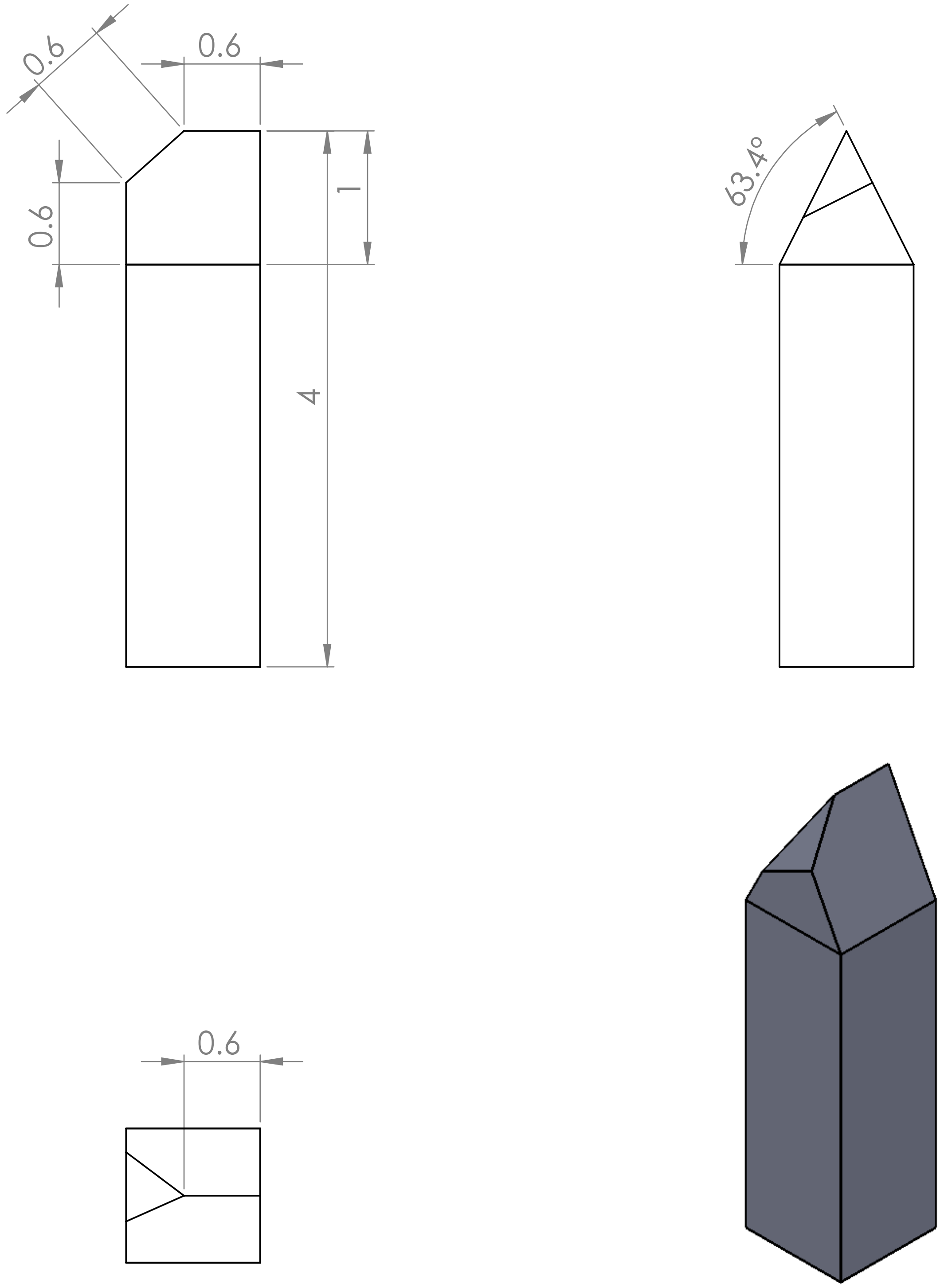
MATERIAL :Steel AISI 1020	SCALE 1:15	Title: Cutting tool suporting frame
All dimensions in Cm		



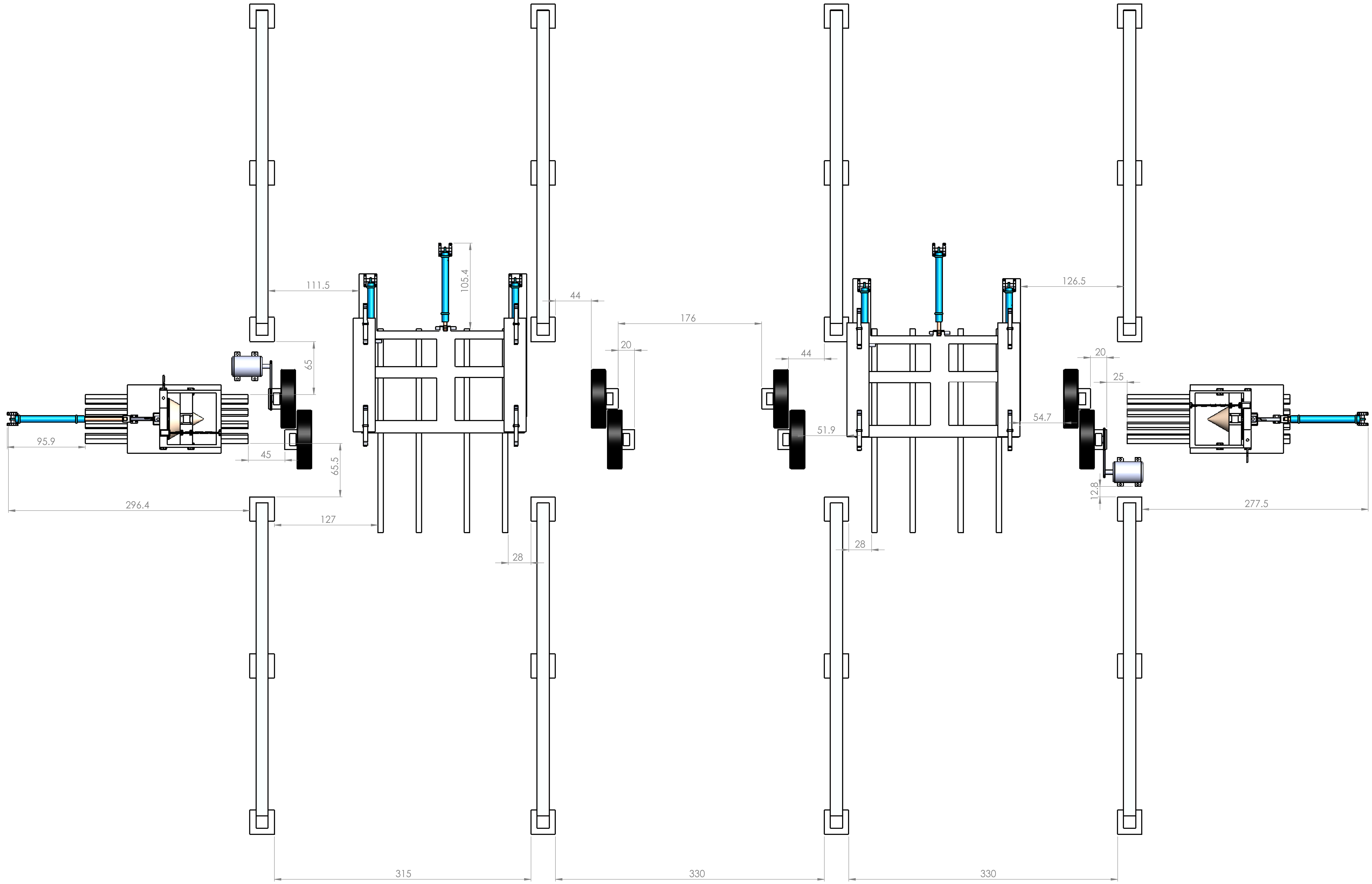
All dimensions in Cm	SCALE:1:10	Title: Cutting tool base frame
MATERIAL :Steel AISI 1020		



MATERIAL :Steel AISI 1020	SCALE:1:10	Title: Cutting tool cart
All dimensions in Cm		

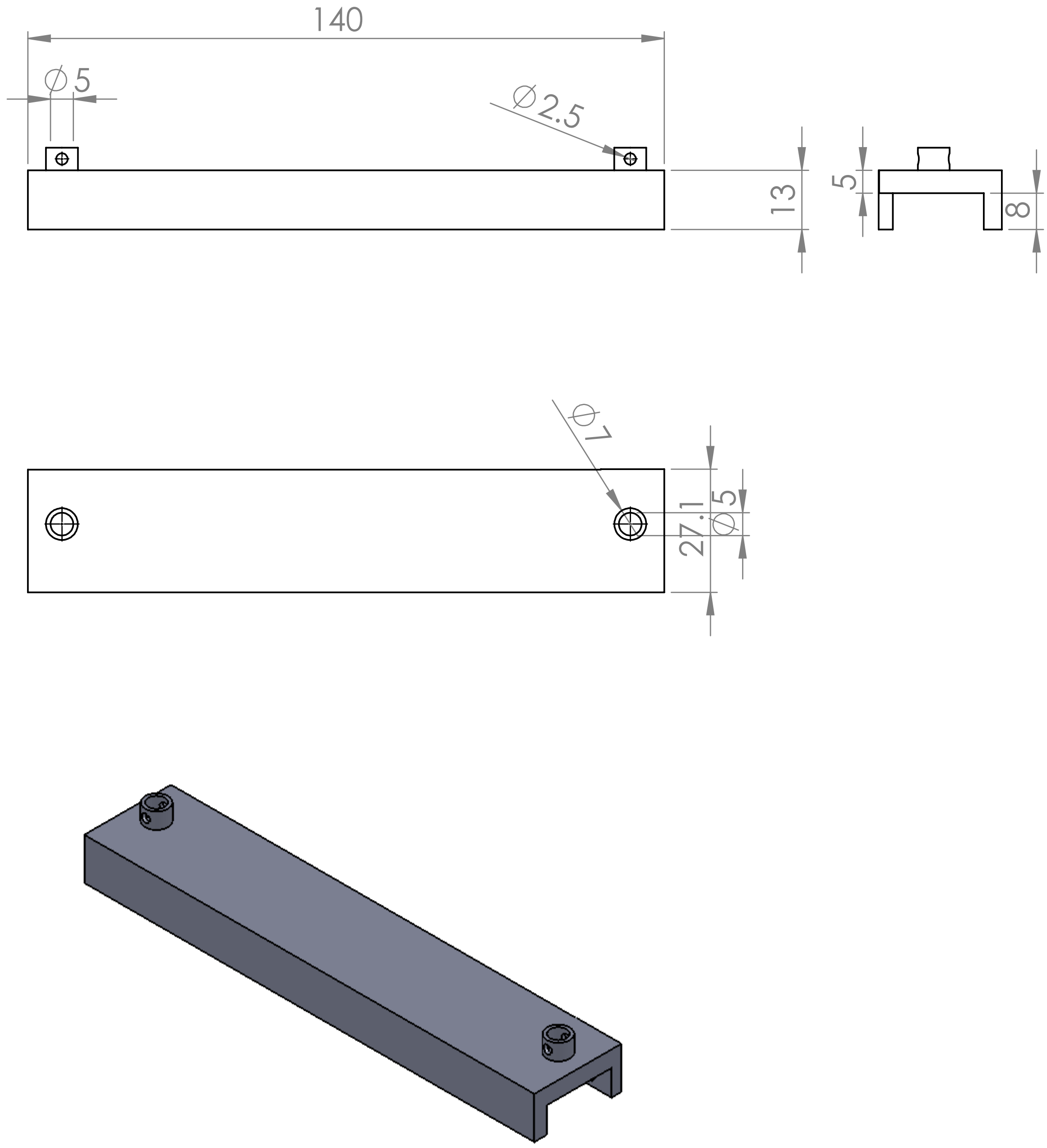


MATERIAL :Carbon Steel	SCALE:2:1	Title:	Cutting Tool
All dimensions in Cm			

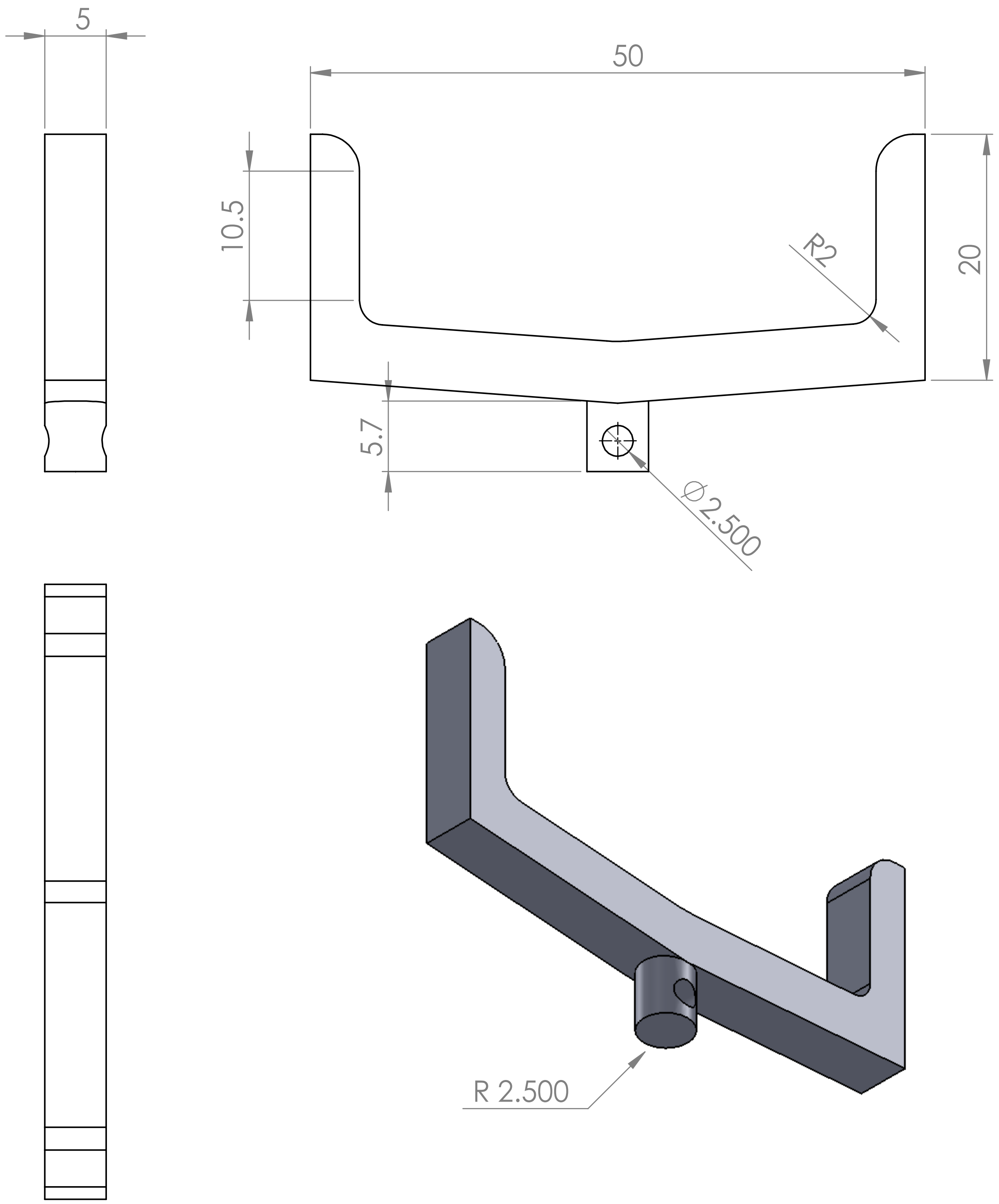


Appendix F | SCALE:1:1 | DWG NO. ECM layout | A1

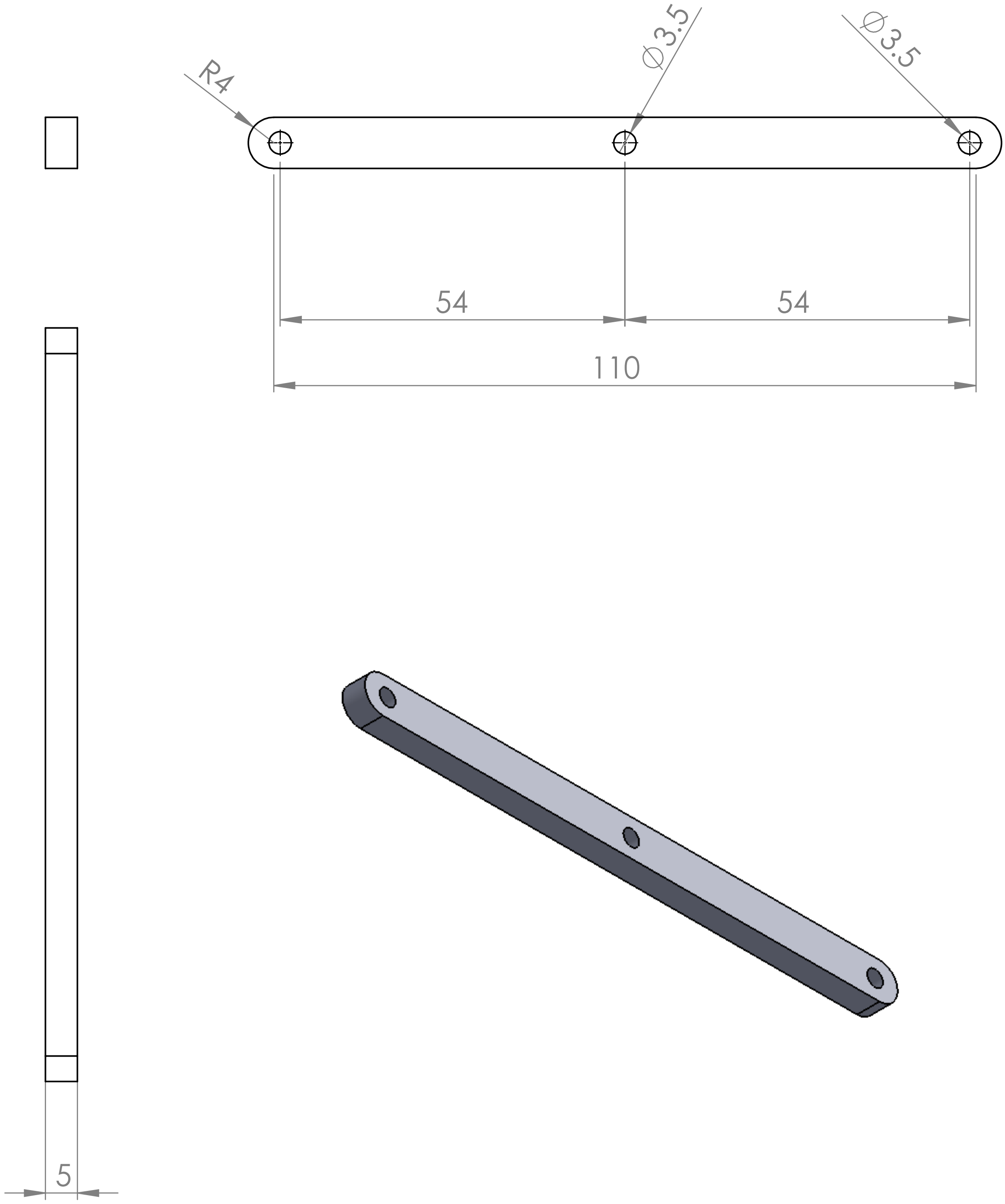
SHEET 1 OF 1



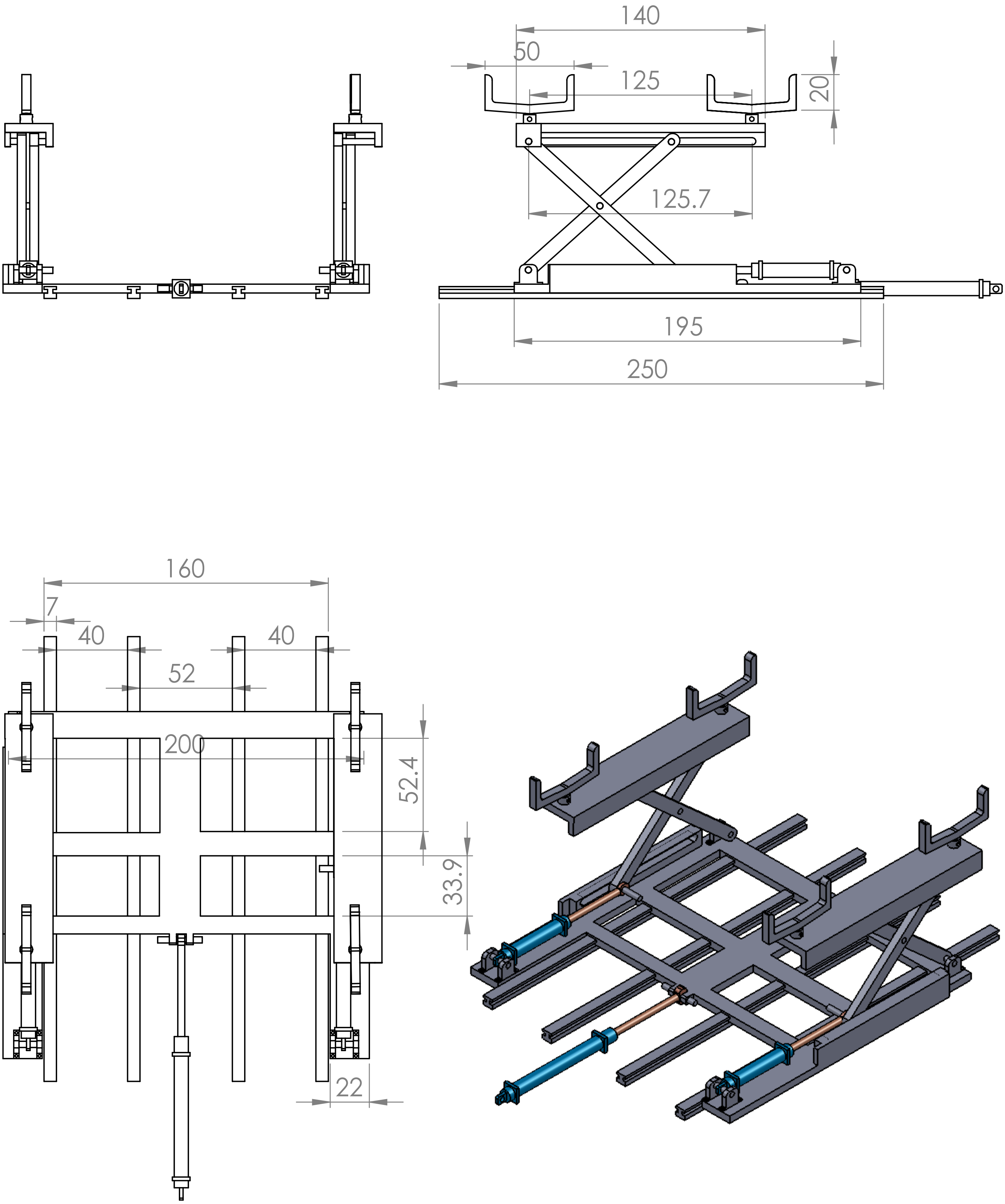
MATERIAL :Steel AISI 1020	SCALE:1:20	Title: head base
All dimensions in Cm		



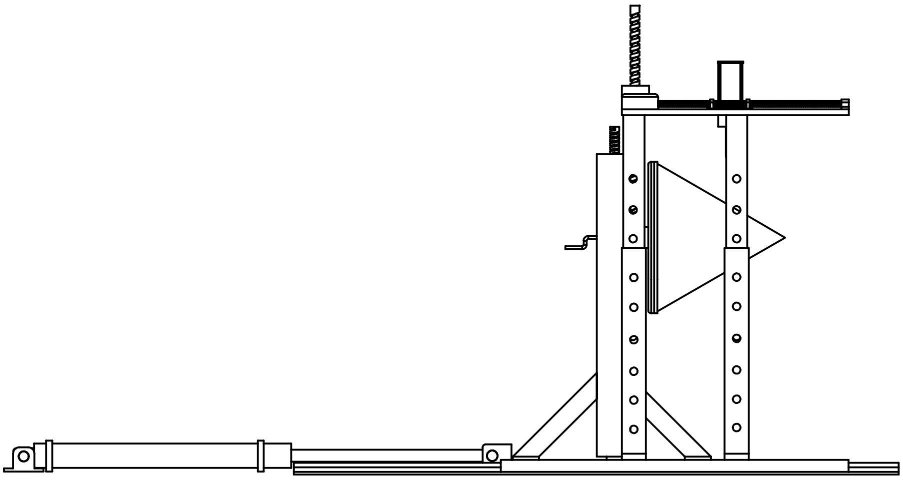
MATERIAL :Steel AISI 1020	SCALE:1:5	Title: Mover Head
All dimensions in Cm		

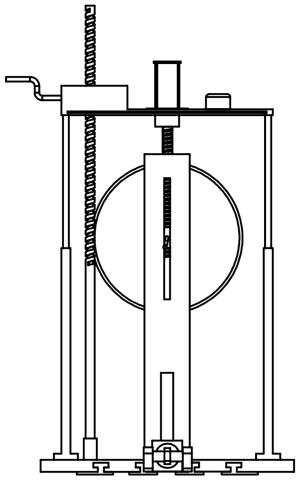


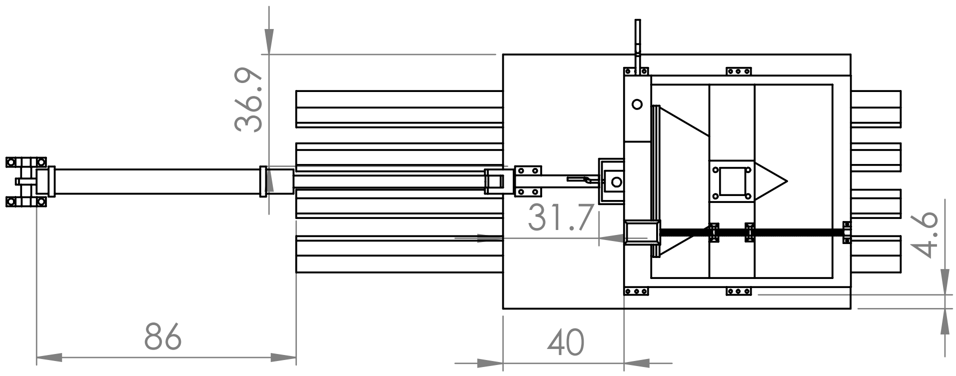
MATERIAL :Steel AISI 1020	SCALE:1:20	Title: Moner Link
All dimensions in Cm		



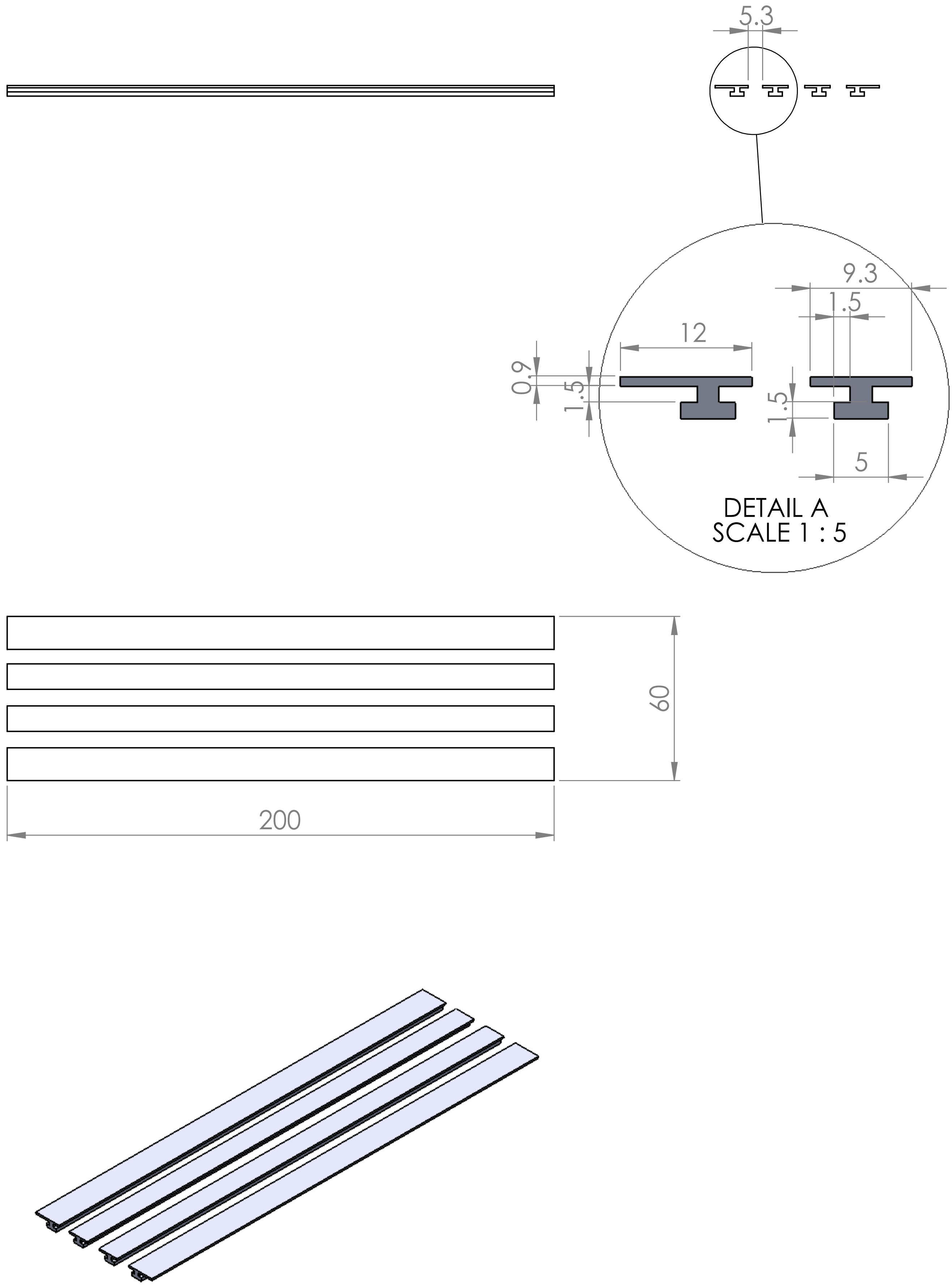
MATERIAL :Steel AISI 1020	SCALE:1:50	Title: The Mover
All dimensions in Cm		



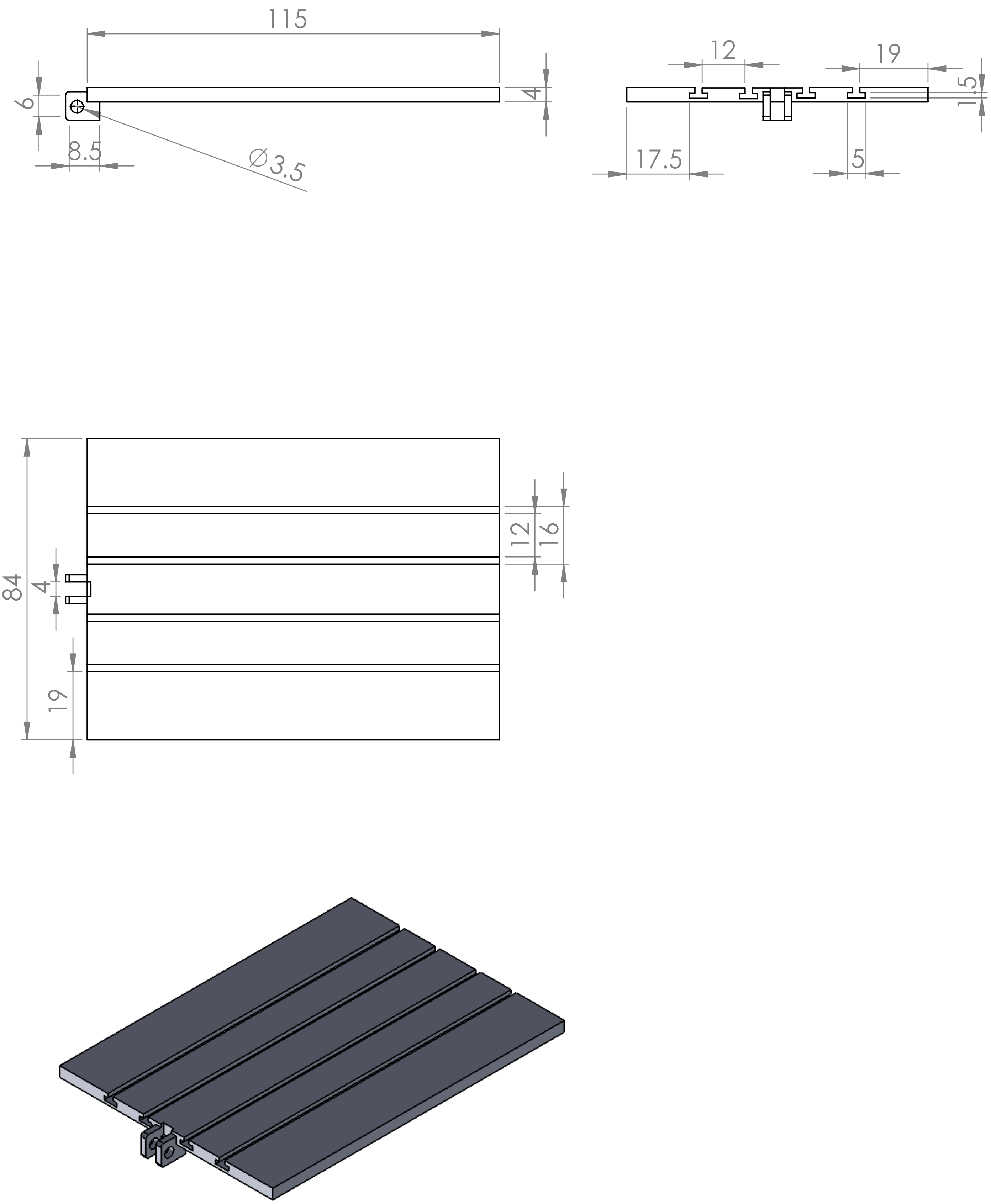




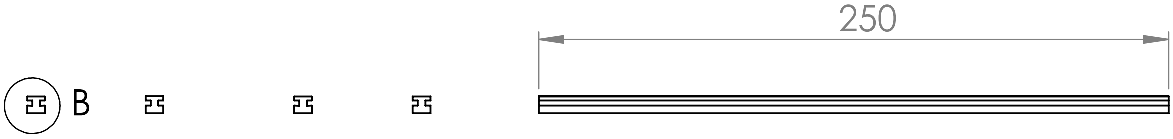
MATERIAL :Steel AISI 1020	SCALE:1:50	Title: Punch and Cutting Machine
All dimensions in Cm		

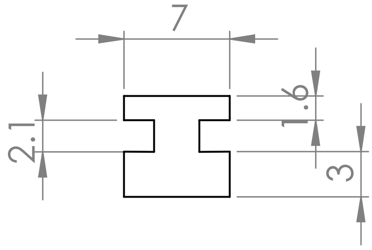


MATERIAL :Steel AISI 1020	SCALE:1:20	Title:	Punch base track
All dimensions in Cm			

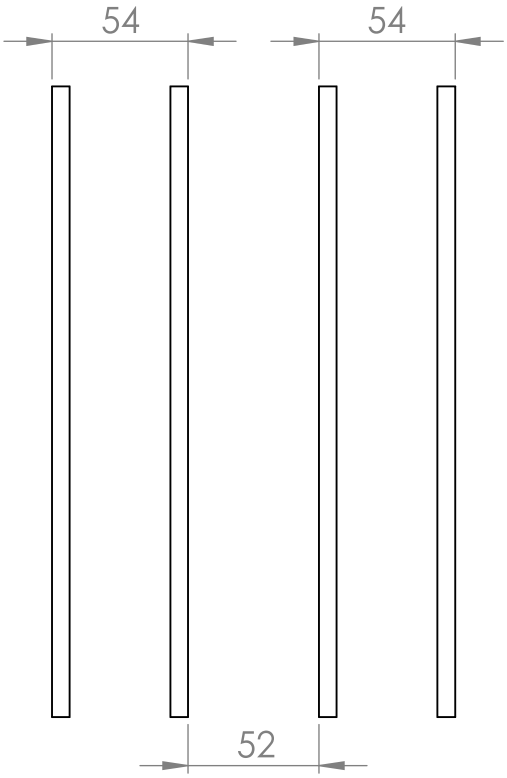


MATERIAL :Steel AISI 1020	SCALE:1:15	Title: Punch base
All dimensions in Cm		

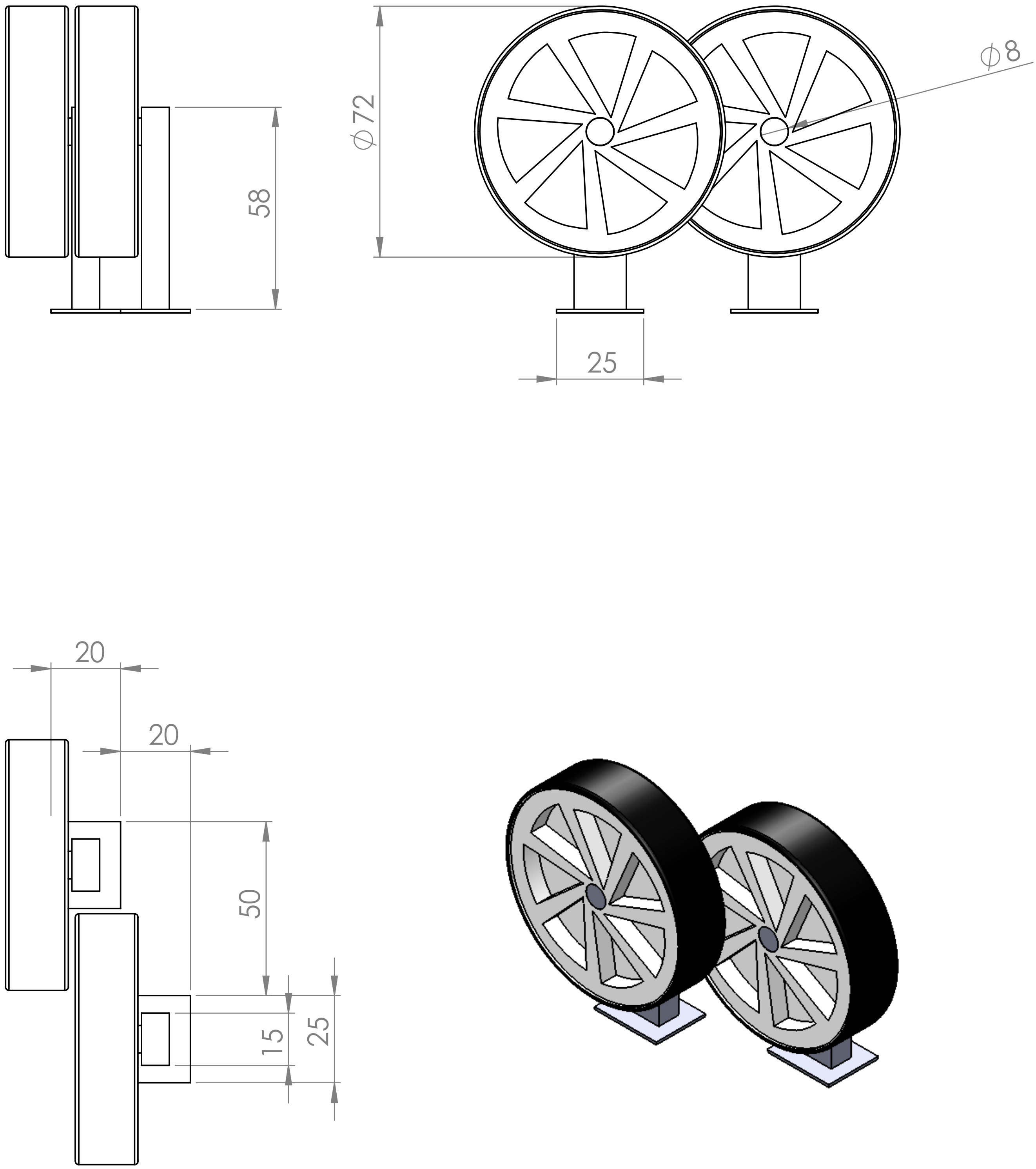




DETAIL B
SCALE 1 : 5



MATERIAL :Steel AISI 1020	SCALE:1:50	Title: Mover track
All dimensions in Cm		



MATERIAL :Steel AISI 1020

All dimensions in Cm

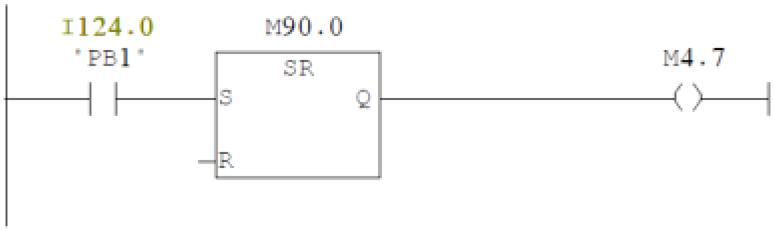
SCALE:1:17

Title: Rollers

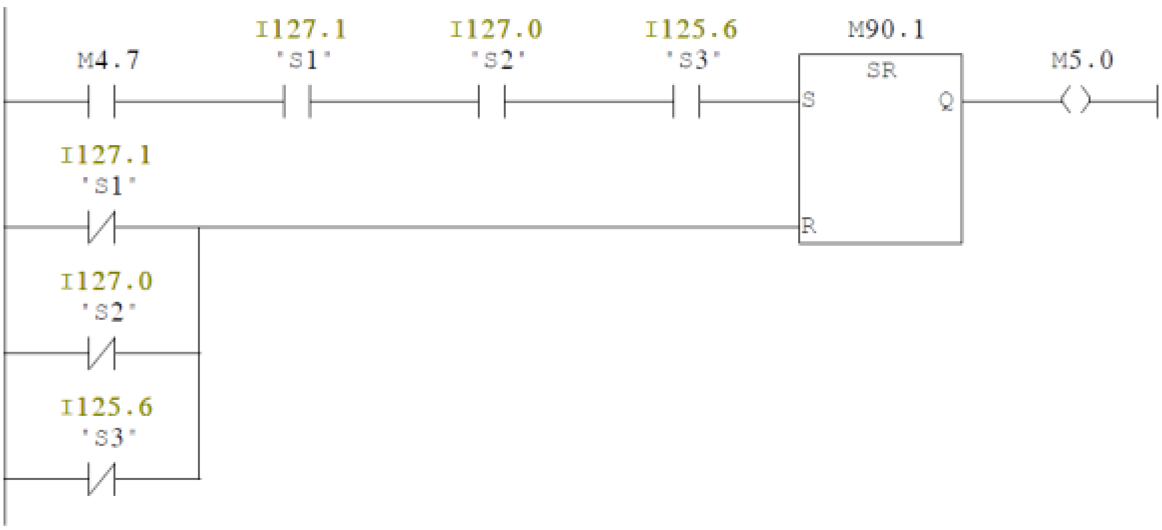
Appendix C

PLC ladder diagram

Network: 1

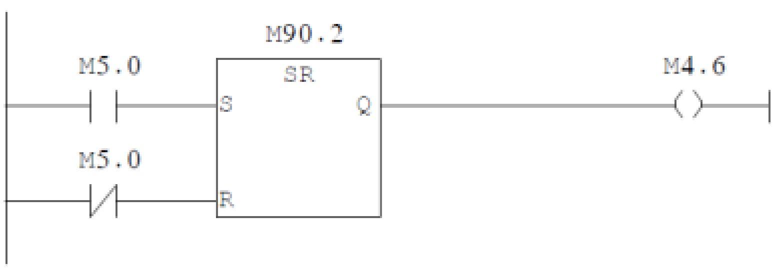


Network: 2

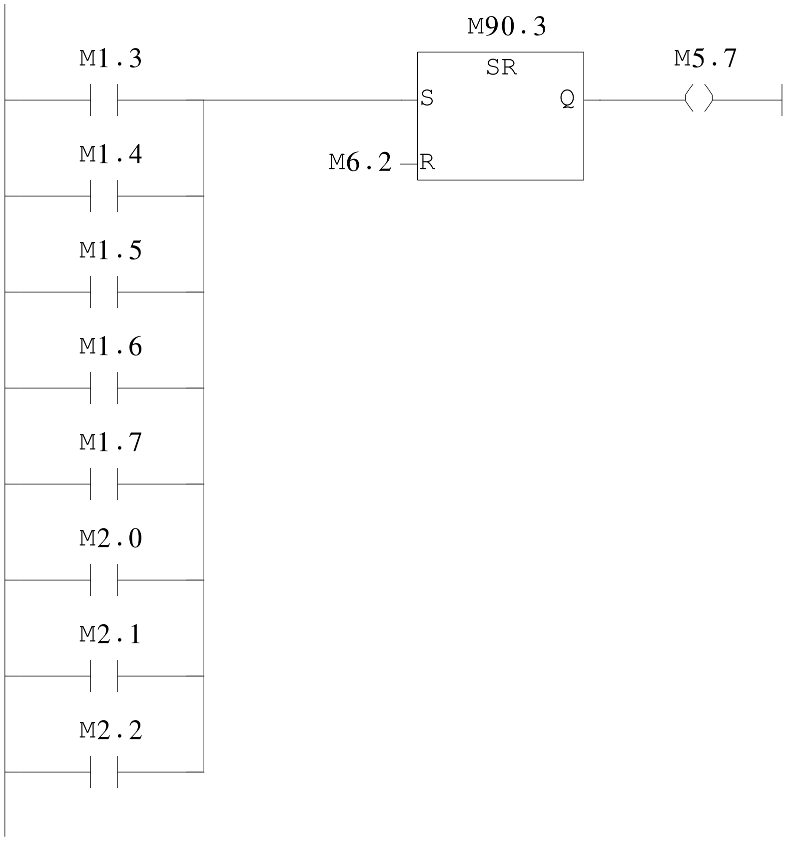


Network: 3

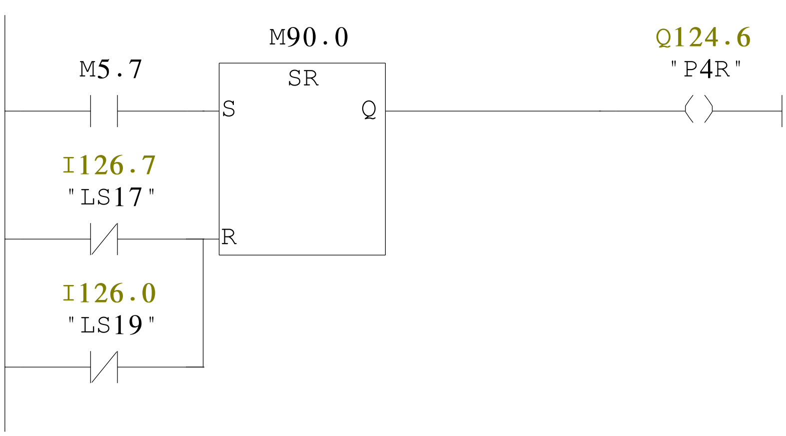
sector is clear go to mode selection



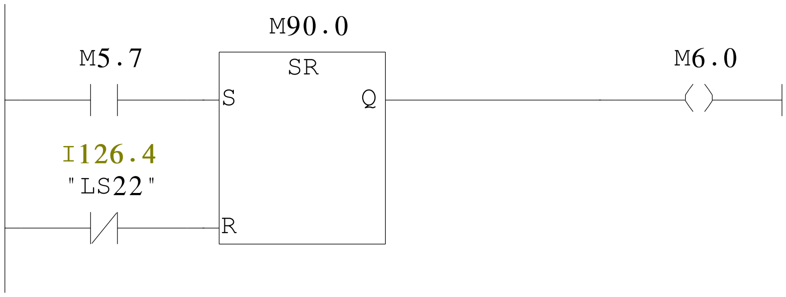
Network: 4



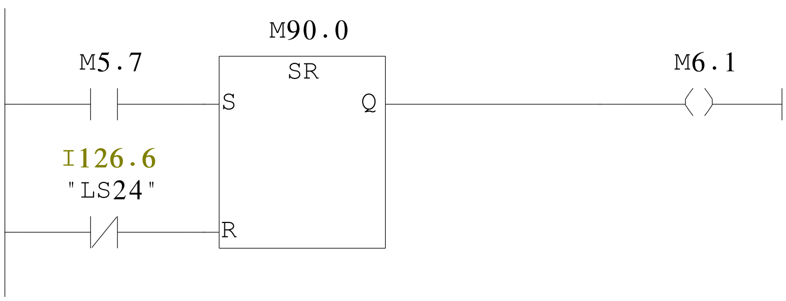
Network: 5



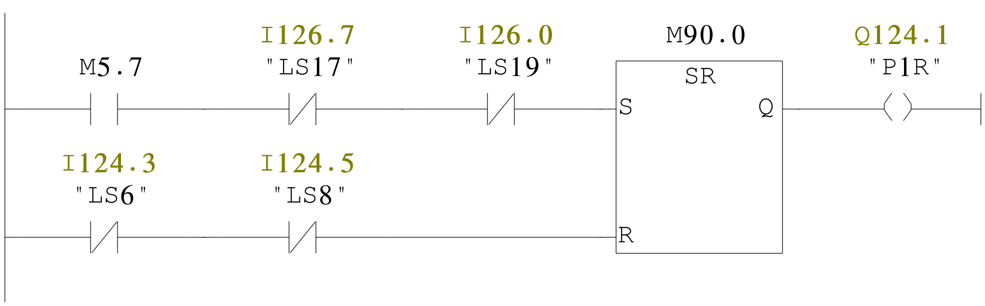
Network: 6



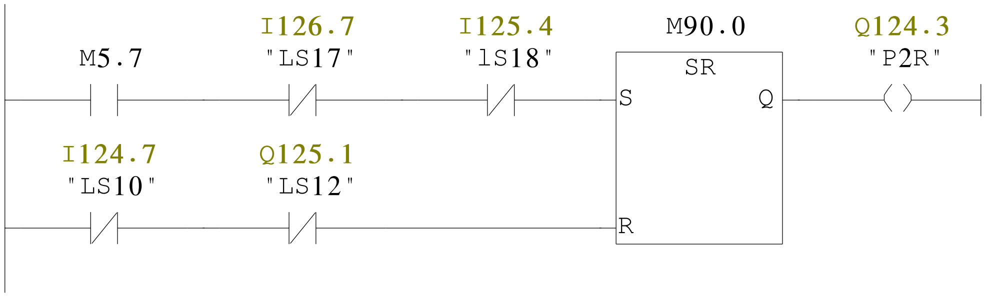
Network: 7



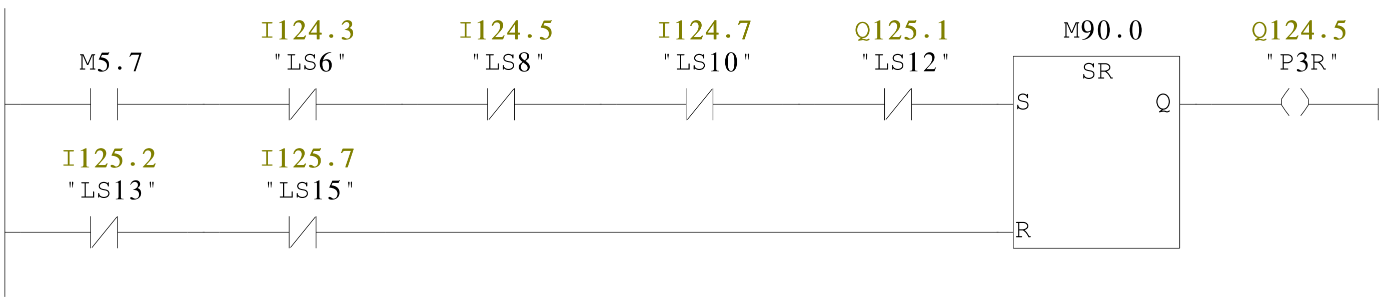
Network: 8



Network: 9



Network: 10

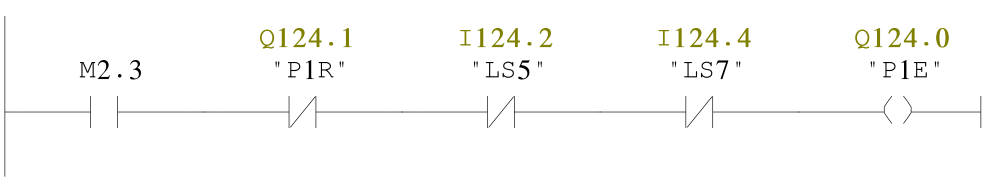


Network: 11

Homing done ..

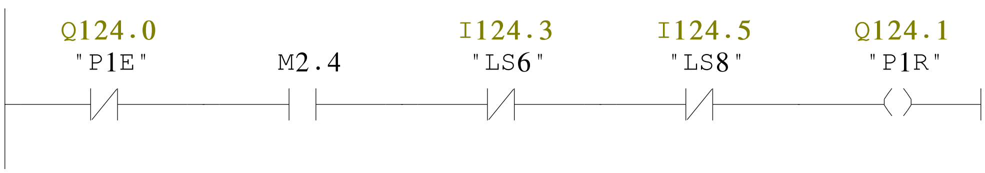
Network: 12

manual moode



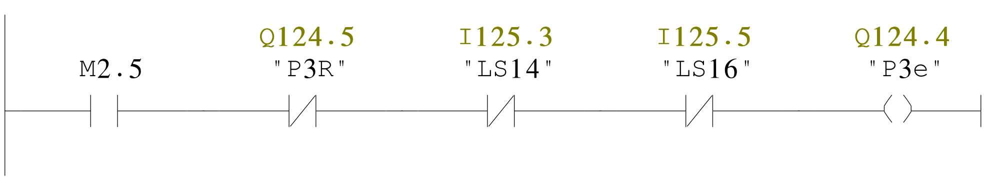
Network: 13

Network: 14



Network: 15

Network: 16



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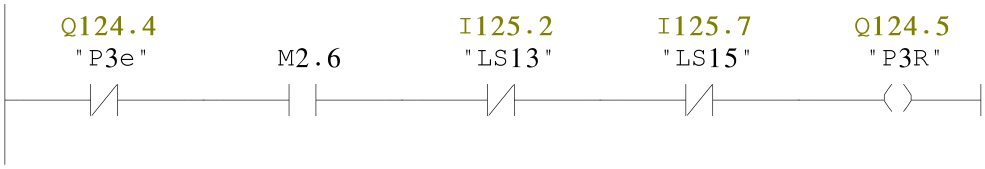

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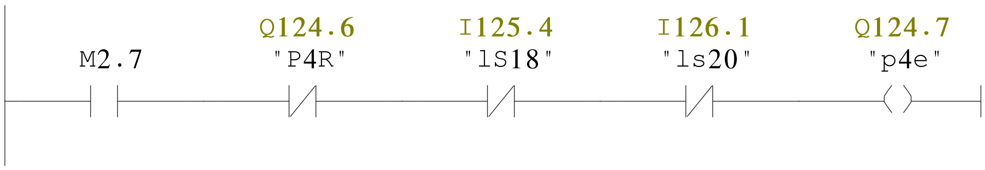
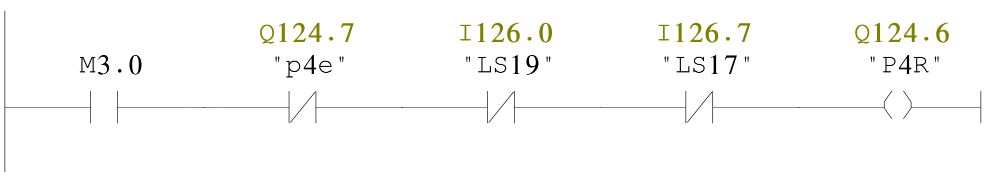
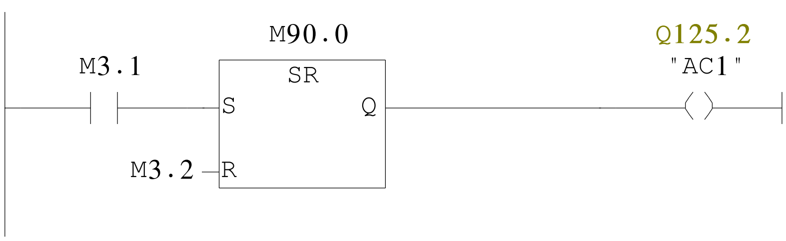


Network: 19



Network: 20



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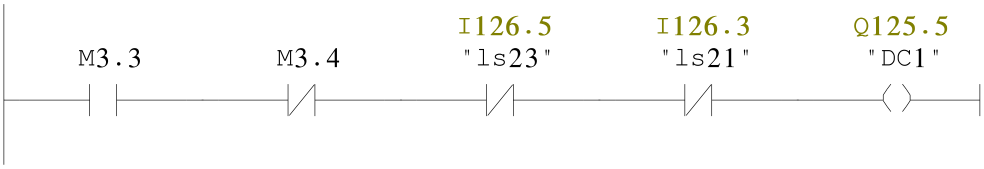
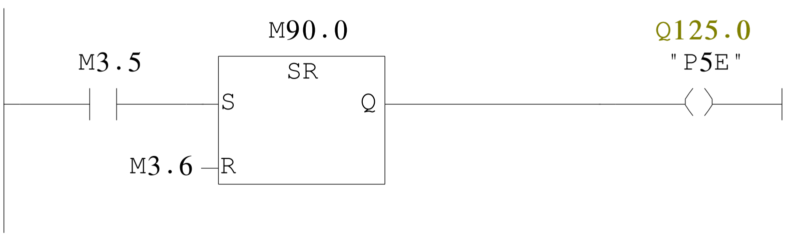


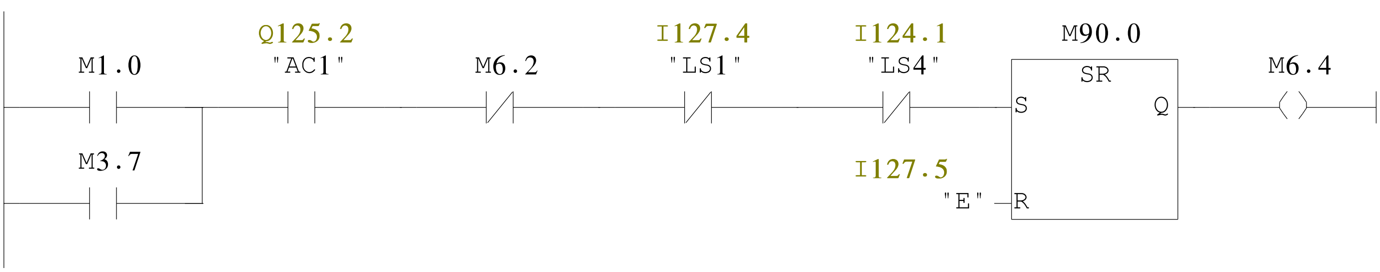
Network: 22

end manual

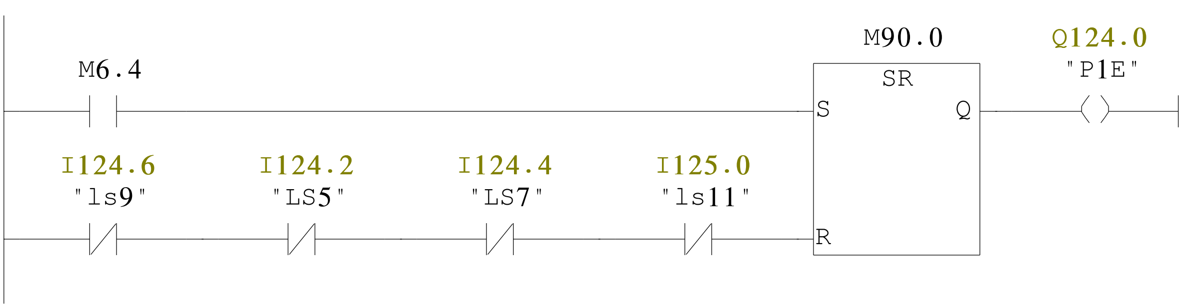


Network: 23

operations

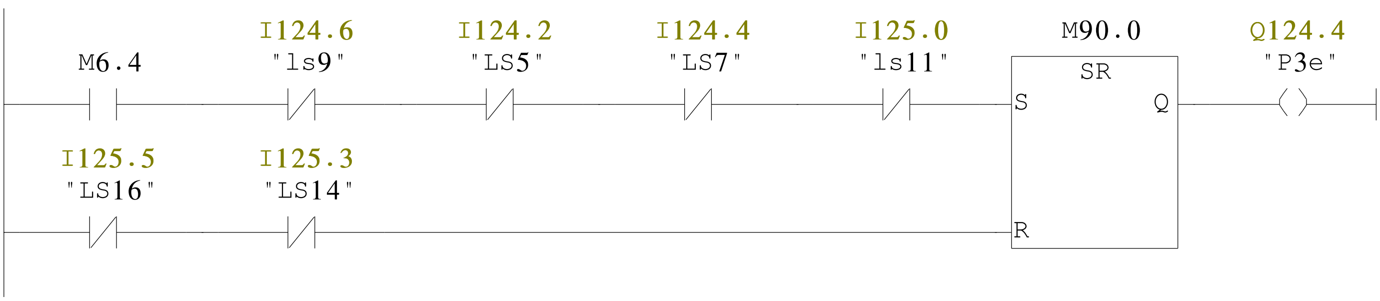


Network: 24

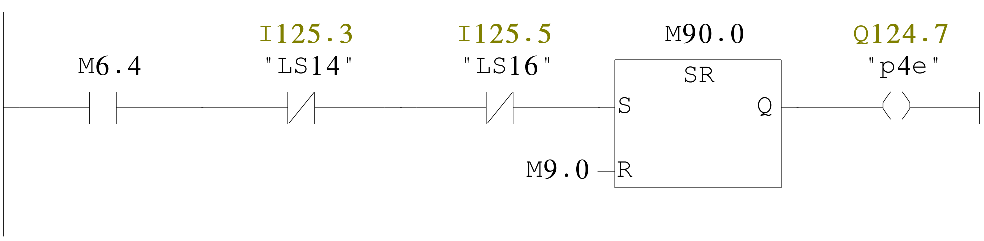


Network: 25

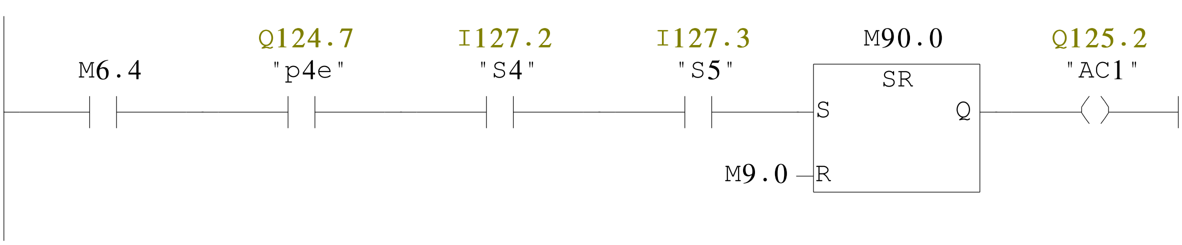
Network: 26



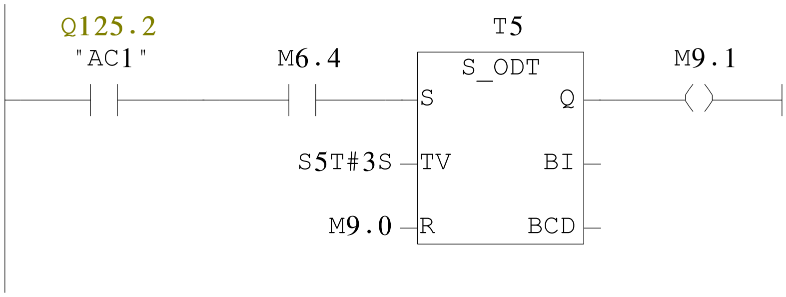
Network: 27



Network: 28

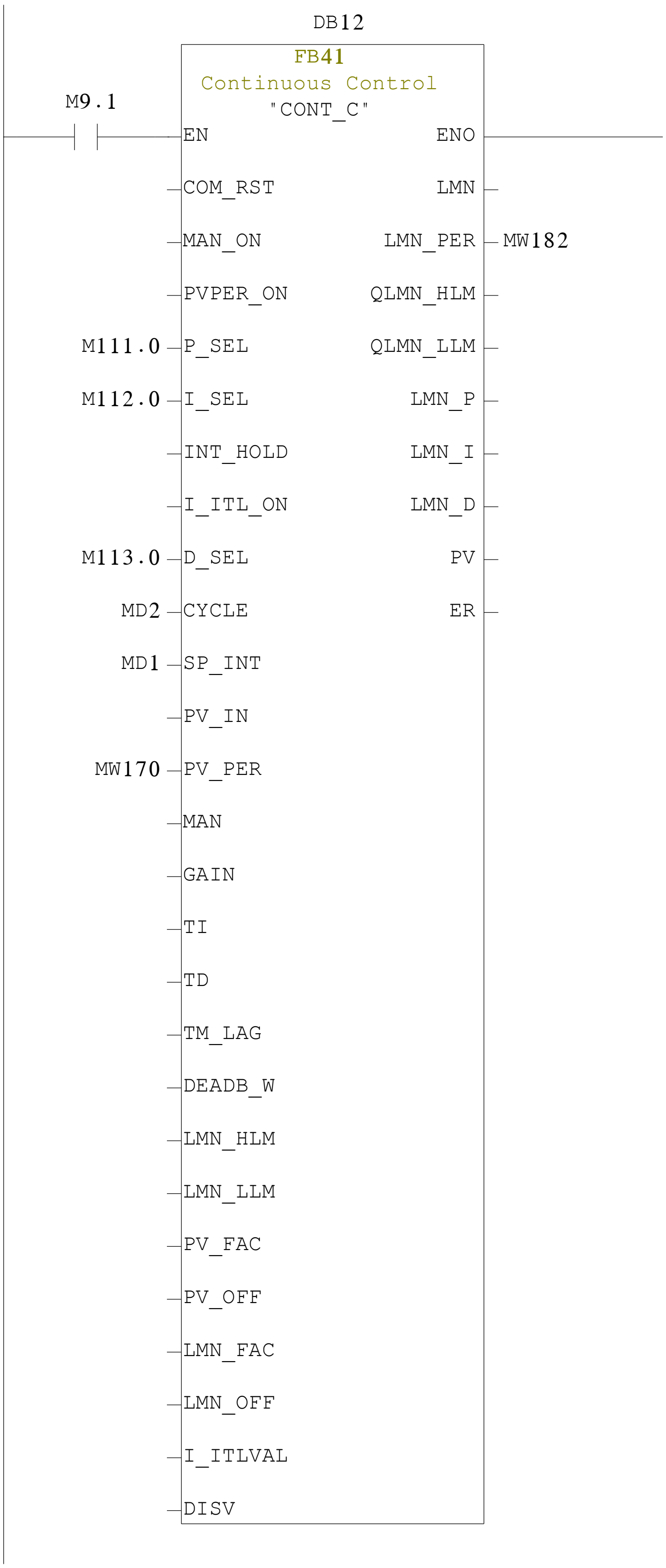


Network: 29



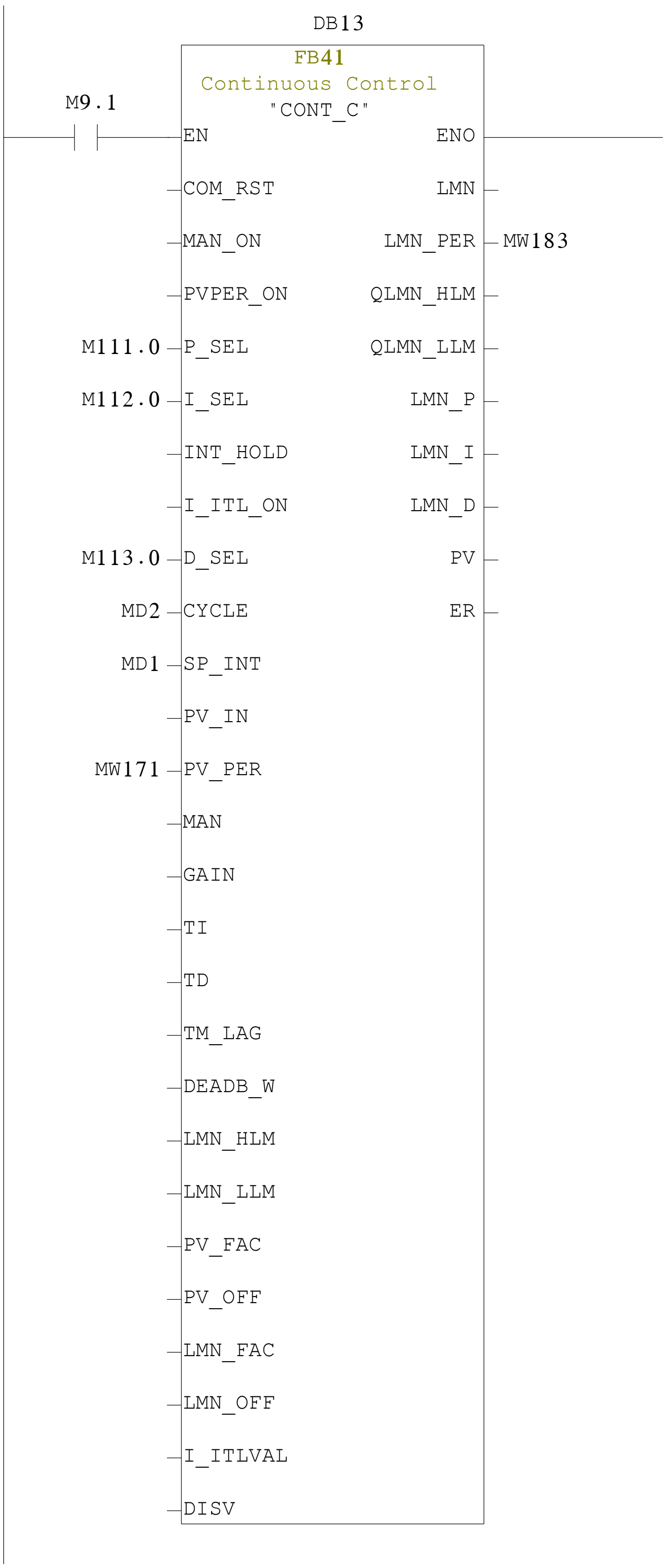
Network: 30

PID for motor1



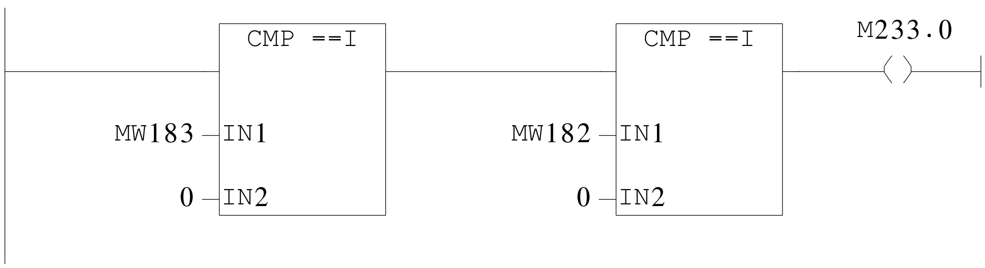
Network: 31

PID for motor 2

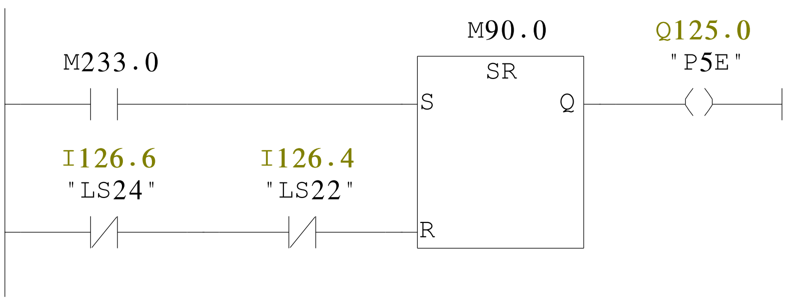


Network: 32

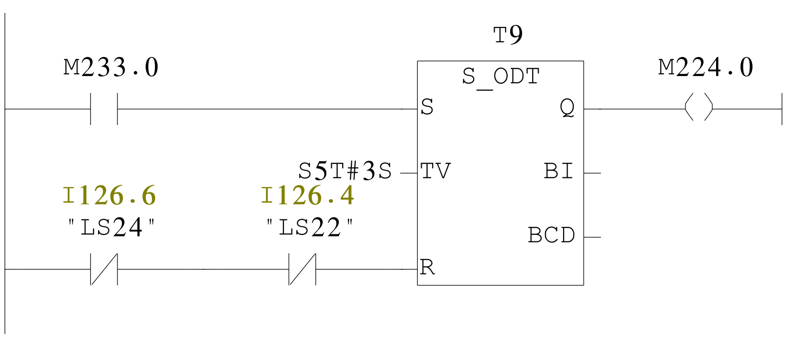
finish cutting



Network: 33

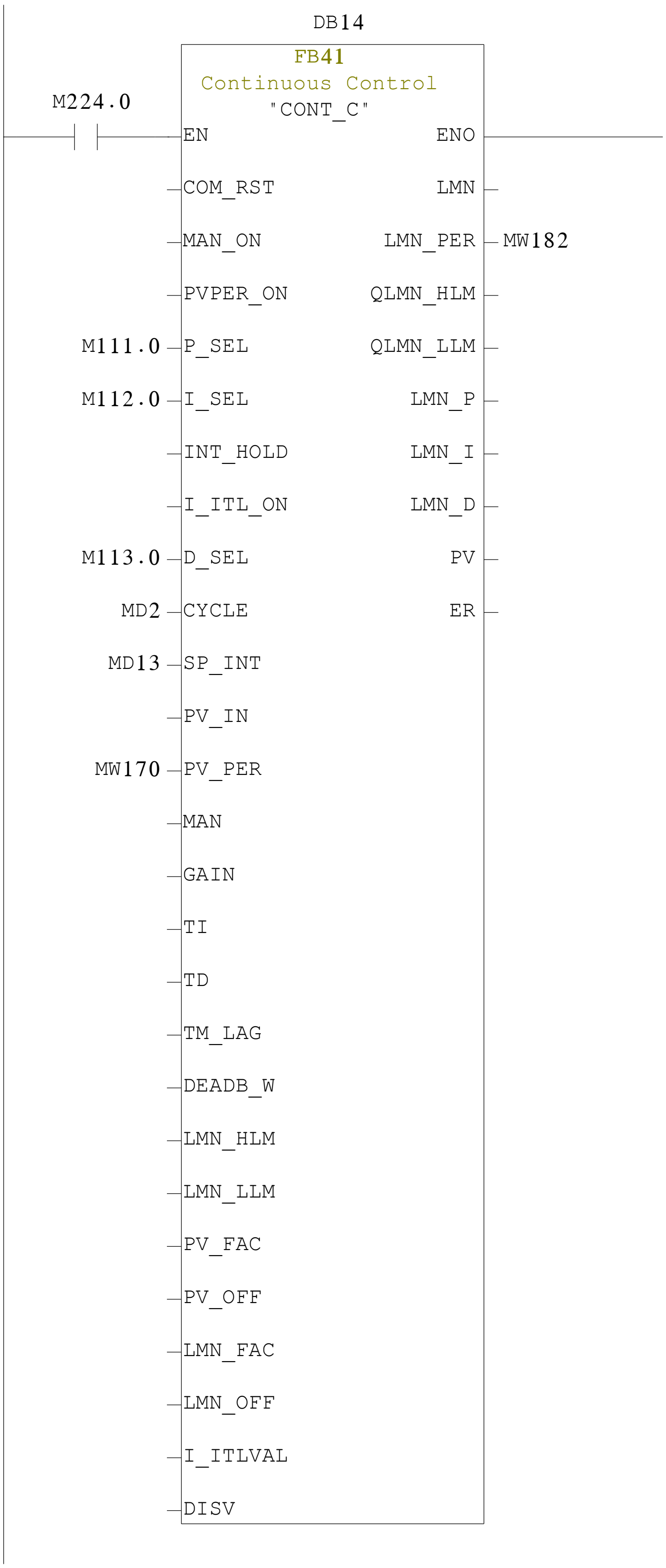


Network: 34

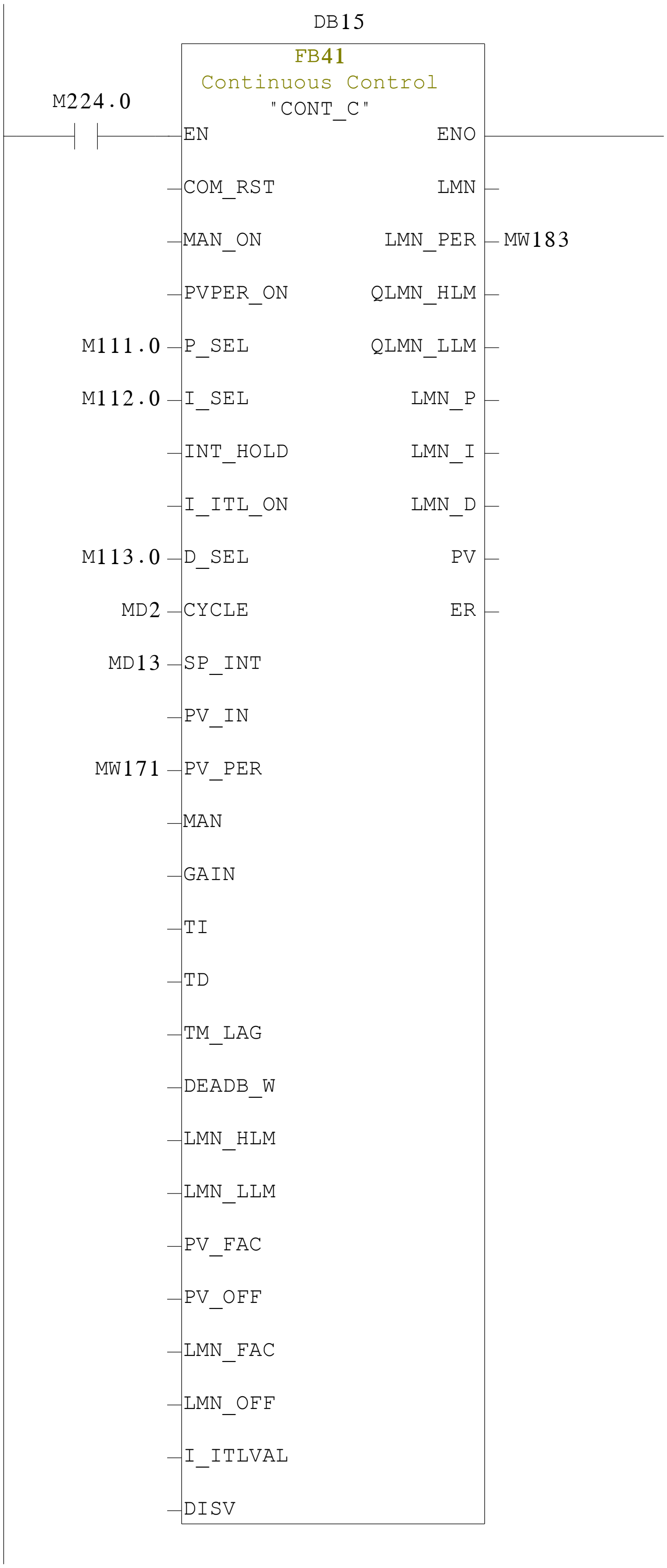


Network: 35

back 15 cm

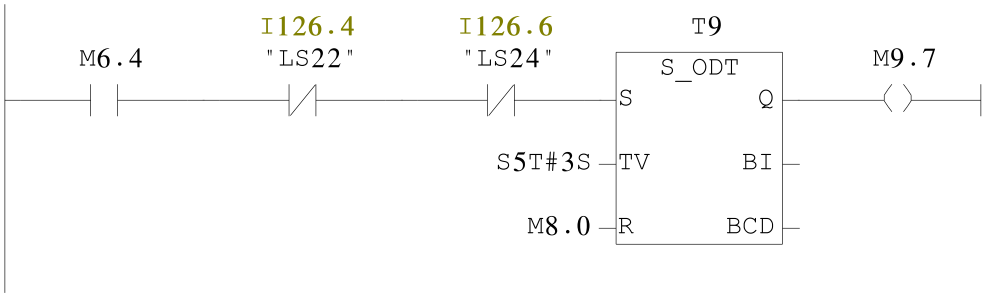


Network: 36

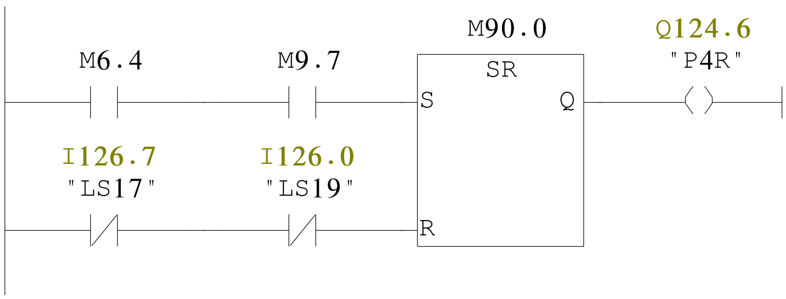


DB15
FB41
Continuous Control
"CONT_C"
M224.0
EN
ENO
COM_RST
LMN
MAN_ON
LMN_PER
MW183
PVPER_ON
QLMN_HLM
M111.0
P_SEL
QLMN_LLM
M112.0
I_SEL
LMN_P
INT_HOLD
LMN_I
I_ITL_ON
LMN_D
M113.0
D_SEL
PV
MD2
CYCLE
ER
MD13
SP_INT
PV_IN
MW171
PV_PER
MAN
GAIN
TI
TD
TM_LAG
DEADB_W
LMN_HLM
LMN_LLM
PV_FAC
PV_OFF
LMN_FAC
LMN_OFF
I_ITLVAL
DISV

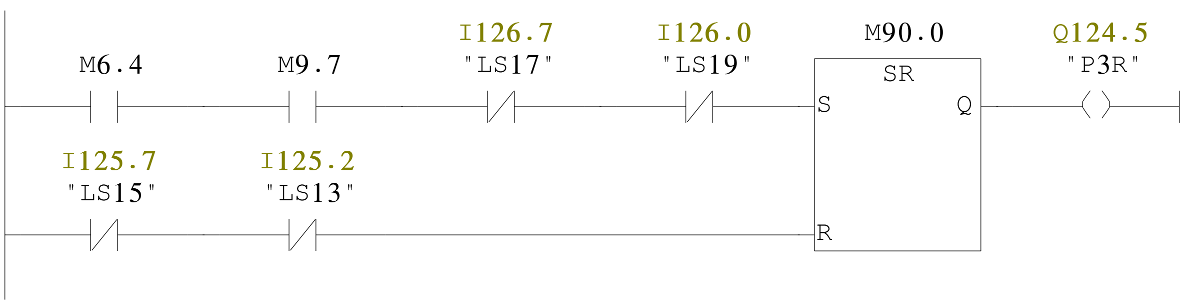
Network: 37



Network: 38

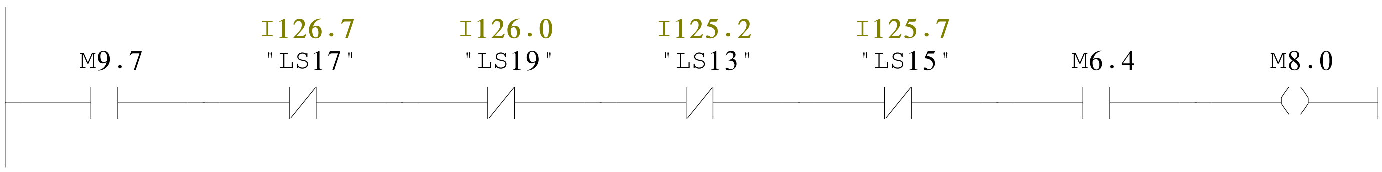


Network: 39



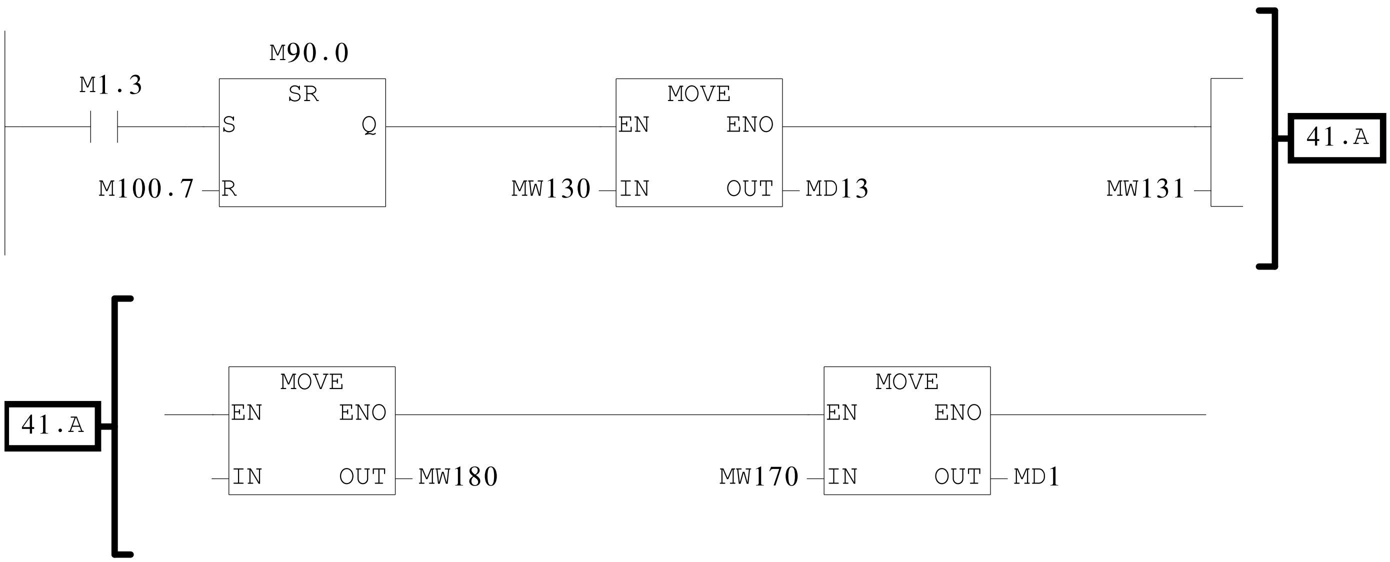
Network: 40

finish

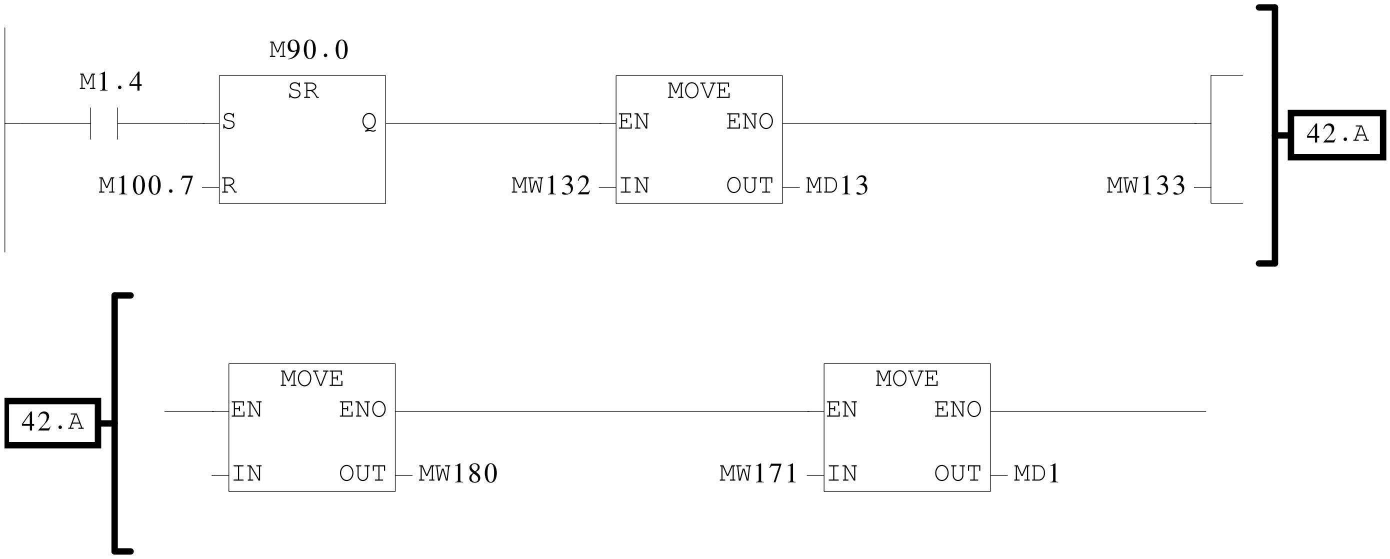


Network: 41

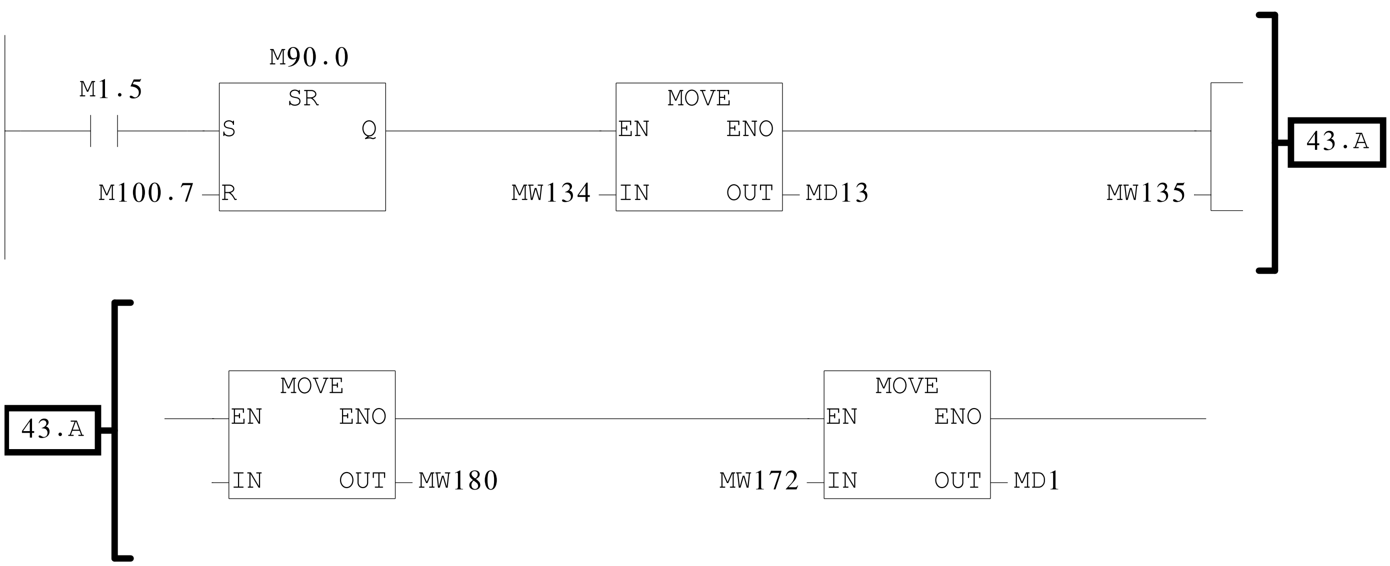
pressure & siting



Network: 42



Network: 43



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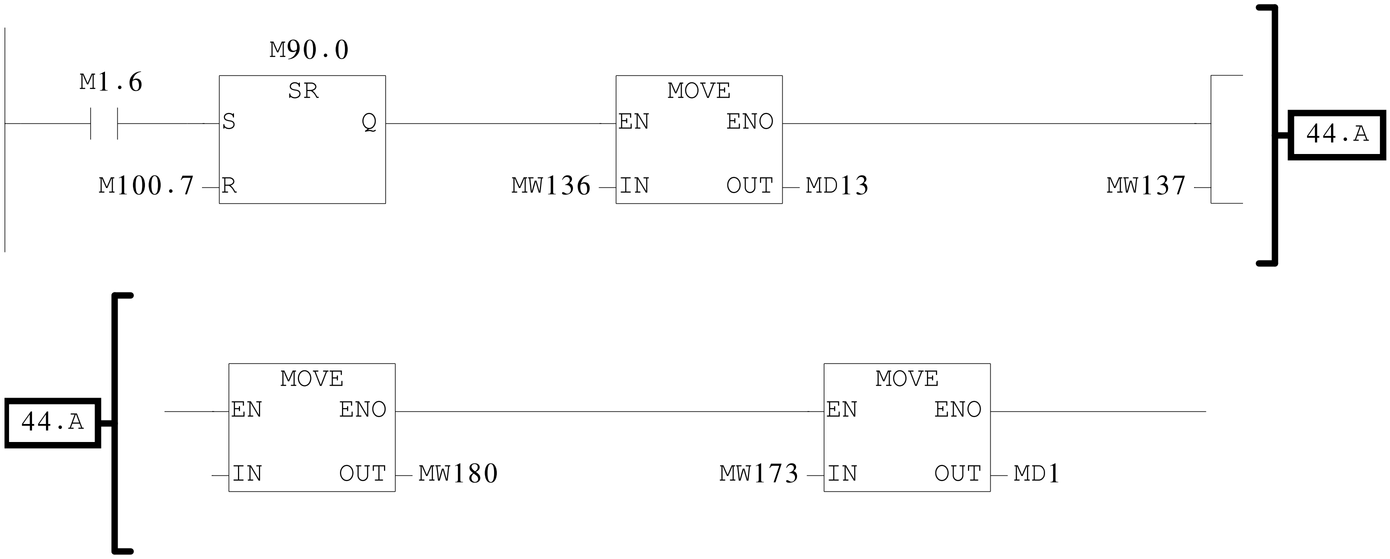

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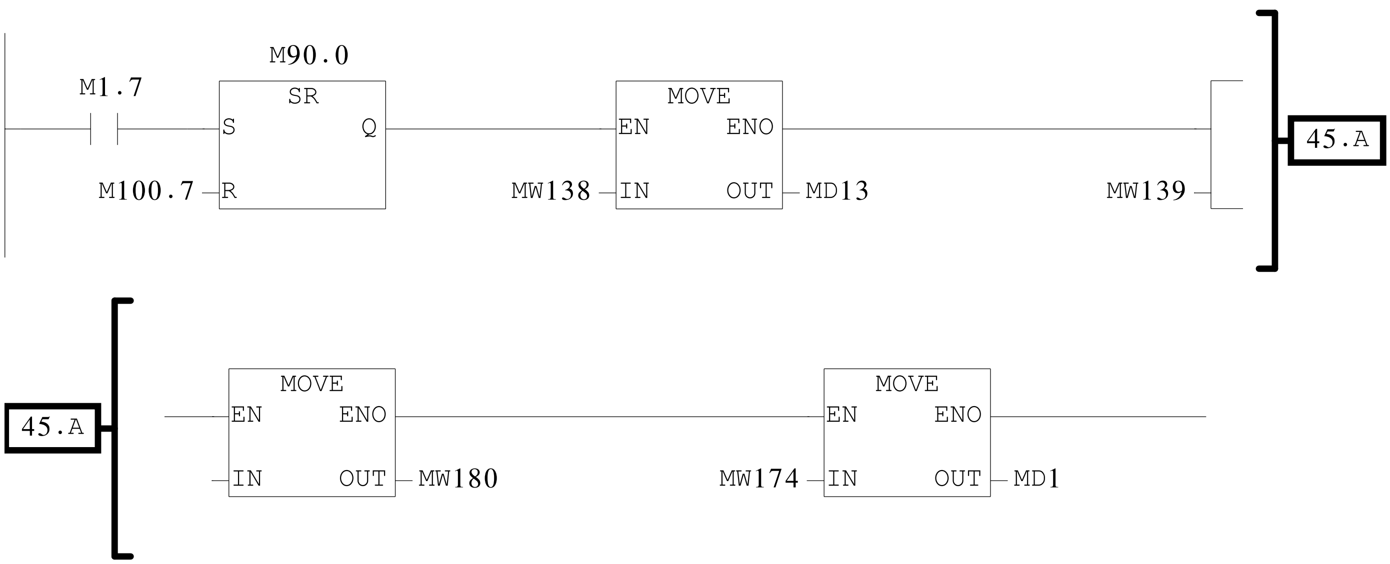

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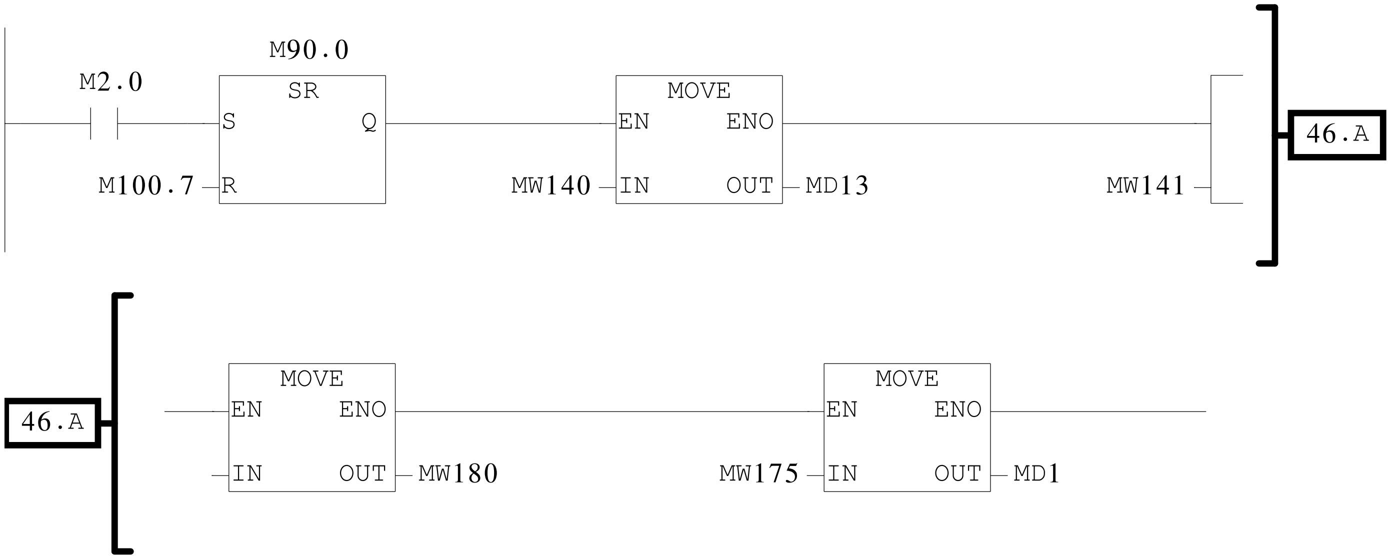
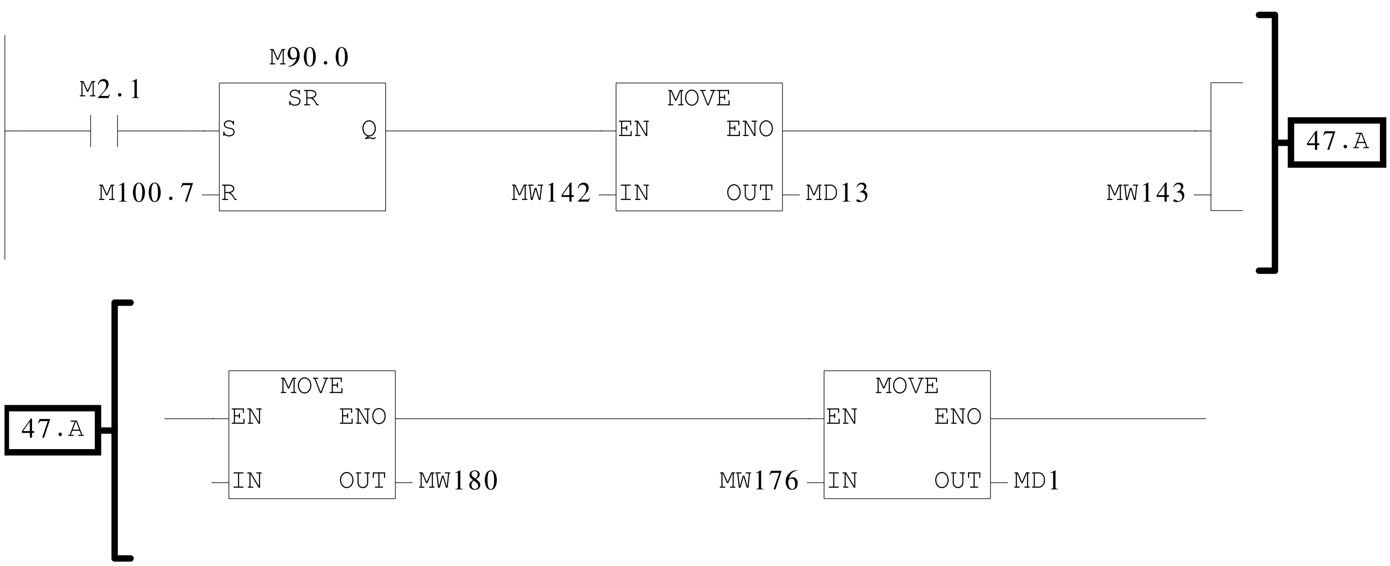
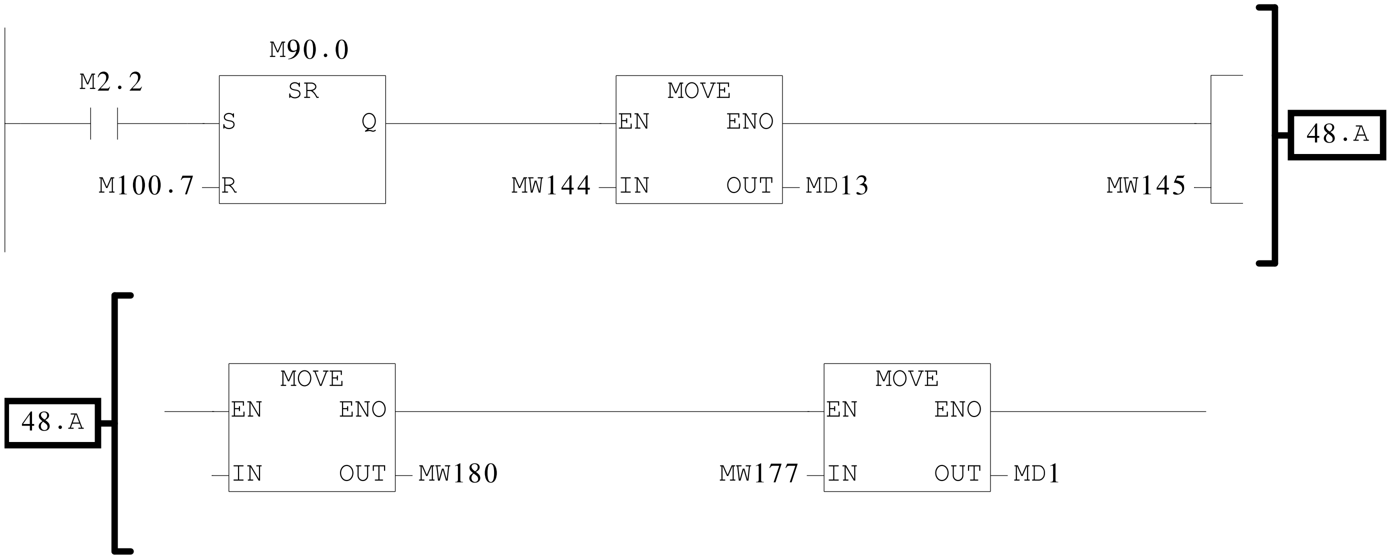


Network: 47



Network: 48


M90.0
M2.2
SR
S
Q
M100.7
R
MOVE
EN
ENO
MW144
IN
OUT
MD13
MW145
48.A
48.A
MOVE
EN
ENO
IN
OUT
MW180
MOVE
EN
ENO
MW177
IN
OUT
MD1

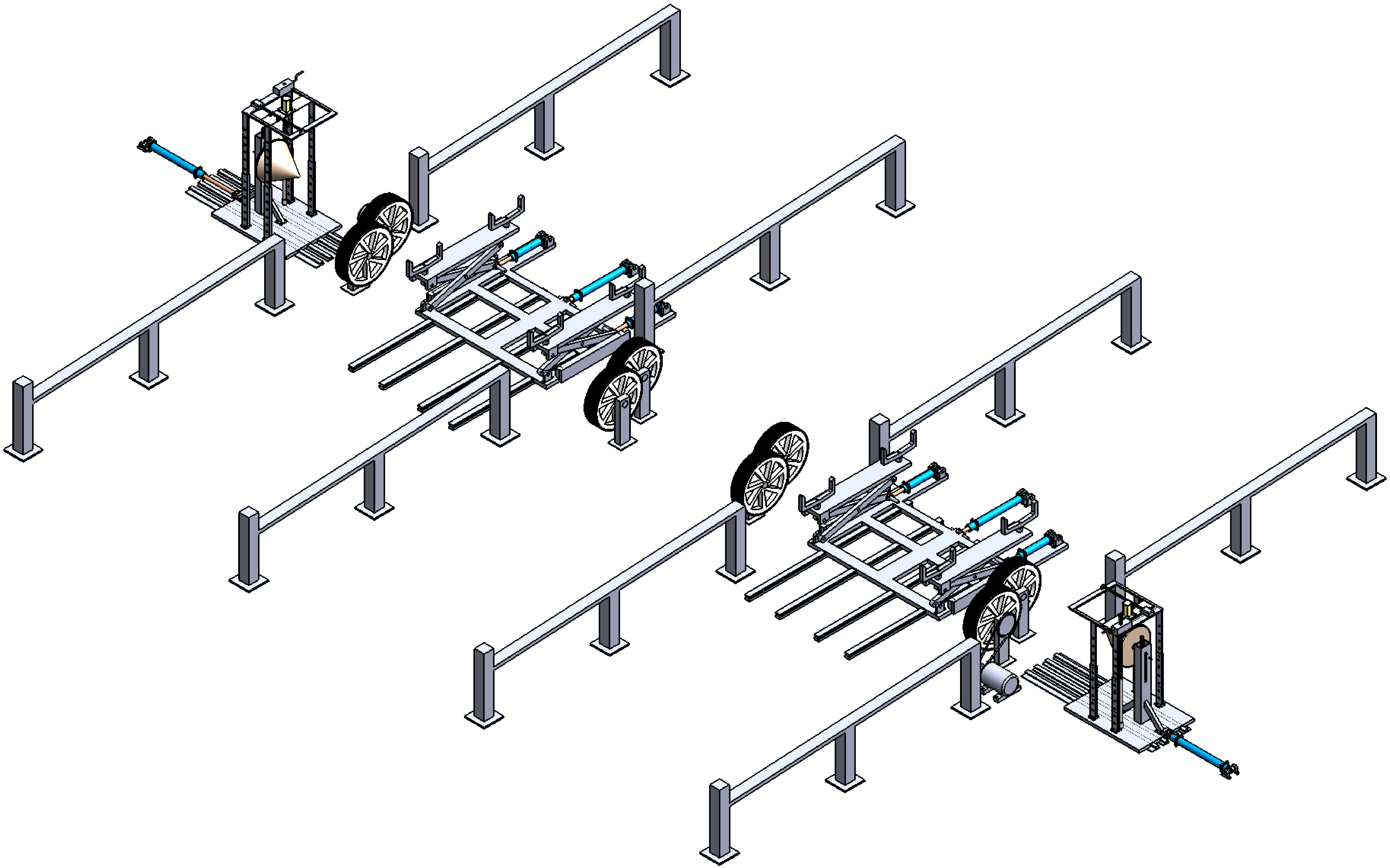
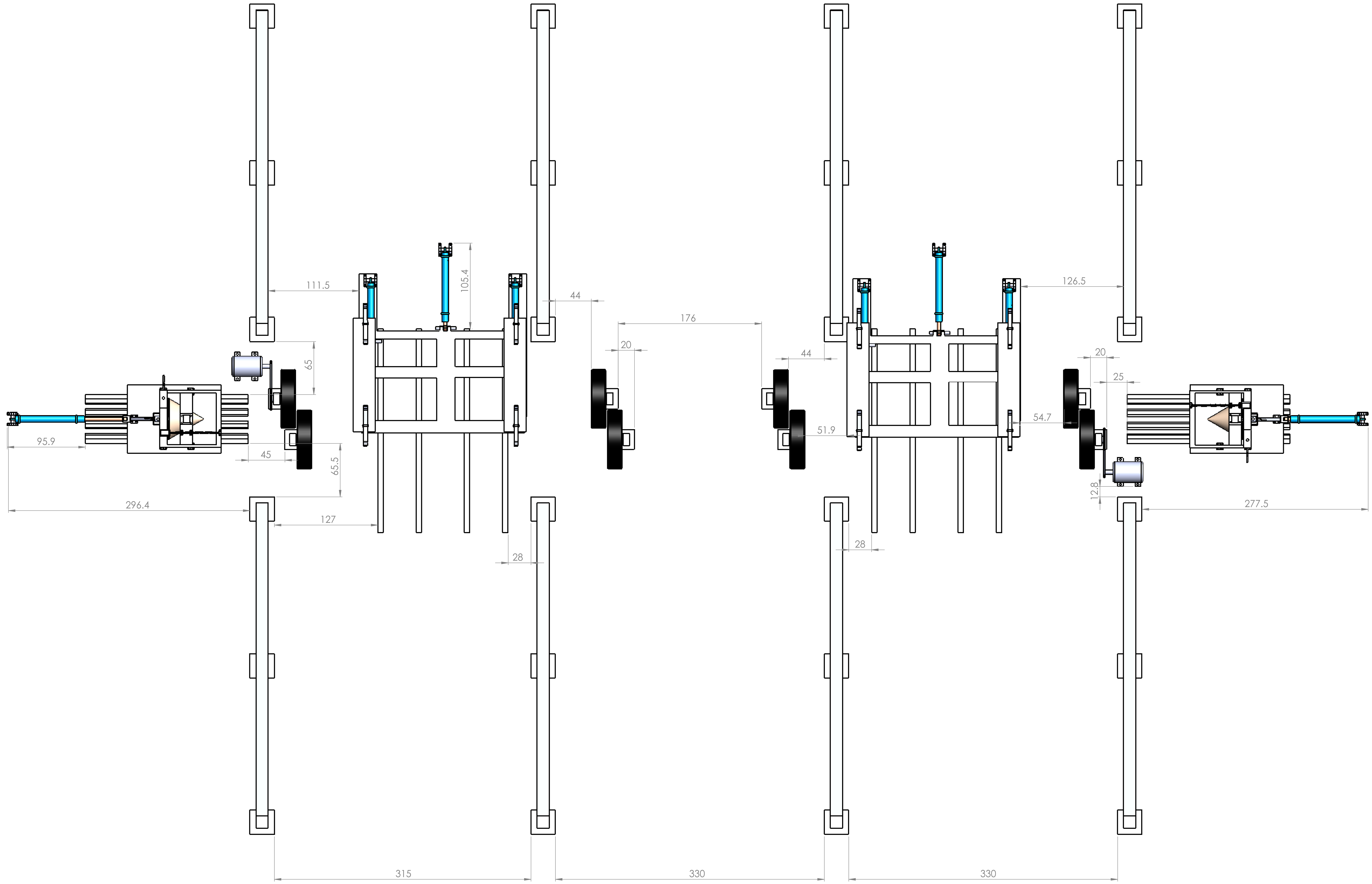


Figure 3.1 : Overall view of the new machine



Appendix F | SCALE:1:1 | DWG NO. ECM layout | A1

SHEET 1 OF 1