MARMARA UNIVERSITY

FACULTY OF ENGINEERING

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GRADUATION PROJECT REPORT

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1000 Ton Deep Drawing Hydraulic Press Design

by

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ABSTRACT

In this article, the definition of hydraulic presses, their working principles, their classification according to their shape and the process performed, and then the design specifically for deepdrawing has been started. At this stage, first the components of the deep drawing press were given, and then, when designing, appropriate materials and components were selected, considering the strength and fluid mechanics criteria. In the next sections, the benefits of the hydraulic deep drawing press, the evaluation of innovative ideas for its improvable areas, and what can be done for industry 4.0 are evaluated. In the Appendices section, technical drawings and analyzes of the designed press are included. After drawing the technical drawings, the accuracy of the calculations will be tested by simulating the strength of the design with using the finite element method. As a result, if there is no problem, the total cost of the hydraulic deep drawing press will be calculated by making a cost analysis.

SYMBOLS

P: Pressure

A: Area

F: Force

Q: Volume flow rate

η: Efficiency

W: Power

σ: Normal stress

τ: Shear stress

a_f: Application factor

S_f: Factor of safety

ABBREVIATIONS

TDC: Top Dead Center of hydraulic cylinders

BDC: Bottom Dead Center of hydraulic cylinders

$\boldsymbol{A_{m,c}}$: Main cylinder fluid area

$\boldsymbol{A_{b,c}}$: Blankholder cylinder fluid area

$\boldsymbol{d_{m,c}}$: Main cylinder inner diameter

$\boldsymbol{d_{b,c}}$: Blankholder cylinder inner diameter

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1. INTRODUCTION

The deep metal containers and single-piece deep materials that we use in many areas in our daily lives have attracted our attention. So how are these products, which take a deep place in our lives, produced? Actually, there are several alternative answers to this question. But we will deal with deep drawing, one of these production techniques. The deep drawing method is a production method that has been in our lives for many years. It is widely preferred in the industry due to its accessibility and ease. Let's take a closer look at this production method; First of all, deep drawing presses work by applying a controllable force to a flat metal plate, giving the part a depth of desired size. Although it does not work so simply in practice, the entire main logic is within this framework. However, we cannot always apply force to a plate and shape it at once. This process must be gradual. Let's briefly talk about these requirements:

- Desired depth of the part
- How many different radii the part to be given depth contains
- Thinning tolerance of the part during shooting
- Thickness of the part

Some factors such as determine the number of steps and the number of dies to be used when machining the part. Of course, depending on these, there are changes that need to be made in the presses. For example, there are many customized factors such as an adjustable table should be made according to the part that the press will produce, and the power of the hydraulic system should be adjusted according to the thickness of the material that the machine will produce. All of these design criteria will be discussed in detail later in this article.

2. WORKING PRINCIPLE

In general terms, hydraulics is the science of analysis of the controllable power and motion transferred by a fluid at a certain desired fluid pressure and fluid velocity. The hydraulic press is a machine that allows changing the shape of materials and making new products thanks to this science.

In the hydraulic press machine, power transfer is used during the compression of the fluid by using hydraulic cylinders. Since fluids are generally incompressible materials. This allows to transmit the comprresion force and this transmission consists of two interconnected cylinders with fluid between them. The primary cylinder, called the plunger cylinder is used to initiate and control fluid flow through system and initially pushes the fluid and the pressure passing over the fluid is transferred and delivered to the ram. The ram is the secondary cylinder, and it is responsible for transmitting this transferred energy to the part to be processed. Due to the working logic of the hydraulic press, the diameter of the plunger cylinder is smaller than the ram.

Considering the ideal situation there will be no pressure losses and the plunger cylinder, which is the starting cylinder, will transfer the same pressure to the ram cylinder at whatever pressure it is compressing. Since the pressure is obtained by dividing the applied force by the area, if the pressures are equal and the cylinder surface areas are known, the force increment in the cylinders can be found according to Pascal Law by the Eq. 2.3 below.

$$P_1 = \frac{F_1}{A_1} \qquad and \qquad P_2 = \frac{F_2}{A_2} \tag{2.1}$$

$$P_1 = P_2 = \frac{F_1}{A_1} = \frac{F_2}{A_2} \tag{2.2}$$

$$F_2 = F_1 \frac{A_2}{A_1} \tag{2.3}$$

At the same time, since the flow rate of the fluid passing through the cylinders will be equal, the stroke length of the cylinder with the smaller area should be longer than the other. This is the advantage of the small diameter of the plunger cylinder, because small diameter means longer stroke and less force applied to move fluid.

But on the other cylinder, the desired force should be high and since the distance is short, a large diameter ram cylinder should be chosen. The below figure shows the effect on the ram cylinder when the plunger is pushed.

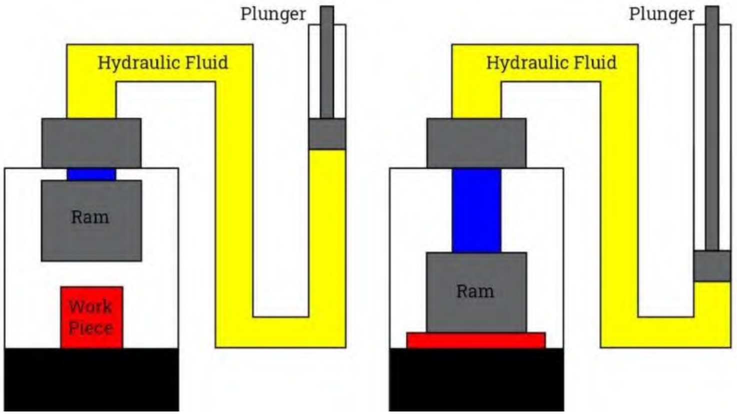


Figure 1: Plunger and ram connection [1].

Also, the change between distances can be found by equalizing volume flow rates. If these values are equalized, below Eq. 2.4 can be found which shows the distance should plunger travel to move ram for 1 unit.

$$y_1 = y_2 \frac{A_2}{A_1} \tag{2.4}$$

Where:

y_1: Distance moved by ram.

y_2: Distance moved by plunger.

A_1: Area of plunger

A_2: Area of ram

3. CLASIFICATION OF HYDRAULIC PRESSES

Classification of hydraulic presses can be divided into two main headings. The first of these is classification according to the shape of the press, and the second is classification according to the material processing performed with the hydraulic press.

3.1. According To Shape

Classification according to shape is important because different shapes and configrations serve for different kinds of purposes and suitable for different variety of industries. Shape of a hydraulic press mainly determines the structural design and configration of press.

3.1.1. H Frame

H frame press or shop press takes its name from the shape of the press. There is a horizontal beam connected to two upward-extending columns. The cylinder and material are located at the center of the H frame press. It is highly preffered as the press design consists of legs that support each other. It is more economical than other press designs. It is easy for the operator t intervene in the press because most of its parts are accessible from the outside. Some of the criteria to consider when choosing among H frame presses in term of dimension are: Workpiece size and weight of the material, strength criterias and maximum applied force, having the capacity to adapt to developing technology.

These presses are generally produced to process medium-sized materials. If heavier and larger materials are wanted to be processes, it will work inefficiently as it will not have enough power. Likewise, if small pieces are wanted to be processes, the price will be higher compared to its power. In addition, it has a structure that is susceptible to vibration and will be difficult to use in process requiring precision.

Figure 2: 60 Ton H-Frame Hydraulic Press [2].

3.1.2. C Frame

C-frame presses, also known as gap-frame presses, are one of the presses frequently used in the industry. It takes its name from the letter c, which its shape resembles. After the section where the material is placed at them bottom the main column rises from the back and holds the cylinder at the top of the press. Since the main column of the press is located at the back, it porvides a spacious usage area from the front, so a faster and more compact process is managed when processing materials. In addition, since die change is easier than other press types, it is a preferred hydraulic press type in factories producing different types and shapes of products. Another advantage is that it is cost-effective as it can quickly process high quality products in many areas compared to its price. Generally, these c-frame presses are used to bend, drill, forming.

The disadvantages can be listed as follows:

- Due to the limitations of its shape, it cannot reach high pressures and cannot process materials that require heavy force.
- Although hhaving an open surrounding area provides an advantage, it poses a security risk.
- Small parts can be processed due to its compactness.

Figure 3: TengZhou Zhongyou Heavy Industry Machinery Equipment Co., Ltd, China [3].

3.1.3. Four Column

In the four-column hydraulic press, there is a plate connected to the main cylinder at the top, this plate is called slider. And there are columns at the 4 corners of this slider. A die is attached to the lower part of the slider or upper part of worktable, as required.

The slider moves up and down on these columns, allowing the workpiece to be processed. Additionally, these four columns ensure that the slider is parallel to the worktable when the cylinder moves the slider. This is valid even under the maximum pressure at the time of processing the part. In this way, a homogeneous result is obtained by providing the necessary equal pressure to all surface of the workpiece.

Four-column has a wide are of usage. It has become a frequently preffered type of press, espacially in deep-drawing, die-cutting, metal forming, pressing and stamping process of materials. Also, it can be used for forming of composite materials and plactics. Th fact that the 4 columns align each other and always remain parallel to the worktable and perform operations accordingly has been a significant advantage in terms of accuracy and precision. In addition, since it is produced using high-quality materials and components, it has a longer lifespan. This also ensures that the press covers the installation cost in the long term and maintains its value in case of second-hand sales, making it economically over other types of presses. It has become a preffered press in industry as it is a press type suitable for Industry 4.0 thanks to its multitude of usage areas and compatibility with automation during production. Below figure shows a four-column press which used for deep drawing operation [1].

Figure 4: 400 Ton 4 column hydraulic deep drawing press [4].

The hydraulic press shown in Figure 4 has 2 main cylinders and each produces 200 tons of force, creating a total drawing force of 400 tons. The section above the columns is called upper beam, and it holds the four columns together in the section down to the lower beam or, as mentioned before, the slider. The section to the right of the press is the control unit. This unit allows controlling many parameters such as the operation of the press, cylinder speed, cylinder pressure, time delay under maximum pressure. Due to the signal coming from this unit, the hydraulic pump operates and pushes the oil inside the main cylinders, allowing the slider to move downwards. This process can be lowered quickly at the beginning, and when the slider reaches the level where the part will be processed, it slows down and reaches maximum pressure. The reason for doing this is to prevent unnecessary waste of time and to use the press in the most efficient way possible.

The four column presses also have disadvantages. The press has a complicated structure compared to the other presses, and repair and maintenance costs are more costly and longer lasting than other press types. Energy consumpiton is higher due to its high power, so it is an impractical press for processing relatively small materials.

3.1.4. Horizontal

Horizontal hydraulic presses have one-sided or two-sided cylinders, and these cylinders push the dies attached to them to each other. Due to this, the workpiece is processed by the compression force between them. It is especially used in bending and shaping operations. There are horizontal hydraulic presses in various sizes, so they are used for different purposes in many industries. It is used for bending a metal bar, shaping a corner piece, assembling a train wheel. For small horizontal presses the workpiece is processed serially, ensuring fast and low-energy production. This type of press is suitable for small-sized shaping operations. Below figure 5 shows a large 500-ton horizontal press used in industry.

Figure 5: 500 Ton horizontal hydraulic press [5].

3.2. According To Process

Another classification method of hydraulic presses is their and according to process methods. This classification is very important. Because classifying presses according to their processing methods guides users in choosing the right machine to work in the area they need. Choosing the right press increases efficiency and productivity.

3.2.1. Blanking

Hydraulic blanking presses are emerging in the field of metal production, where precision and interchange are very important. These presses are a method that involves cutting complex shapes and contours from metal sheets with exact accuracy. The control of hydraulic cutting presses includes an advanced hydraulic system that utilizes fluid power during the controlled power generation required for precise cutting operations. These presses are designed as a machine that makes precise cuts from sheets of metal to create products for a variety of industries, in complex shapes from simple geometries to complex contours.

The blanking process begins with careful material selection and die installation. Metal sheets selected according to customized specifications in line with the desired cuts are placed in the printing machine, and special tools consisting of punches and dies are adjusted to achieve the desired die cutting. Hydraulic blanking presses offer adaptability in many aspects, helping to produce parts uniformly and with high precision.

When activated, the hydraulic system compresses the punch through the metal sheet, cutting the exact desired shape. This process, known as blanking, is carried out with meticulous control and ensures clean and accurate cuts are made without the need for a second operation. The versatility of hydraulic cutting presses is used on a wide range of breakdowns, from complex automotive parts to precision electronic programs. Hydraulic cutting presses make an important contribution to increasing efficiency in production parts. Automated operations combined with advanced control systems facilitate high-speed and repeatable cutting operations, reducing production time and costs. The ability to process a variety of sheet metals, including abundant steel, aluminum and alloys, contributes to the versatility of these presses in meeting a variety of industry needs [1]. Below figure shows this process.

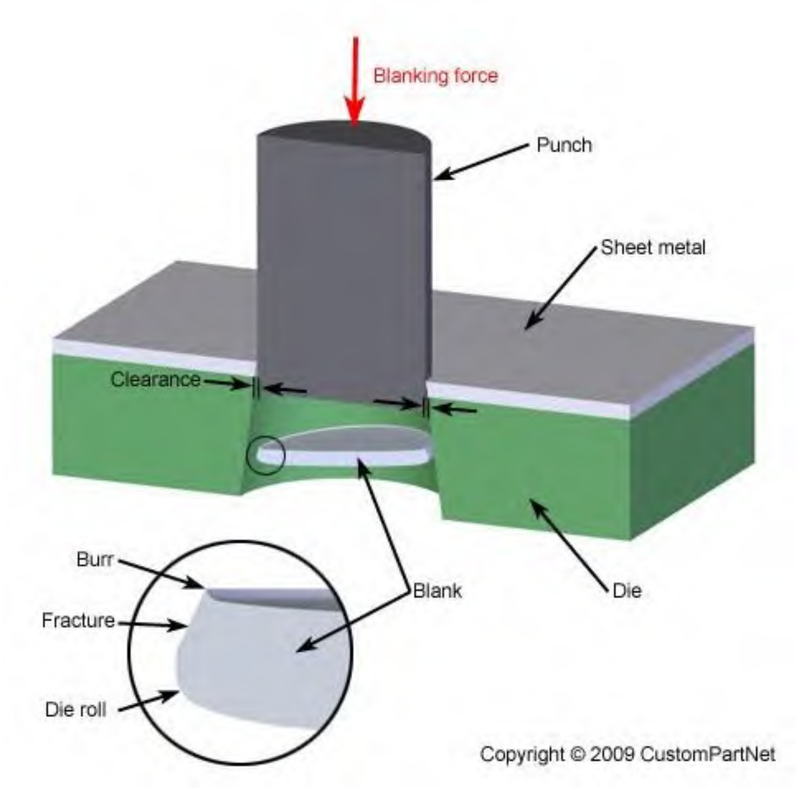


Figure 6: Blanking hydraulic process [6].

As can be seen from figure 6 blanking forc forces the sheet metal to be cut, allowing holes to be opened on the part.

3.2.2. Drawing

Deep drawing is a widely used form of manufacturing for forming sheet metal into tube- or box-shaped structures. Automotive parts such as pots and pans, containers, sinks, panels and gas tanks are some of the products resulting from the shaping of sheet metal using the deep drawing process. If we look at the deep drawing process in general, it can be said that a flat metal sheet is turned into a three-dimensional container or box by applying the necessary forces. The shape of the piece to be created does not need to be limited to a circle or square; It is also possible to produce more complex shapes. However, as complexity increases, the difficulties encountered in production also increase at the same rate.

It is ideal to make the deep drawing form as simple as possible. In primary sheet deep drawing, the bottom of the part is flat and the edges are straight. Sheet metal is deep drawn using a punch and die. The stamp is the desired shape of the base of the part after it has been drawn. The sheet metal workpiece, called the blank, is placed over the die opening. A blank holder surrounding the punch applies pressure to the entire surface of the blank (except the area under the punch) and keeps the sheet flat on top of the die. The fist moves into space. After contacting the workpiece, the punch presses the metal sheet into the cavity of the die, forming its shape.

Sheet metal deep drawing equipment includes a double-action process, one for the sheet holder and the other for the punch. Both mechanical and hydraulic presses are used in the manufacturing industry. Typically, the hydraulic press can control the movements of the holder and the punch separately, but the mechanical press is faster. Stamping materials for deep drawing of sheet metal are generally tool steels and iron. However, the range of materials for punches and dies can vary from plastic to hard metal. Parts are pulled at 4 to 12 inches per second, depending on the type and thickness of the material [2].

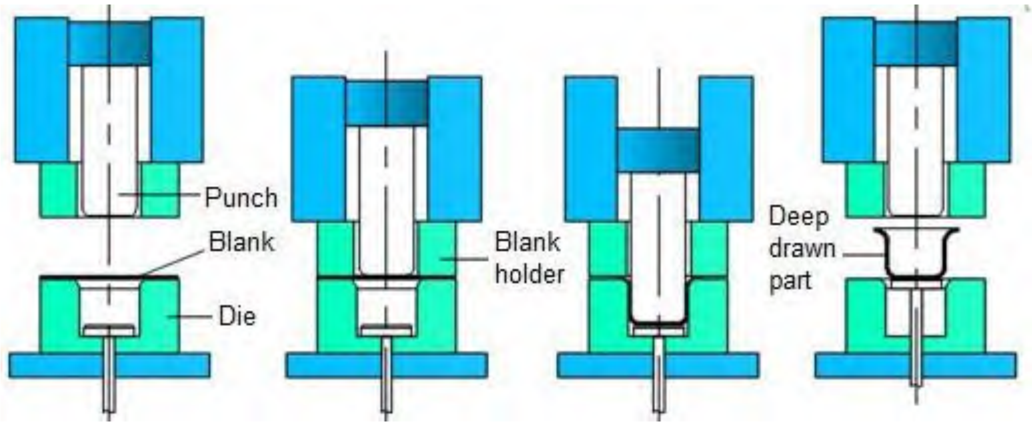


Figure 7: Deep drawing process animation [7].

3.2.3. Piercing

Hydraulic piercing presses are one of the important presses used to precisely create holes and perforations in metal sheets. The basis of hydraulic drilling presses is a robust hydraulic system that uses the power of fluid dynamics to perform controlled drilling operations. These presses are designed to create precision holes or perforations in sheet metal, addressing numerous applications in industries such as automotive, aerospace and general manufacturing.

The drilling process begins with the selection of material without any defects and tool setup. Metal sheets of different thicknesses are loaded into the press, and special tools consisting of punches and dies are arranged to create the desired hole pattern. When the press is started by the operator, the hydraulic system pushes the punch and applies a controlled force to contact the metal sheet. This process, known as drilling, is performed with precision to minimize the risk of deformation or irregularity.

Hydraulic drilling presses are very good at achieving repeatable and consistent results, making them indispensable in the manufacturing industry. Applications for hydraulic punch presses range from creating vents in automotive components to producing perforated metal sheets for architectural and decorative purposes.

It appears as a versatile machine thanks to its possibilities of processing various materials, including steel, aluminum and alloys. In addition, these machines seem to be modernized with industry 4.0 compatibility and will be used in the metal processing industry for many years to come.

3.2.4.Strechting

Hydraulic stretching presses undertake a challenging job in the field of metal forming. It is used in a wide range of areas in the automotive manufacturing, aerospace and general metal manufacturing sectors in metal forming by stretching, which is a field that requires controlled force and high consistency. At the heart of the hydraulic stretching press is an advanced hydraulic system that harnesses the power of fluid dynamics to generate the force required for the stretching process. Hydraulic stretching presses, with the help of the force received from hydraulics and the special dies used, stretch the metal sheets with the least possible deformation and allow them to take the shape of the diesdies. That is why they are used in many areas.

The process begins with meticulous material preparation, where metal sheets or plates are carefully selected based on composition and thickness. Tooling follows with a meticulously configured set of punches and dies to achieve the desired stretching pattern. The punch, which acts as a catalyst for the transformation, applies force to the material, while the die provides the necessary support.

Loading the material into the die prepares the necessary environment for the hydraulic press to come to life. When the press is activated, the hydraulic cylinder begins applying controlled force, moving the punch. The material undergoes plastic deformation, stretches and assumes the intended shape defined by the tool. The design of the hydraulic system allows manufacturers to tailor the stretching process to specific designs, ensuring uniformity and minimizing the risk of defects. One of the key advantages of hydraulic stretching presses lies in their versatility.

From machining automotive body panels to forming components for aerospace applications, these presses fit across countless industries, providing a cost-effective and efficient solution for complex metal forming processes. The controlled and powerful force applied by hydraulic stretching presses not only ensures precision but also minimizes material waste. In this respect, it is both environmentally friendly and economical.

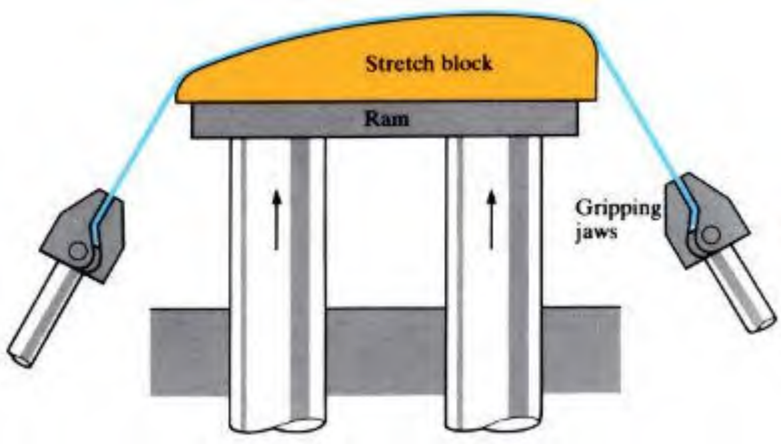


Figure 8: Streching Process [8].

3.2.5. Straightening

In the world of metal fabrication, precision is not just a desire but a necessity. Hydraulic straightening presses are equipment used to correct distortions and defects in metal components. At the core of these hydraulic presses is a robust hydraulic system that harnesses the power of fluid dynamics to apply controlled pressure on amorphous metal. The straightening process is a job that requires strength and mastery and allows manufacturers to correct bends, slopes and deformations to the most optimal values.

The journey begins with identifying misaligned metal components. Whether it is a structural beam, a pipe or a plate, hydraulic straightening presses are very good at this. The versatility of these machines allows them to eliminate distortions caused by various production processes, allowing the final product to meet stringent quality standards. Tool setup is a critical aspect of the trimming process.

Manufacturers use some tools, such as hydraulic cylinders and dies, that are designed according to the specific needs of the material and the degree of correction required. This adaptability allows the flattening process to be customized, ensuring that each component is meticulously returned to its intended form.

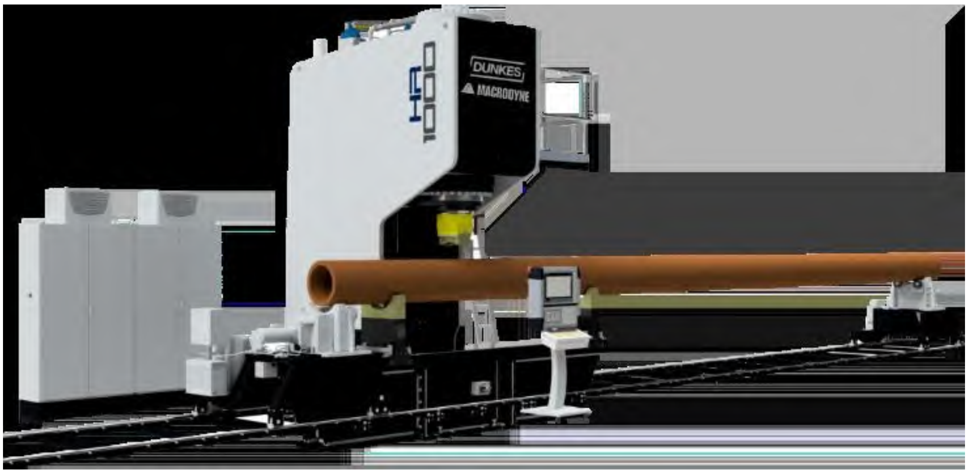


Figure 9: Straightening process [9].

The correction process begins when the deformed metal is placed in the hydraulic press. Activating the hydraulic system, the press gradually returns the material to its original shape by applying the necessary force in the direction of distortion. Controlled pressure ensures smoothing is precise and even, minimizing the risk of excessive bending or damaging the material. The applications of hydraulic straightening presses are wide-ranging. From salvaging salvaged parts to upgrading machined parts, these presses play a crucial role in salvaging materials that may have been deemed unusable.

In sectors such as construction, automotive and manufacturing, where structural integrity is very important, the ability to correct deformations so precisely makes production easier. Additionally, hydraulic straightening presses contribute to sustainability by reducing material waste. The ability to recover and correct faulty material not only saves resources but also accompanies ethical responsible manufacturing standards.

3.2.6. Folding

In the field of metal fabrication, the art of folding and shaping complex designs requires strength and precision. Hydraulic folding presses are emerging as indispensable tools that bridge the gap between functionality and aesthetic appeal. At the heart of hydraulic folding presses is an advanced hydraulic system that uses fluid power to generate the force required for precise folding. These machines are designed to bend and shape sheets of metal with unparalleled accuracy; This makes them indispensable in industries where complex designs and precise angles are crucial.

The process begins with meticulous material selection and die installation. Metal sheets selected for their specific properties are loaded into the press, while a combination of punches and dies are configured to achieve the desired folding pattern. The adjustability of hydraulic folding presses allows manufacturers to service a wide range of designs, from simple bends to complex, multi-fold geometries. The folding process begins with the start of the hydraulic system.

The hydraulic press applies force with precise control, guiding the sheet metal through the bending process. This controlled force ensures that the folds are smooth, perfect and match the intended design exactly. The versatility of these presses allows seamless switching between various folding angles, helping manufacturers realize products of different shapes. Hydraulic folding presses are used in a wide range of applications in industries such as architecture, automotive manufacturing and metalworking, where precision folding is widely used to create components with both structural integrity and aesthetic appeal.

From creating complex details on automotive body panels to machining sharp-edged architectural parts, these presses play an important role in improving the quality and functionality of a variety of products. One of the notable advantages of hydraulic folding presses is their efficiency in processing a variety of materials, including stainless steel, aluminum and other alloys. This versatility makes them indispensable in meeting the needs of modern metal manufacturing in many areas, contributing to the creation of durable and aesthetically perfect products.

Figure 10: Folding process [10].

3.2.7. Coining

In the complex world of metalworking, achieving unparalleled precision and detail is a pursuit that requires cutting-edge technology. Hydraulic coining presses are at the forefront of this pursuit, offering tremendous possibilities for creating finely detailed and precisely shaped coins, medallions and complex components. At the heart of hydraulic printing presses lies an advanced hydraulic system that harnesses the power of fluid dynamics to apply controlled pressure on metal blanks. These presses are designed with precision and strength in mind so that they can engrave complex designs and fine details on the surface of coins and medals.

The controlled force provided by the hydraulic system ensures consistency, accuracy and clarity in the pressing process. The printing process begins with careful selection of metal blanks and die setup. Each printing press is equipped with special dies engraved with the desired design or pattern. Metal blanks, typically made from alloys such as copper, nickel or gold, are loaded into the press and the hydraulic system is engaged to apply force through complexly designed dies.

What sets hydraulic coining presses apart is their ability to produce coins with sharp details and sharp edges. The controlled pressure applied by the hydraulic system ensures that the metal precisely conforms to the engraving properties of the dies, resulting in coins that are not only aesthetically pleasing but also meet the stringent quality standards required for coins and souvenirs.

These presses are widely used in mints where coin production is a delicate process requiring extreme precision. Additionally, hydraulic presses are used to create commemorative medals, tokens, and other finely detailed metal components used in a variety of industries. The versatility of hydraulic coining presses allows for the production of coins and medals in a variety of sizes and shapes, meeting the diverse needs of numismatists, collectors, and industries requiring custom-designed metal coins.

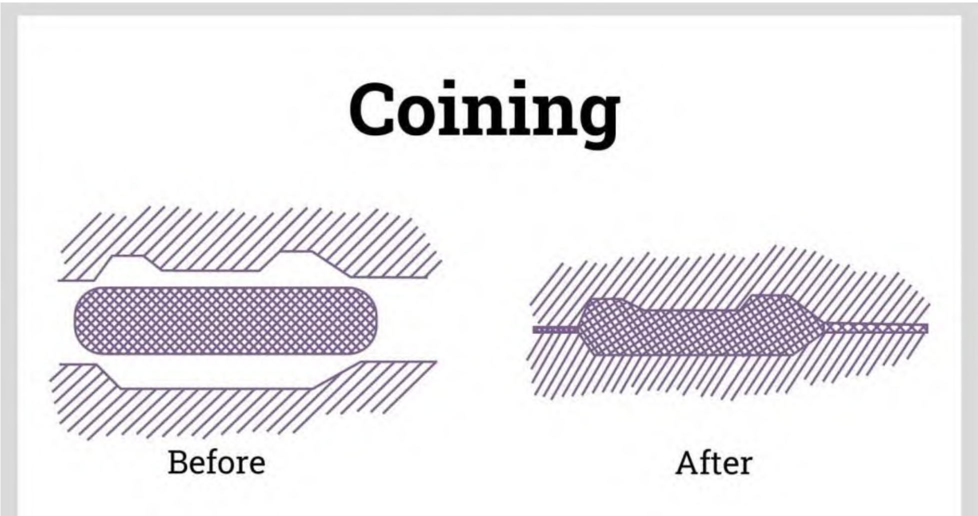


Figure 11: Coining process [11].

4. DESIGN OF DEEP DRAWING HYDRAULIC PRESS

4.1. Components of hydraulic deep drawing press

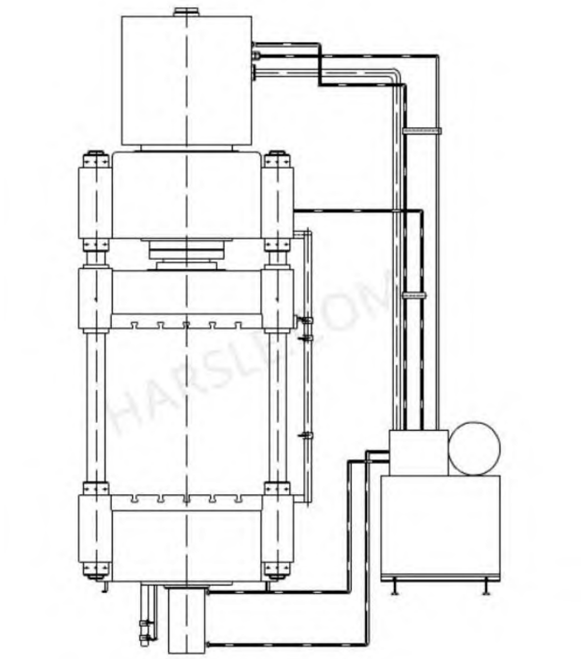


Figure 12: Four-column hydraulic press and hydraulic pump unit with 1 main and 1 blankholder cylinder [12].

Figure 12 shows the technical drawing of four column hydraulic press with one main cylinder and one blankholder cylinder. And at the right side of the press there is pump unit which is connected with these cylinders. Also there is a cable goes columns which is used to lubricate 4-columns.

4.1.1. Hydraulic pump

Hydraulic pumps generally work electrically and are equipment that converts electrical energy first into mechanical energy and then into hydraulic energy. According to the amount of current given to the electric motor, the revolution speed of the hydraulic pump is increased, and thus high pressures and fluid speeds are achieved.

The Q (volume flow rate) value of this high-pressure fluid in the hydraulic pump is equal to the Q value entering the main cylinders. Since there will be 2 main identical cylinders in the deep drawing press to be designed, the flow rate of the hydraulic pump, Q value, can be found by dividing by 2 for each cylinder.

4.1.2. Main cylinder

Main cylinder is the most important element of hydraulic presses. The function of the main cylinderin deep drawing presses is to push the slider downwards, ensuring that the workpiece can be processed while it remains stationary. There are two ports on the cylinder, these are used for both working fluid inlet and outlet. These inlets and outlets are connected to the hydraulic pump via a high-pressure pipe. And they serve to transmit the flow from the pump into the main cylinder. The Figure 13 below shows the cross section of this cylinder. As seen from the Figure 13, a typical hydraulic cylinder consists of the following elements: Cylinder rod, rod seals, cylinder seals, retract flow port and extend flow port [3].

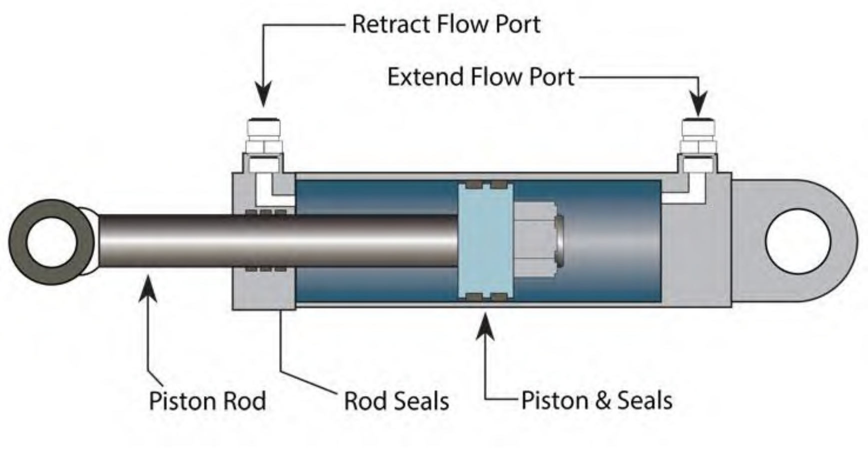


Figure 13: Cross section of cylinder used in hydraulic applications [13].

As can be seen in Figure 13, when the cylinder is wanted to be extended, a signal is sent to the hydraulic pump and fluid flow is started from the extend flow port. Due to the incompressible feature of liquids, the fluid on the left side of the cylinder leaves the retract flow port secton and goes to the other end of the hydraulic pump. As the pressure increases, the cylinder moves to the left and becomes longer. Mean while, the slider moves downwards.

When the cylinder is to be shortened or the slider is lifted up, the flow is reversed and this time the flow is provided by the hydraulic pump from the retract flow port section and the cylinder moves to the right. It is important that the fluids in two separate compartments do not mix each other during this event, because this causes power and pressure losses, so when designing the cylinder, it should be tight enough to not to leak the fluid but slippery enough to minimize friction.

4.1.3. Blankholder cylinder

Likewise, the blankholder cylinder is the same as the main cylinder in terms of its working principle, but it differs in terms of its function. In hydraulic deep drawing presses, the actual drawing process is done by the blankholder cylinder.

The purpose of the main cylinder is to hold the materials stably while the blankholder cylinder applies the drawing process to the material. For this reason, the force of the blankholder cylinder is less than the main cylinder and thus the process is completed without the material moving vertically. The presence of the blankholder cylinder also ensures that the material is subjected to upward pulling. Therefore, after the process is completed, the workpiece is removed, and new material is placed.

4.1.4. Column

Column shaft plays a guiding role for slider and dies during material deep drawing processing. The slider constantly moves parallel to the lower beam and upper beam. Having columns is also important for the stability of the press, they form an extra support elemnt and enable processing at maximum force. By spreading the force transferred from the main cylinder evenly over the part, it minimizes bending-induced deflection and provides a smooth material geometry. The upper point of the column shaft is fixed to the upper beam and passes through the slider, base and lower beam respectively.

4.1.5. Slider

The are two types of sliders in the deep drawing press to be designed. The first one is the slider connected to the main cylinder, and the other one is the slider connected to the bottom blankholder cylinders. The bottom slider can be called base and the top one can be called slider. Accordingly, a female die will be attached to the slider and a male die will be attached to the base. The slider has a longer movement length than the base and the compression force will be greater.

4.1.6. Die

Dies in the hydraulic deep drawing press consist of three parts. These are: upper die, lower die and blank holder. As can be seen from figure 7, the upper die is a female die and lower die is a male die. Male die or also known as puncher die is mainly responsible forming process. It creates cavity inside the material, reduce thickness, aligment of workpiece. It ensures that the material is dispersed and elongated homogeneously thanks to the plastic deformation caused by the stress applied on the material during the deep drawing process. The femal die works together with the male die to determine the boundaries of the outer surface of the material and prevent thickness differences. It is also an important element that determines the outer surface quality of the material.

The blank holder is used to ensure the gap between the dies. If this gap is not provided, the workpiece will be pierced, warp and wrinkle may occur [2].

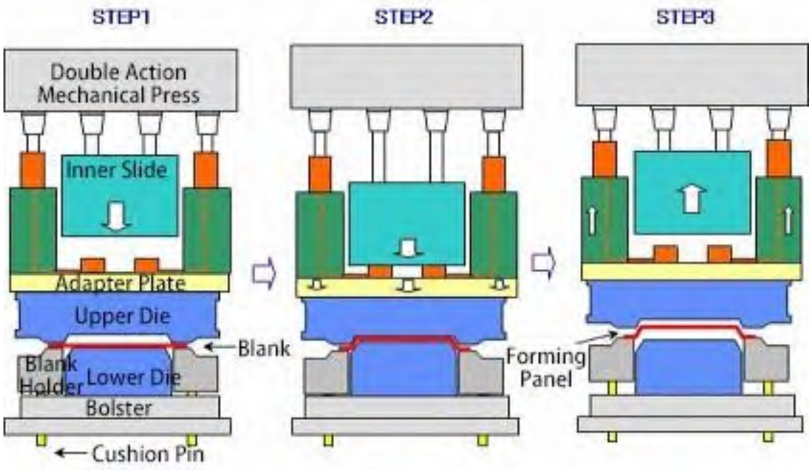


Figure 14: Dies in hydraulic double action deep drawing presses [14].

4.1.7. Lower beam

The lower beam forms the section at the bottom of the press where it contacts the ground. It ensures that a position as stable as possible is maintained while performing operations on the hydraulic deep drawing press. The flexibility margin is very low because slips will cause deterioration on the material. The lower part of the four-columns is fixed to this part.

4.1.8. Upper beam

As seen in figure 7, the upper beam is the support element that holds the upper body of the hydraulic press together. The main cylinder is located at the midpoint of this beam. And it ensures that the load distribution is balanced. At the same time, the upper point of the four-columns is connected to this beam and they become fixed-ended vertical elements.

4.1.9. Control system

The control system is what enables the press to operate, or in other words, it is the brain of the press. All electrical components, including signal cables going to the hydraulic pump, sensors measuring the stroke distance of cylinders, and pressure plates measuring the drawing force, are evaluated through this unit and accordingly ensure that the process continues in a safe and sustainable manner. These systems can be fully automatic or simi-automatic depending on the way the press operates. It functions in various areas such as automation, security, material quality.

4.2. Design Criterions and Critical Parameters

Hydraulic Press Type

When choosing the frame structures of hydraulic presses, it is important which material processing method will be used. Precision and accuracy are one of the most important factors in deep drawing processes. For this reason, a column press was chosen to guide the slider. In addition, since each column is loaded equally, higher tonnages can be processed since a more rigid loading will be made [4].

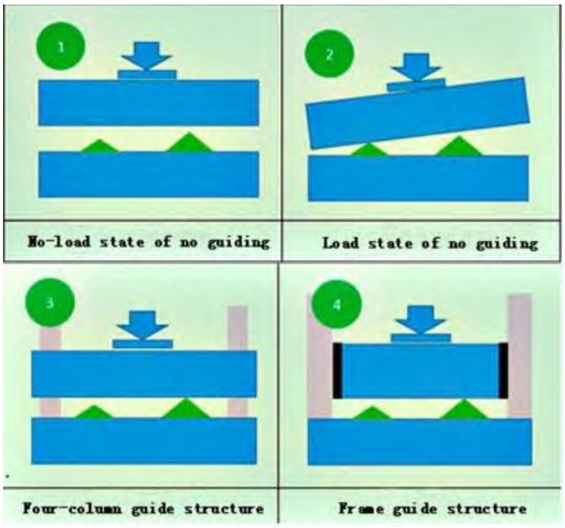


Figure 15: Loading types in hydraulic presses: no guiding, four-column and frame structure [15].

Hydraulic cylinders

In line with the customers who will use the hydraulic deep drawing press, 1000 tons of pressing power and 400 tons of holding power were selected. The factor that concerns us here in terms of design is how these forces will be transmitted. These criteria are number of cylinders, cylinder stroke, cylinder pressure and cylinder speed.

As the number of hydraulic cylinders increases, a more homogeneous machining is performed on the die, and since the cylinders to be used share their power, their diameters will be smaller, making it cost-effective, but the hydraulic system becomes more complex, the piping increases and the number of parts increases. In this design, a 2-cylinder design was chosen to ensure that the printing plate size was 2500mm by 1500mm, the force used was 1000 tons and to make an economical design. Likewise, 2 cylinders will be used for blankholder cylinders.

As seen in the structural analysis comparison below, the 2-cylinder design shows a more uniform distribution on the part than the single-cylinder design. The force spreads out on the slider instead of concentrating at a single point. Single cylinder designs can be used in lower tonnage hydraulic presses, these presses are mostly used in products produced for the end consumer. For example: like a kitchen pot.

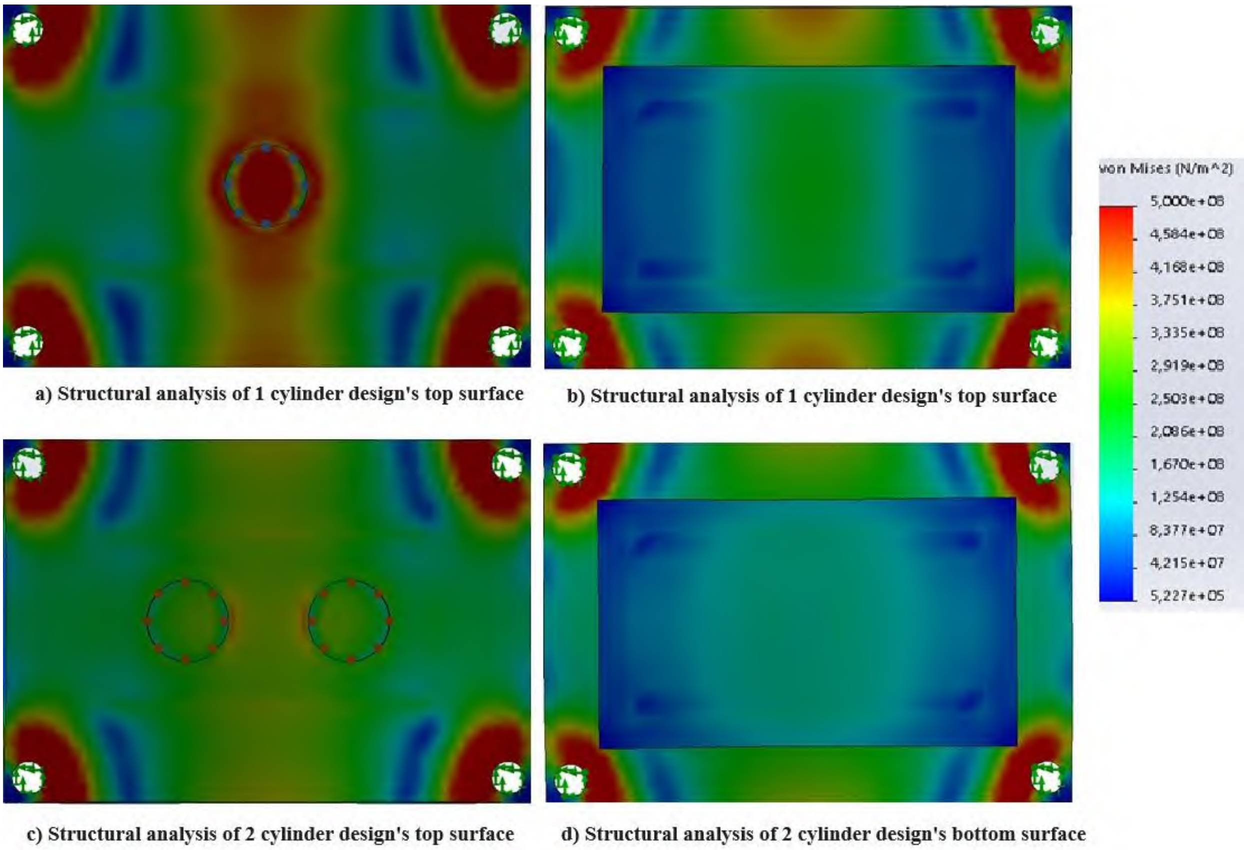


Figure 16: Comparison between structural analysis of 1 cylinder and 2-cylinder systems.

The stroke of the cylinders was also created thanks to the feedback received from the customer. Accordingly, 1100mm for main cylinders and 400mm for blankholder cylinders were deemed appropriate. In addition, the clearance between the ram parts of the cylinders was chosen as 1500 mm.

Pressing speed is also a factor to consider when making an economical design. While the main cylinder moves downwards at the moment of processing the part, it moves at a speed of 300 mm/s with the effect of gravity. After this stage, the die overlap each other and pressing will be done at a speed of 20mm/s up to 125 bar in order to ensure minimum deformation on the part to be processed. After 125 bar, pressing is done at a speed of 10mm/s up to 250 bar, producing the most ductile product possible. Operating at 250 bar provides a good balance between size and power, making hydraulic systems efficient without being excessively large or complex.

After 250 bar, the return process is started because the part is ready. At this stage, the maximum working pressure in the hydraulic cylinders is not used because the pump does not want to operate unnecessarily. For this reason, in the market, lifting is generally done with a pressure of 1/5 of the maximum working pressure. The faster this process is done, the more time is gained for the next piece, so the rollers come to the starting position at a speed of 90 mm/s.

The reason why the pump operates at 250 bar is that this pressure allows the pump to reach maximum efficiency. At low pressure and low speed, the internal gear pump leaks more and works inefficiently. The higher the pressure difference across the pump, the lower the volumetric efficiency [5]. Below figure shows the correlation between operating pressure and efficiency of various pumps.

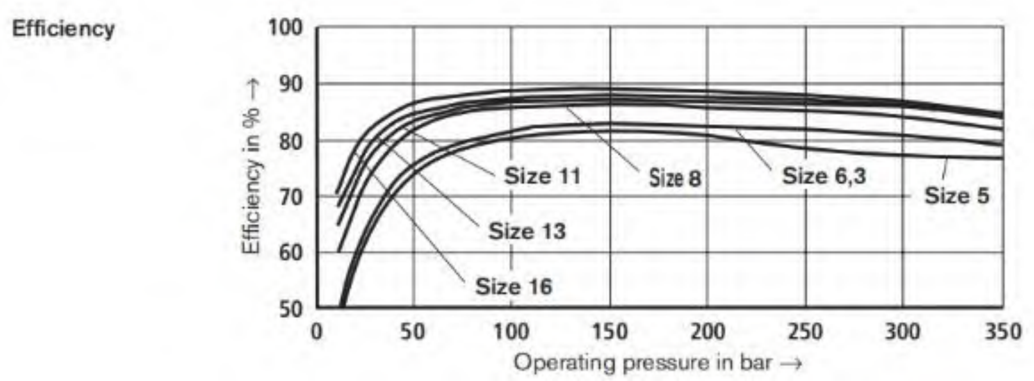


Figure 17: Efficiency vs operating pressure in bar chart for different size of hydraulic pumps [16].

The criterias and parameters to be used in the design of a 4-column 1000 tons hydraulic deep drawing press are given below table in accordance with this design.

Hydraulic press type	4-column
Main hydraulic cylinder compression force	1000 tons
Blankholder hydraulic cylinder holding force	400 tons
Main hydraulic cylinder count	2 cylinder
Blankholder hydraulic cylinder count	2 cylinder
Pressing plate dimension	2500 mm × 1500 mm
Press clearence	1500 mm
Main hydraulic cylinder stroke	1100 mm
Blankholder hydraulic cylinder stroke	400 mm
Working Pressure	250 bar
Holding Pressure	Working Pressure/5 = 50 bar
Free-falling speed	300 mm/s
Pressing speed	20 mm/s up to 125 bar, 10 mm/s up to 250 bar
Returning speed	90 mm/s
Lower die material weight	15 Tons
Upper die material weight	15 Tons

Table 1: 1000 Ton Hydraulic deep drawing press design specifications.

4.3. Design of 1000 Ton Deep Drawing Hydraulic Press

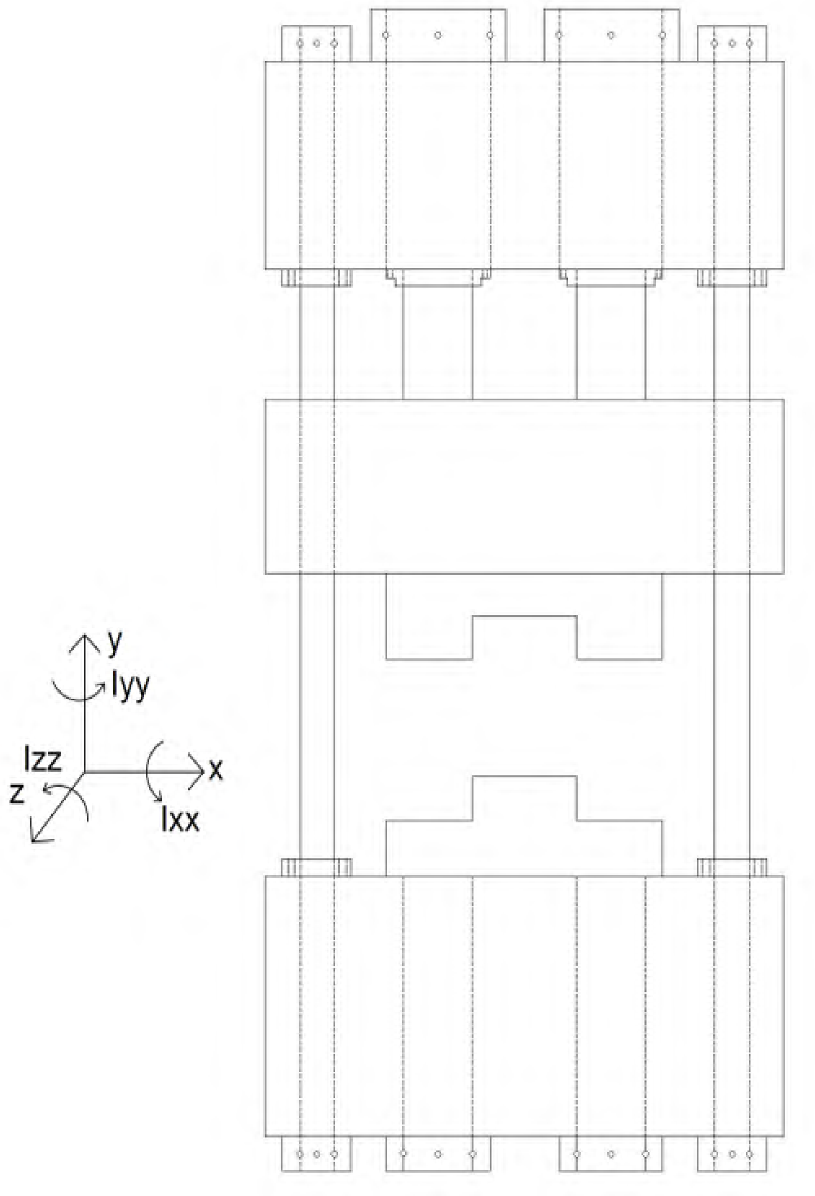


Figure 18: 1000-ton deep drawing press design draft drawing.

Main hydraulic cylinder

$$P = \frac{F}{A} \tag{4.1}$$

The required cylinder area can be determined using Pascal's formula (Eq: 4.1) as stated above.

Where:

$P = 250$ bar $= 250 \times 10^5 N/m^2$

$F_{main} = mg = \dfrac{1 \times 10^6\ kg}{2} \times 9.81 \dfrac{m}{s^2} = 4.9 \times 10^6 N$

$A_{m,c} = \dfrac{F_{main}}{P} = \dfrac{4.9 \times 10^6}{250 \times 10^5} = 0.1962\ m^2 = 196200\ mm^2$

$A_{m,c} = \dfrac{\pi {d_{m,c}}^2}{4} \rightarrow d_{m,c} = 499mm \cong 500\ mm$

For main cylinder 500 mm inner diameter two cylinders will be used. Since diameter changed little bit, area will be differed also:

$A_{m,c} = \dfrac{\pi {d_{m,c}}^2}{4} = 196350\ mm^2$

According to Clavarino's Equation [6] for closed-end cylinders, cylinder thickness can be found as:

$$t_c = r_{ci} \left[\sqrt{\frac{(\sigma_t + (1 - 2\mu)P}{(\sigma_t - (1 - \mu)P}} - 1 \right] \tag{4.2}$$

Where:

t_c: Thickness of cylinder

r_{ci}: Inner radius of cylinder

σ_t: Allowable tangential stress

μ: Poisson's ratio

P: Maximum working pressure in N/mm^2

The most preferred material for the hydraulic industry is AISI alloy 4140 steel, both in terms of material strength and suitability for hydraulic systems. Below table shows properties of this steel.

Properties	Metric	Imperial
Tensile strength	655 MPa	95000 psi
Yield strength	415 MPa	60200 psi
Bulk modulus (typical for steel)	140 GPa	20300 ksi
Shear modulus (typical for steel)	80 GPa	11600 ksi
Elastic modulus	190-210 GPa	27557-30458 ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Elongation at break (in 50 mm)	25.70%	25.70%
Hardness, Brinell	197	197
Hardness, Knoop (converted from Brinell hardness)	219	219
Hardness, Rockwell B (converted from Brinell hardness)	92	92
Hardness, Rockwell C (converted from Brinell hardness. Value below normal HRC range, for comparison purposes only)	13	13
Hardness, Vickers (converted from Brinell hardness)	207	207
Machinability (based on AISI 1212 as 100 machinability)	65	65

Table 2: Mechanical properties of AISI 4140 [17].

$$\sigma_t = \frac{Tensile\ strength}{2\ (Factor\ of\ safety)} = \frac{655\ MPa}{2(2.0)} = 163\ MPa$$

$$P = 250\ bar \times \frac{1}{10} = 25\ MPa$$

$$\mu = 0.3$$

So according to Eq. 4.2:

$$t_c = \frac{500}{2}\left[\sqrt{\frac{(163 + \left(1 - 2(0.3)\right)(25))}{(163 - (1 - 0.3)(25))}} - 1\right] = 23\ mm \cong 30\ mm$$

30 mm thickness for main cylinder is selected.

Since die material has weight of 15 tons, slider is 7.66 tons and main cylinder rod is 1.7 tons. How to find these given quantities is shown in the relevant section below.

$$15 + 7.66 + (1.7 \times 2) = 26.06\ Tons$$

In addition to this load, an application factor must be added. because this load may change when the material to be pressed, the die to be used or frictions are considered. This application factor is taken as 1.3. So:

$26.06\ \times (1.3) = 33.9\, Tons$

Total of 33.9 tons weight will be lifted at 50 bar pressure by two main cylinders together.

$P\ = 50\ \text{bar} = 50 \times 10^5 N/m^2$

$$F_{m,lift} = \frac{mg}{2} = \frac{33.9 \times 10^3\ kg \times 9.81 \frac{m}{s^2}}{2} = 1.66 \times 10^5 N$$

$$A_{m,lift} = \frac{F_{m,lift}}{P} = \frac{1.66 \times 10^5}{50 \times 10^5} = 0.0332\ m^2 = 33200\ mm^2$$

$$33200 = \frac{\pi {d_{m,c}}^2}{4} - \frac{\pi {d_{m,lift}}^2}{4} \rightarrow d_{m,lift} = 455mm \cong 450\ mm$$

Flow rate of main cylinder

The flow rate calculation for the press depends on the speed of the slider and the press during work. The maximum value found from these calculated flow rate values, is used to calculate the pump and motor power required. Calculated flow rate depending on the values of the pre-fill used in front of the hydraulic cylinders. The type and capacity of the valves are also determined.

Working principle of pre-fill valves are on-off type valves. However, these valves are used especially in fast-working hydraulic presses. Working behind the cylinder, the oil needed by the cylinders is produced by the pumps. They are transmitted to the cylinders without being pressed [7]. The pre-fill valve calculation is determined according to the speed of the cylinder at the time of free fall.

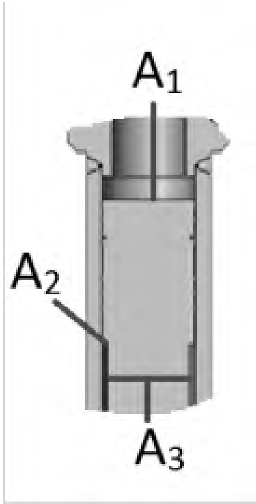


Figure 19: Representation of pre-fill valve [18].

The flow rate through hydraulic cylinder can be found by multiplying flow area with fluid velocity.

$$Q = A \times V \tag{4.3}$$

Calculation of pre-fill valve for main cylinder

$A_{1,m} = 196350\ mm^2$

$A_{2,m} = 37306\ mm^2$

$A_{3,m} = 196350\ mm^2 - 37306\ mm^2 = 159043 mm^2$

Flow rate for extension (Free fall)

$Q_{1,m} = A_{1,m}V_{m,c} = 196350\ mm^2 \times 300\ {}^{mm}/_{s} = 5.89 \times 10^7\ {}^{mm^3}/_{s}$

$5.89 \times 10^7\ {}^{mm^3}/_{s} = 5.89 \times 10^7 \times 60 \times 10^{-6} = 3534$ lt/min for pre-fill.

$Q_{1,tot} = Q_{1,m} \times 2$ cylinder $= 3534 \times 2 = 7068$ lt/min.

Flow rate for retracting (Returning)

$Q_{2,m} = A_{2,m}V_{m,c} = 37306\ mm^2 \times 90\ {}^{mm}/_{s} = 3.3575 \times 10^6\ {}^{mm^3}/_{s}$

$3.3575 \times 10^6\ {}^{mm^3}/_{s} = 3.3575 \times 10^6 \times 60 \times 10^{-6} = 201.45$ lt/min.

$Q_{2,tot} = Q_{2,m} \times 2$ cylinder $= 201.45 \times 2 = 402$ lt/min.

Working region

$Q_{W,125} = A_{1,m}V_{m,W,125} = 196350\, mm^2 \times 20\, {}^{mm}/_{s} = 3.927 \times 10^6\, {}^{mm^3}/_{s}$

$3.927 \times 10^6\, {}^{mm^3}/_{s} = 3.927 \times 10^6 \times 60 \times 10^{-6} = 236$ lt/min up to 125 bar.

$Q_{W,250} = A_{1,m}V_{m,W,250} = 196350\, mm^2 \times 10\, {}^{mm}/_{s} = 1.964 \times 10^6\, {}^{mm^3}/_{s}$

$1.964 \times 10^6\, {}^{mm^3}/_{s} = 1.964 \times 10^6 \times 60 \times 10^{-6} = 118$ lt/min up to 250 bar.

The flow rate at this work speed determines the flow rate of the pump to be used in the hydraulic press and the engine is selected accordingly. The selection of pre-fill valves is also selected depending on this value. If the pre-fill valve was not used, all flow would be provided by the pump and unnecessary energy loss would occur. This would cause unnecessary size and cost. Pre-fill valves play an important role in cylinders that need to move quickly. Additionally, due to the high flow rate, the oil installation would have to be made more durable [7].

Below figure shows drawing of this main cylinder and its cross-sectional view.

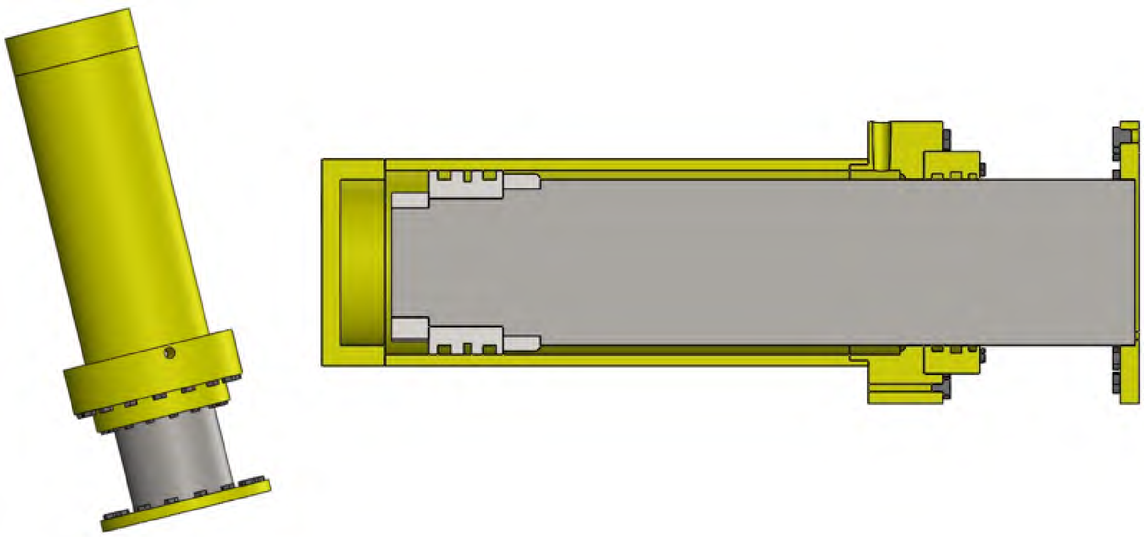


Figure 20: General view and cross section view of main cylinder.

4.3.1. Blankholder hydraulic cylinder

From Eq. 4.1:

$$F_{blank} = mg = \frac{4 \times 10^5\ kg}{2} \times 9.81 \frac{m}{s^2} = 1.962 \times 10^6 N$$

$$A_{b,c} = \frac{F_{blank}}{P} = \frac{1.962 \times 10^6}{250 \times 10^5} = 0.07848\ m^2 = 78480\ mm^2$$

$$A_{b,c} = \frac{\pi {d_{b,c}}^2}{4} \rightarrow d_{b,c} = 316 mm \cong 320\ mm$$

For blankholder cylinder 320 mm inner diameter two cylinders will be used. Since diameter changed little bit, area will be differed also:

$$A_{b,c} = \frac{\pi {d_{b,c}}^2}{4} = 80425\ mm^2$$

Also, from Eq. 4.2:

$$t_c = \frac{320}{2}\left[\sqrt{\frac{(163 + (1 - 2(0.3))(25)}{(163 - (1 - 0.3)(25)}} - 1\right] = 15\ mm \cong 20\ mm$$

20 mm thickness for blankholder cylinder is selected.

Since lower die material has weight of 15 tons, the movebale part of this lower die can vary between 500 kg to 1000 kg. So, 1000 kgs weight can be selected for design. Blankholder cylinder's rod weight is 450kgs. How to find these given quantities is shown in the relevant section below.

$$1000 kg + 450 \times 2 = 1900\ kg$$

And after multiplying by application factor.

$$1900 \times 1.3 = 2470 kg$$

Total of 2470 kg weight will be lifted at 50 bar pressure by two blankholder cylinders.

$$P = 50 \text{ bar} = 50 \times 10^5 N/m^2$$

$$F_{b,lift} = \frac{mg}{2} = \frac{2470\ kg \times 9.81\frac{m}{s^2}}{2} = 1.21 \times 10^4 N$$

$$A_{b,lift} = \frac{F_{b,lift}}{P} = \frac{1.21 \times 10^4}{50 \times 10^5} = 0.00242\ m^2 = 2423\ mm^2$$

$$2423 = \frac{\pi {d_{b,c}}^2}{4} \rightarrow d_{b,c,min} = 55mm$$

Since the diameter found in previous steps are 320 mm. This blankholder cylinder is suitable.

Calculation of flow rate for blankholder cylinder

$A_{1,b} = 80425\ mm^2$

$A_{2,b} = 29452\ mm^2$

$A_{3,b} = 80425\ mm^2 - 29452\ mm^2 = 50973\ mm^2$

Flow rate for extension

According to Eq. 4.3:

$Q_{1,b} = A_{1,b}V_{b,c} = 80425\ mm^2 \times 180\ {}^{mm}/_{s} = 1.448 \times 10^7\ {}^{mm^3}/_{s}$

$1.448 \times 10^7\ {}^{mm^3}/_{s} = 1.448 \times 10^7 \times 60 \times 10^{-6} = 869$ lt/min.

$Q_{1,tot} = Q_{1,b} \times 2$ cylinder $= 869 \times 2 = 1738$ lt/min.

Since blankholder cylinder is single direction acting hydraulic cylinder. There is only extension flow.

If the pre-fill valve was not used, we would have to choose a pump with a flow rate of 7068 lt/min. With pre-fill valves, a pump with a 236 lt/min flow rate will be sufficient. Below figure shows drawing of this blankholding cylinder and its cross-sectional view.

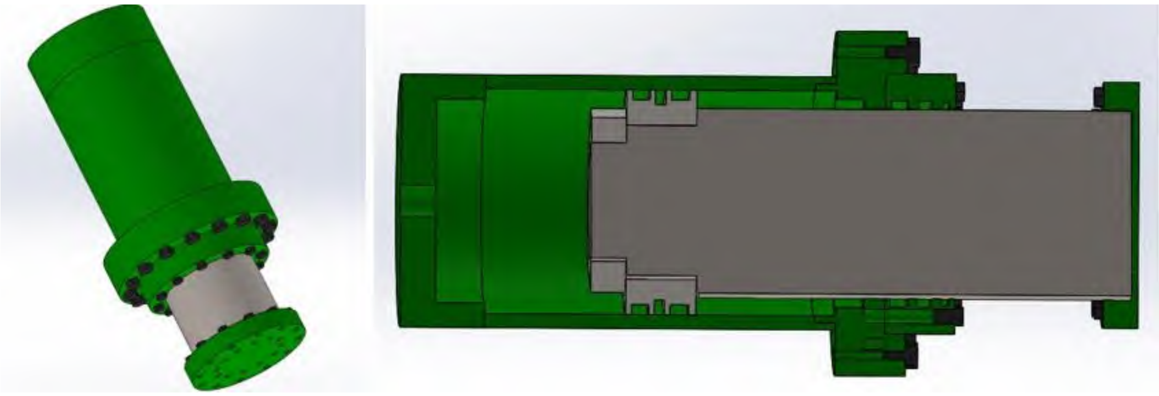


Figure 21: General view and cross section view of blankholding cylinder.

4.3.2. Columns

Columns take part in absorbing the stress on the hydraulic press without deflection. In 4-column hydraulic presses, the column material is generally produced using high-strength steel alloys. AISI 1045 (C45) steel is a suitable material for column design. Below figure shows mechanical properties of this material:

Physical Properties	Metric
Density	7.87 g/cc
Mechanical Properties	**Metric**
Hardness, Brinell	163
Hardness, Knoop	184
Hardness, Rockwell B	84
Hardness, Vickers	170
Tensile Strength, Ultimate	585 MPa
Tensile Strength, Yield	450 MPa
Elongation at Break	12 %
Reduction of Area	35 %
Modulus of Elasticity	206 GPa
Bulk Modulus	163 GPa
Poissons Ratio	0.29
Shear Modulus	80.0 GPa

Table 3: Mechanical properties of AISI 1045 steel [19].

Since the 400-ton load coming from the blankholder cylinders and 1000-ton load coming from the main cylinders will be kept in a stable position by the columns, this 1400-ton load will be distributed among 4 columns. When calculating the stress on the columns in the hydraulic presses used in the market, it was observed that the factor of safety value was taken as 2.0 when conditions such as irregularity of the die and stress concentrations were taken into account.

So total force acting to all four columns is 1400 tons. We can convert it into Newtons.

$1400 \times 1000 \times 9.81\ m/s^2 = 13{,}734{,}000\ N$

This stress type is axial stress so if we use Eq. 4.1. And yield strength of material can be obtained from Table 3 as 450 MPa.

$$A_{min,total} = \frac{13{,}734{,}000}{450/_{2.0}} = 61{,}040\ mm^2$$

$$A_{min} = \frac{A_{min,total}}{4} = \frac{61{,}040\ mm^2}{4} = 15{,}260\ mm^2$$

$15{,}260\ mm^2 = \pi \frac{d^2}{4} \rightarrow d = 139mm \cong 140mm$ diameter is selected.

This diameter is the minimum diameter on the column and will be at the connection points. Because half-moon parts will be used. After determining the minimum diameter of the column, which is 140 mm, its length should be determined. A 200 mm torque screw section will be made under the lower beam and above the upper beam. The purpose of this torque screw is to prevent the column from bending by applying a preforce to the column. The diameter in this section is 160 mm. Then, the column passing through the lower beam will reduce its diameter to 140 mm for the assembly of the half-moon piece. After the 100 mm half-moon piece gap, it will again travel with a diameter of 160 mm to the press opening + slider length, and then under the lower beam, it will again decrease to 140 mm diameter for the half-moon piece. Finally, the design of the column passing through the upper beam will be completed after the 200 mm torque screw section.

Below figure shows this column according to previous specifications.

Figure 22: General view of column.

Sliding bearing material must be used to connect the columns to the slider. Lubrication channels are designed in this material to allow oil to pass to the surfaces in contact with the column. The drawing of this bearing material is shown in the image below. The outer diameter of the bearing is 200 mm and the inner diameter is 160 mm. Below figure shows the drawing of this bearing element.

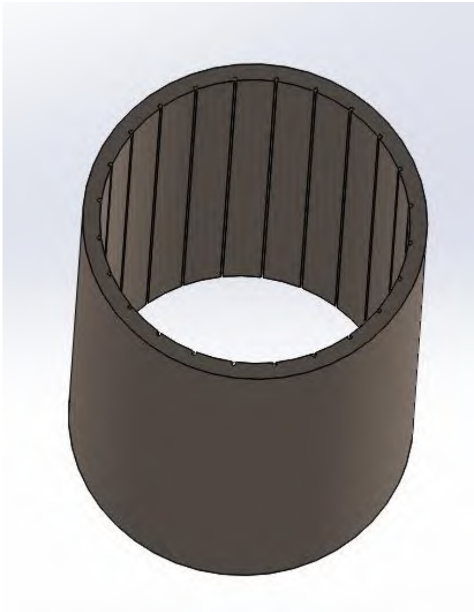


Figure 23: Drawing of sliding bearing element inside slider’s hole.

4.3.3. Slider

As an assumption in the design, the columns will be installed after leaving a space of 100 mm from the size of the worktable. Then, another 50 mm space will be left. Considering the spaces where the columns will be placed and the bedding materials, a gap of 200 mm will be sufficient. So, slider dimension can be seen from below figure:

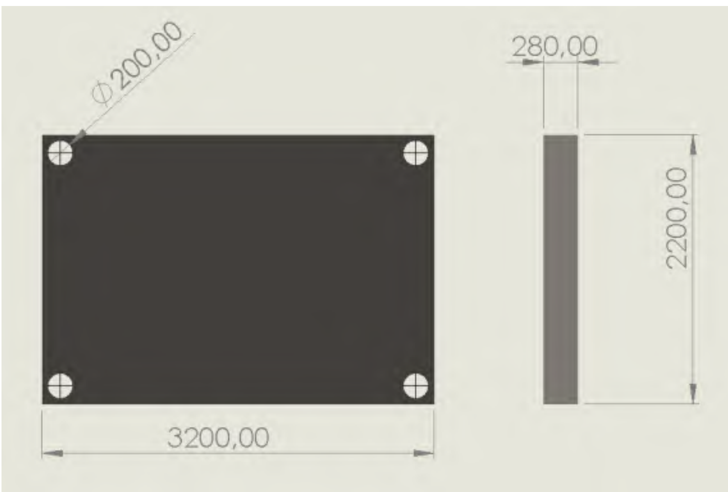


Figure 24: Dimensions of slider.

The forces on the slider are as follows: vertically downwards, 500 tons of force is transferred by 2 circular uniformly distributed loads coming from the main cylinders. Below, the uniformly distributed load meets the 400-ton load coming from the blankholder cylinders, which is against this force, distributed on the worktable.

For along x-axis.

$$\frac{500 \times 10^3 \times 9.81}{500\ mm} = 9810\ N/mm$$

$$\frac{400 \times 10^3 \times 9.81}{2500\ mm} = 1570\ N/mm$$

For along z-axis.

$$\frac{500 \times 10^3 \times 9.81 + 500 \times 10^3 \times 9.81}{500\ mm} = 19620\ N/mm$$

$$\frac{400 \times 10^3 \times 9.81}{1500\ mm} = 2616\ N/mm$$

The stress on the slider can be found according to these forces. What is important here is the bending stress value. After finding the maximum stress value, we obtain a moment of inertia value according to the bending stress formula. Slider design will be made according to this moment of inertia. When designing, a lightweight slider with maximum moment of inertia should be designed. Likewise, this slider must also withstand axial stress from the vertical direction. A slider with a rib will be designed to achieve this purpose. As can be seen from figure at maximum stress moment column connection points are roller supports. According to this information free-body-diagram of slider on x and z axis can be seen from below figure.

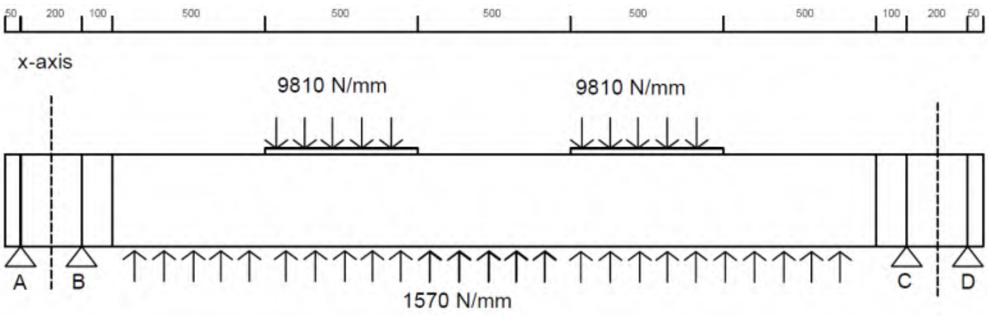


Figure 25: Free-body-diagram of slider on x-axis.

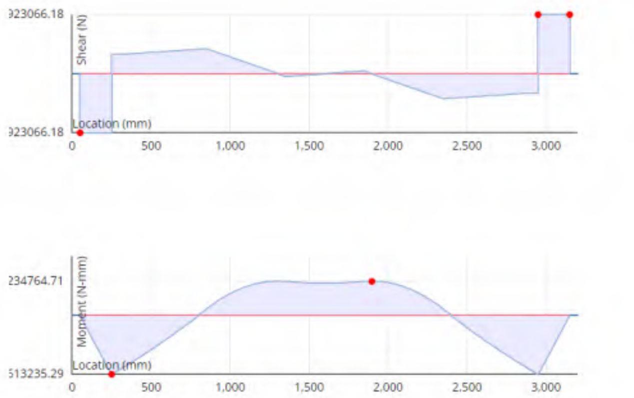


Figure 26: Shear force and moment diagram of slider on x-axis.

Maximum bending moment occurs at location 250 mm and 2950 from left and value of -1.79×10^{9} N.mm. According to this bending moment value, the maximum stress can be calculated with the following equation.

$$\frac{My}{I} = \frac{\sigma_{ys}}{S_f} \tag{4.4}$$

Where:

M: Bending moment on that point.

y: Perpendicular distance to the neutral axis

I: Moment of inertia

σ_{allow}: Maximum yield strength

S_f: Factor of safety

For simplfy the design process slider height will be taken as 280 mm. Therefore, the y value will be 140 mm, which is half of this height.

So, along x axis:

$$\frac{(1.79 \times 10^9)(140)}{I_{zz}} = \frac{450MPa}{2.0}$$

$$I_{zz,min} = 1.12 \times 10^9\ mm^4$$

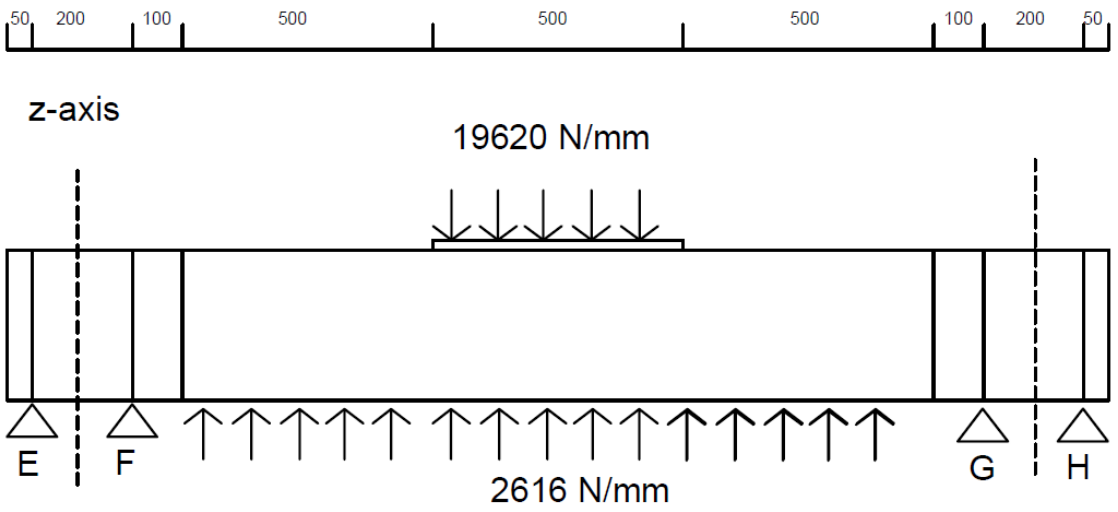


Figure 27: Free-body-diagram of slider on z-axis.

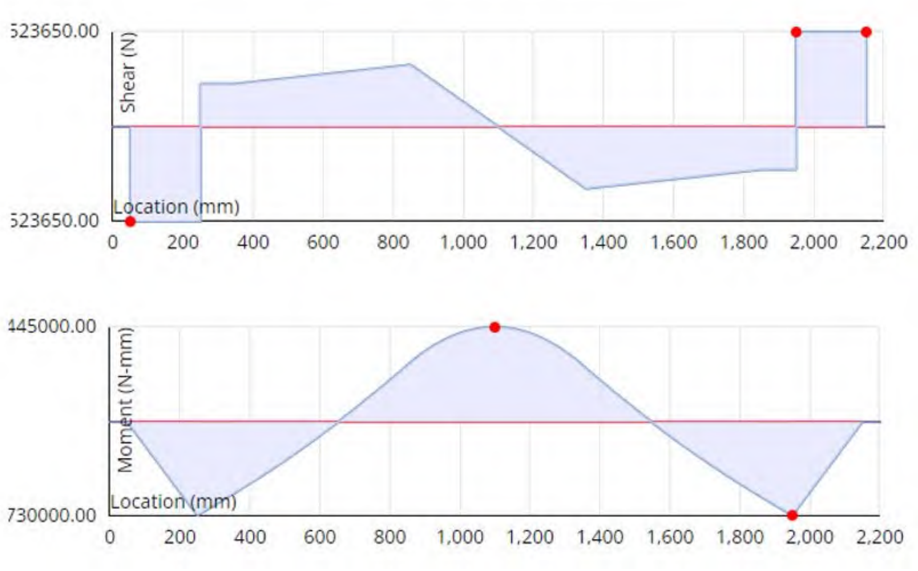


Figure 28: Shear force and moment diagram of slider on z-axis.

Maximum bending moment occurs at location 250 mm and 2950 from left and value of -1.30×10^9 N.mm. According to this bending moment value, the maximum stress can be calculated with the following equation.

Along z axis:

$$\frac{(1.30 \times 10^9)(140)}{I_{xx}} = \frac{450MPa}{2.0}$$

$$I_{xx,min} = 8.1 \times 10^8 \, mm^4$$

In addition, it must be strong enough to withstand vertical axial stress at any point on slider. The slider is compressed from two-way by hydraulic cylinders with a total force of 1400 tons. For this reason, the required minimum area caused by axial stress can be found by using the axial stress formula.

$$\frac{F}{A} = \frac{\sigma_{ys}}{S_f} = \frac{(1400 \times 10^3 kg)\left(9.81 \, {}^{m}/_{s^2}\right)}{A_{min}} = \frac{450MPa}{2.0}$$

$$A_{min} = 61040 \, mm^2$$

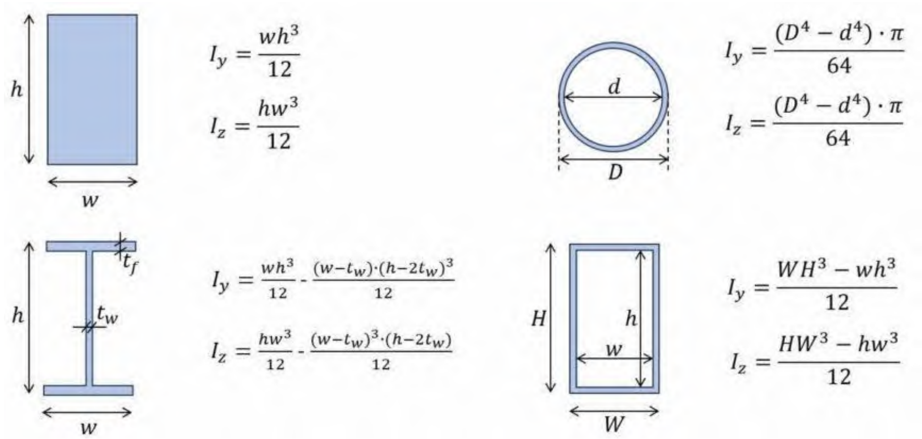


Figure 29: Moment inertia formulas of simple cross-sections [20].

The important factor here when designing the slider is to create the shape with the highest moment of inertia value in the lightest way possible. As can be seen from above figure, if a rectangular cross section is chosen, the piece will be very heavy. Therefore, the best choice would be a design with rib gaps. Slider can be designed according to these minimum parameters. We can find the moment of inertia of ribbed design by parallel axis theorem [8].

$$I_{total} = \sum_{i=0}^{n} \left(I_i + A_i {d_i}^2\right) \tag{4.5}$$

Where:

n: Number of defined shape

I_i: Moment of inertia of selected shape

A_i: Area of selected shape

d_i: Distance between the centers of gravity of the selected shape of the entire object

According to this formula SolidWorks interface can be used.

Below figure shows the drawings of slider.

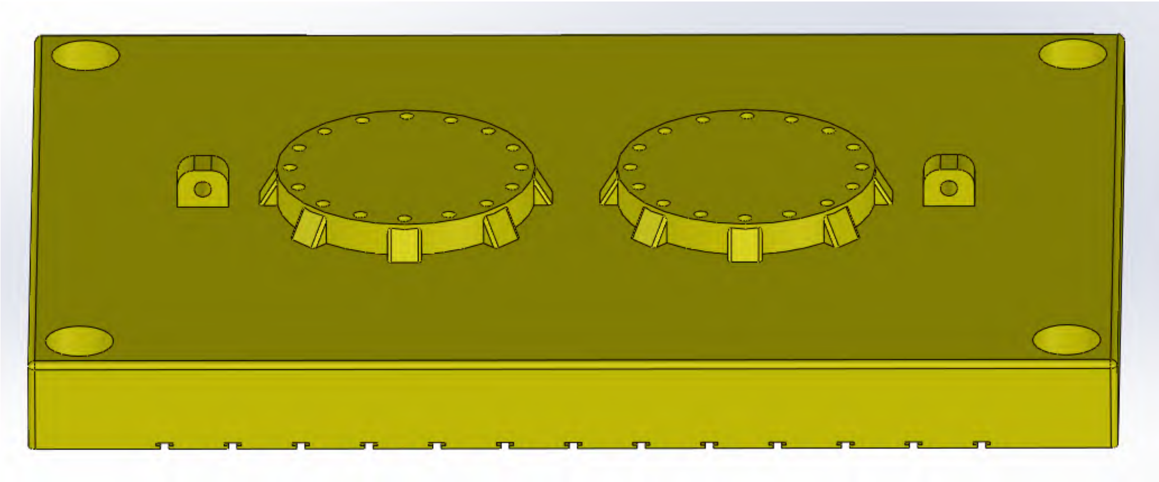


Figure 30: General view of slider.

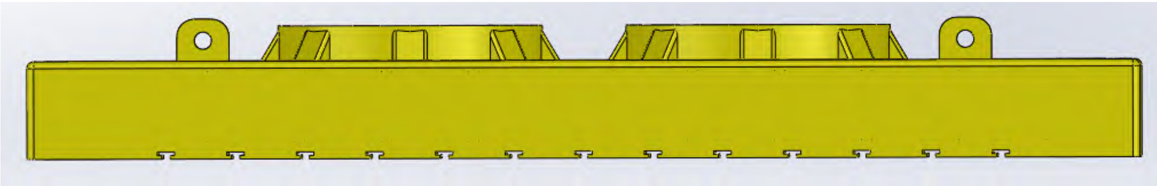


Figure 31: Side view of slider.

Additionally, two holes connected to the body were created on the slider. The purpose of this is to insert safety cylinders into these holes when the hydraulic press is not working. It is aimed to prevent a possible accident. The static calculation of these holes is as follows.

τ_{ys} of AISI 4140 is 260 MPa. So according to shear stress formula we can obtain required diameter of this safety element. Length of the hole is 100 mm. Safety factor is taken as 3.0.

$$\frac{V}{A} = \frac{\tau_{ys}}{S_f} \tag{4.6}$$

$$\frac{355000N}{2 \times A_{min}} = \frac{260\ MPa}{3.0}$$

This 355000N is weight of the upper part. There is calculation about this value in its part.

$$A_{min} = 2050\ mm^2$$

This area is diameter times length so, since length is 100 mm, diameter should be 20.5 mm.

As can be seen from Solidworks interface Figure 28 minimum moment of inertia along x axis is at $x = 150mm$ is $8.66 \times 10^{10}\ mm^4$

Alan = 219828.32 milimetre^2

Çıktı koordinat sistemi orijinine göre merkez noktası: (milimetre)
X = -1450.00
Y = 0.00
Z = 123.03

Alanın eylemsizlik momentleri, merkez noktasında: (milimetre ^ 4)

Lzz = 86613763386.80	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 2277283154.05	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lxx = 8433648023.

Figure 32: Moment of inertia value from Solidworks for slider on I_{zz} direction.

For z axis:

Alan = 315703.32 milimetre^2

Çıktı koordinat sistemi orijinine göre merkez noktası: (milimetre)
X = 0.00
Y = 950.00
Z = 121.33

Alanın eylemsizlik momentleri, merkez noktasında: (milimetre ^ 4)

Lzz = 3364302565.74	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 260916042407.89	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lxx= 257551739842.14

Figure 33: Moment of inertia value from Solidworks for slider on I_{xx} direction.

Minimum moment of inertia along z axis is at $z = 150mm$ is $2.57 \times 10^{11}\ mm^4$

Also minimum area in vertical direction is $2.0 \times 10^6\ mm^2$

So in summary:

$8.66 \times 10^{10}\ mm^4 > 1.12 \times 10^9\ mm^4$

$2.57 \times 10^{11}\ mm^4 > 8.1 \times 10^8\ mm^4$

$2.0 \times 10^6\ mm^2 > 6.1\ 10^4\ mm^2$

So our slider design is applicaple. The reason why the design is a little too conservative is that the size of the part printing plate is 2500 mm by 1500 mm, so the moment of inertia is indirectly higher.

Additionally, the weight of the slider must be included as it must be used in hydraulic calculations. For this, the volume of the part can be found using the Solidworks software. Accordingly, the weight of the slider is 8000 kg.

Structural analysis of slider

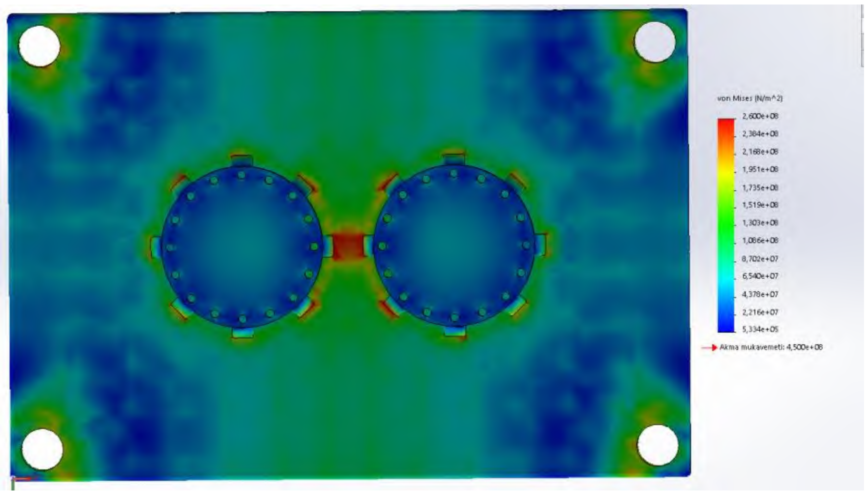


Figure 34: von Mises stress analysis of slider.

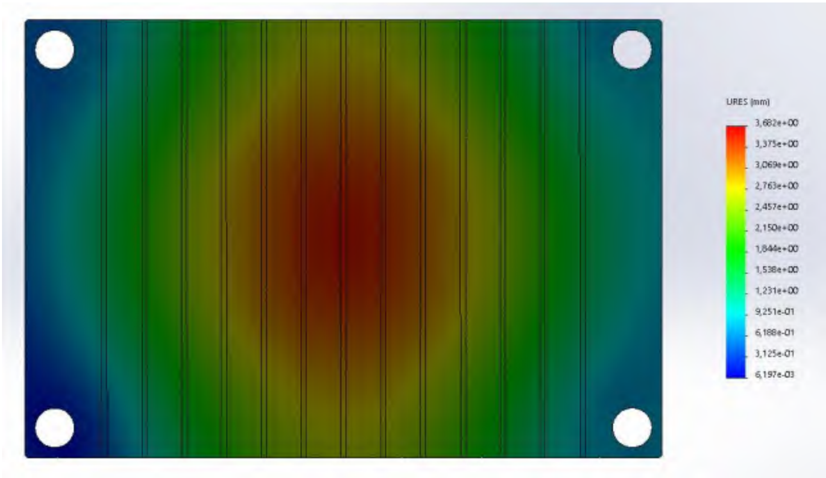


Figure 35: Deflection analysis of slider.

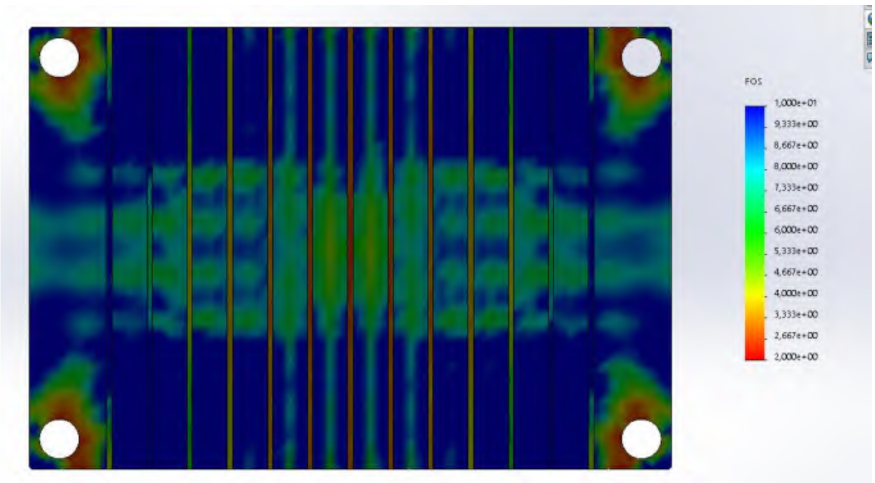


Figure 36: Factor of safety analysis of slider.

4.3.4. Upper Beam

The same procedure applied when designing the slider can also be used in the upper beam. The only difference is that the placement of the forces will be different. Unlike the slider, there will only be an upward force of 1000 tons, which is the reaction force of the hydraulic cylinder. There will be reaction forces on the columns that support this force.

For along x-axis.

$$\frac{500 \times 10^3 \times 9.81}{500\ mm} = 9810\ N/mm$$

For along z-axis.

$$\frac{500 \times 10^3 \times 9.81 + 500 \times 10^3 \times 9.81}{500\ mm} = 19620\ N/mm$$

Accordingly, the free-body diagram of the part can be drawn as seen in the image below.

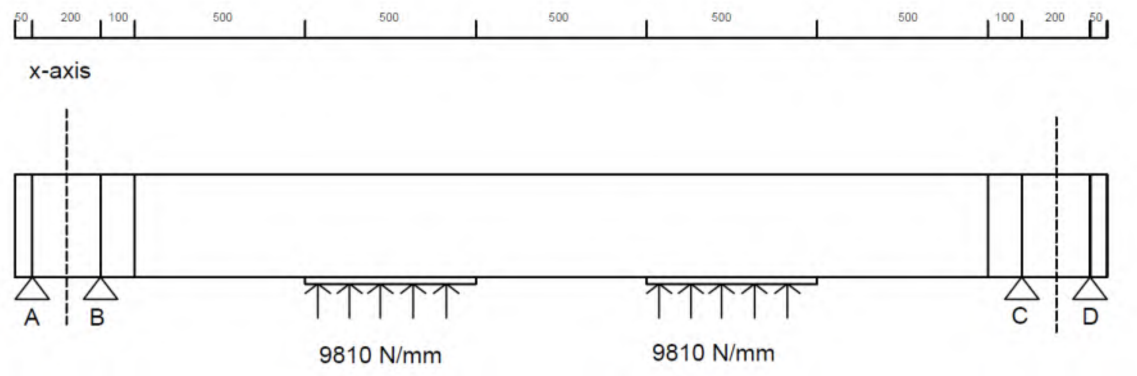


Figure 37: Free-body-diagram of upper beam on x-axis.

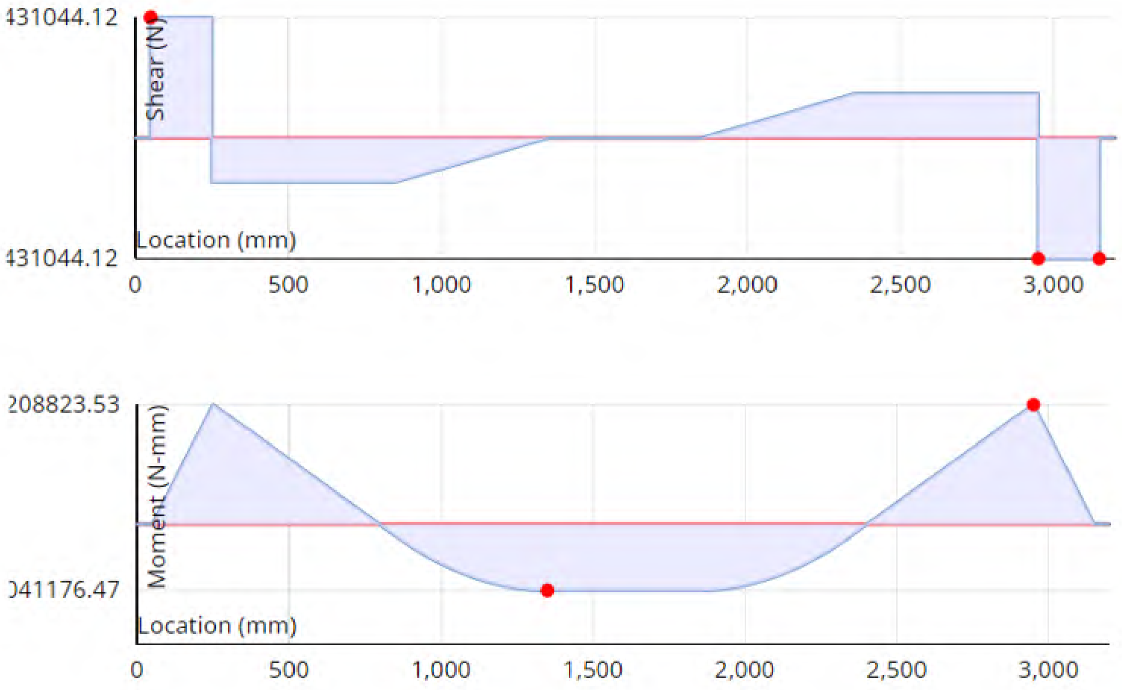


Figure 38: Shear force and moment diagram of upper beam on x-axis.

According to moment diagram maximum bending moment is equal to $2.7 \times 10^{9}\ N.mm$ at location 1600mm.

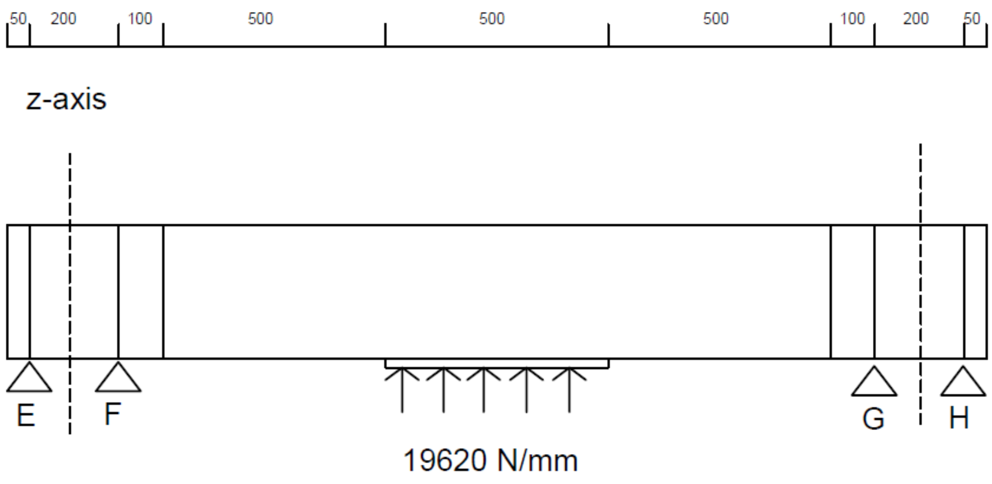


Figure 39: Free-body-diagram of upper beam on z-axis.

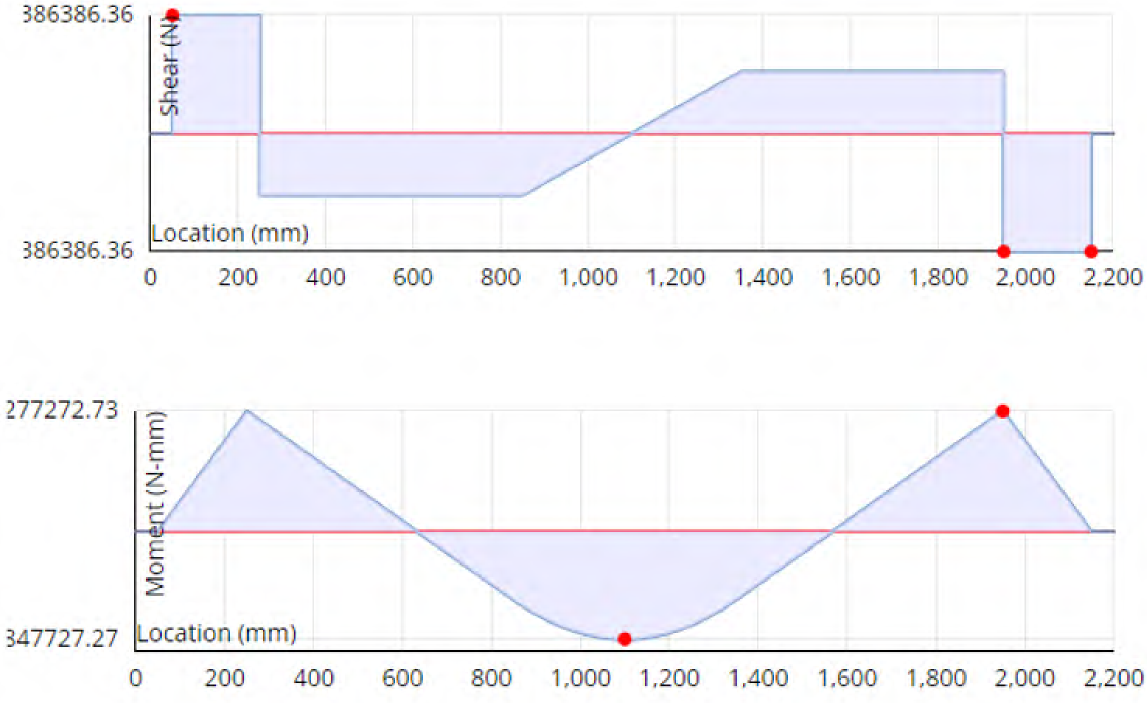


Figure 40: Shear force and moment diagram of upper beam on z-axis.

According to moment diagram maximum bending moment is equal to $1.9 \times 10^9\ N.mm$ at location 1150mm.

So, along x axis:

$$\frac{(2.7 \times 10^9)(140)}{I_{zz}} = \frac{450MPa}{2.0}$$

$$I_{zz,min} = 1.68 \times 10^9\ mm^4$$

Along z axis:

$$\frac{(1.9 \times 10^9)(140)}{I_{xx}} = \frac{450MPa}{2.0}$$

$$I_{xx,min} = 1.18 \times 10^9\ mm^4$$

Also, minimum vertical section area can be computed as before:

$$\frac{F}{A_{min}} = \frac{\sigma_{ys}}{S_f} \rightarrow \frac{(1000 \times 10^3\ kg)(9.81\ {}^{m}/_{s^2})}{A_{min}} = \frac{450\ MPa}{2.0}$$

$$A_{min} = 43600\ mm^2$$

According to these 3 critical parameters we can obtain a design for upper beam. Below figures shows drawings of upper beam. Additionally, since there will be hydraulic units on the upper beam, people must be able to go out for maintenance when necessary. For this purpose, a railing was built on the platform.

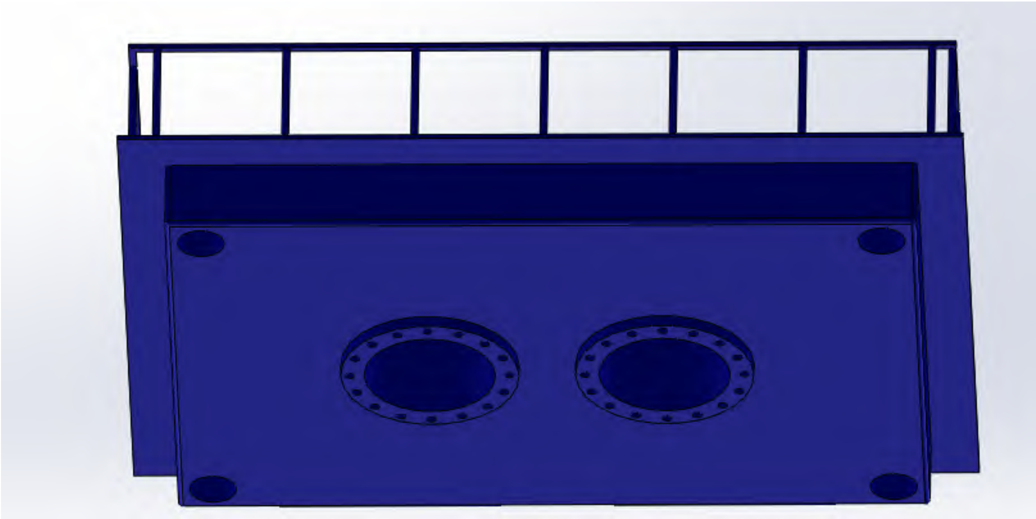


Figure 41: General view of upper beam.

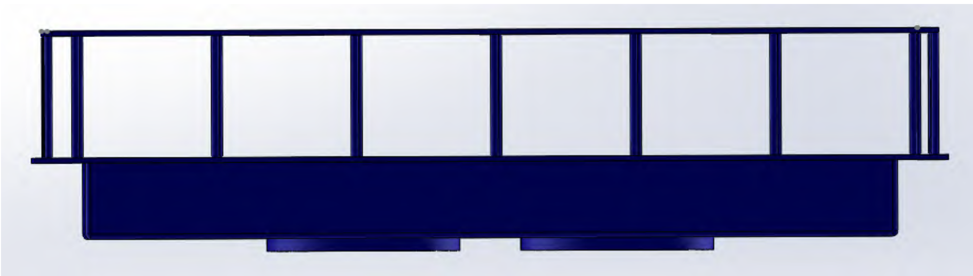
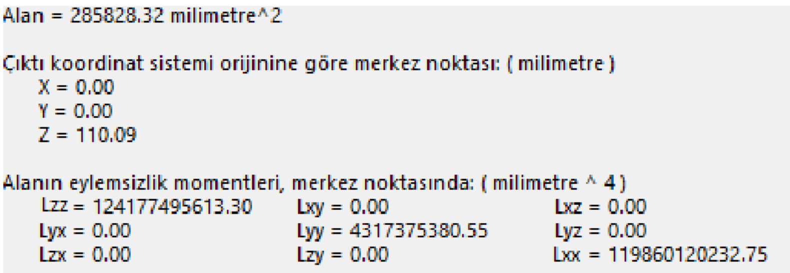


Figure 42: Side view of upper beam.

According to this design we can compare the moment of inertia values with critical ones. Below figure shows moment of inertia on zz axis.



Alan = 285828.32 milimetre^2

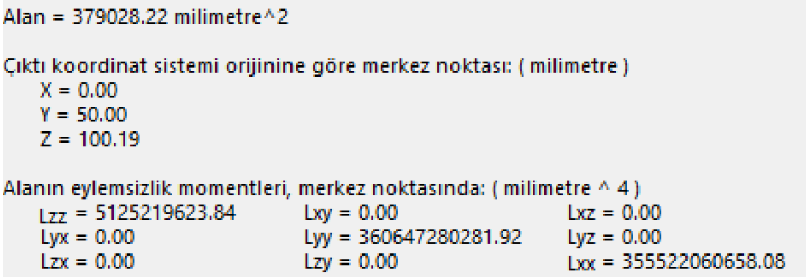
Çıktı koordinat sistemi orijinine göre merkez noktası: (milimetre)
X = 0.00
Y = 0.00
Z = 110.09

Alanın eylemsizlik momentleri, merkez noktasında: (milimetre ^ 4)

Lzz = 124177495613.30	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 4317375380.55	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lxx = 119860120232.75

Figure 43: Moment of inertia value from Solidworks for upper beam on I_{zz} direction.

As can be seen from above figure $I_{zz} = 1.24 \times 10^{11}\ mm^4$ at $x = 1600$mm.


Alan = 379028.22 milimetre^2

Çıktı koordinat sistemi orijinine göre merkez noktası: (milimetre)
X = 0.00
Y = 50.00
Z = 100.19

Alanın eylemsizlik momentleri, merkez noktasında: (milimetre ^ 4)

Lzz = 5125219623.84	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 360647280281.92	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lxx = 355522060658.08

Figure 44: Moment of inertia value from Solidworks for upper beam on I_{zz} direction.

As can be seen from above figure $I_{xx} = 5.12 \times 10^{9}\ mm^4$ at $z = 1150$mm.

Minimum area in vertical direction is $2.18 \times 10^{6}\ mm^2$.

So in summary:

$1.24 \times 10^{11}\ mm^4 > 1.68 \times 10^{8}\ mm^4$

$5.12 \times 10^{9}\ mm^4 > 1.18 \times 10^{8}\ mm^4$

$2.18 \times 10^{6}\ mm^2 > 4.36\ 10^{4}\ mm^2$

So upper beam design is applicaple.

Structural analysis of upper beam

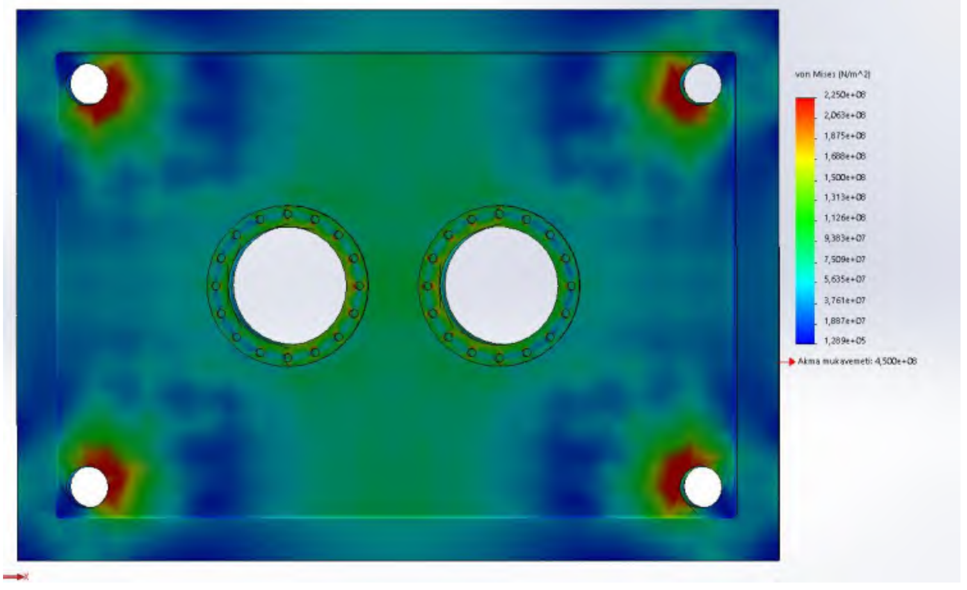


Figure 45: von Mises stress analysis of upper beam.

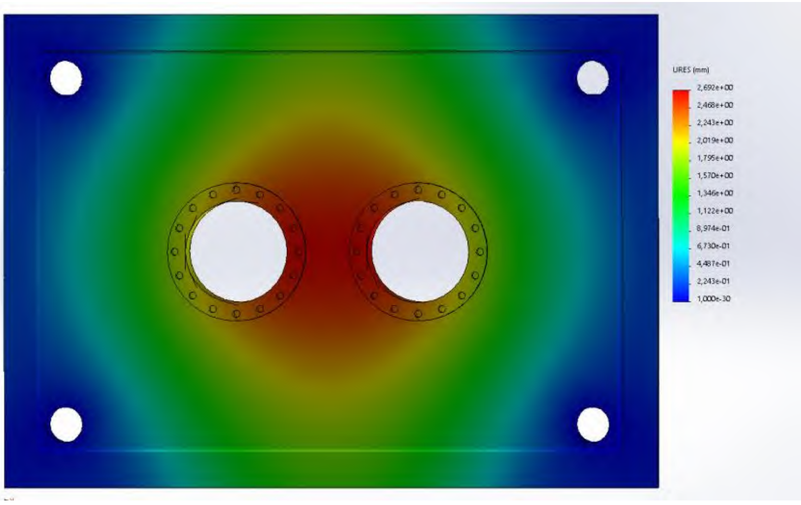


Figure 46: Deflection analysis of upper beam.

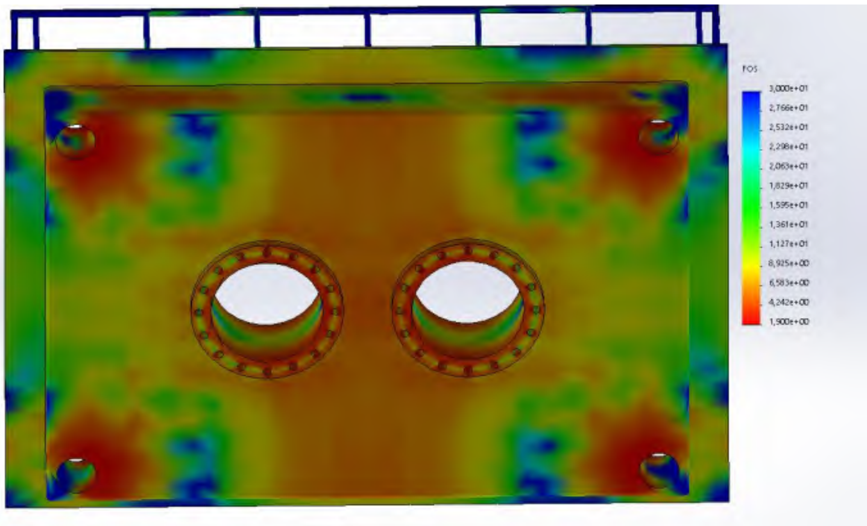


Figure 47: Factor of safety analysis of upper beam.

4.3.5. Lower Beam

The same procedure applied when designing the upper beam will be used. 400-ton load comes from blankholder cylinder's body in vertical direction and below of the lower beam is fixed to the ground.

For along x-axis.

$$\frac{200 \times 10^3 \times 9.81}{400\ mm} = 4905\ N/mm$$

For along z-axis.

$$\frac{200 \times 10^3 \times 9.81 + 200 \times 10^3 \times 9.81}{400\ mm} = 9810\ N/mm$$

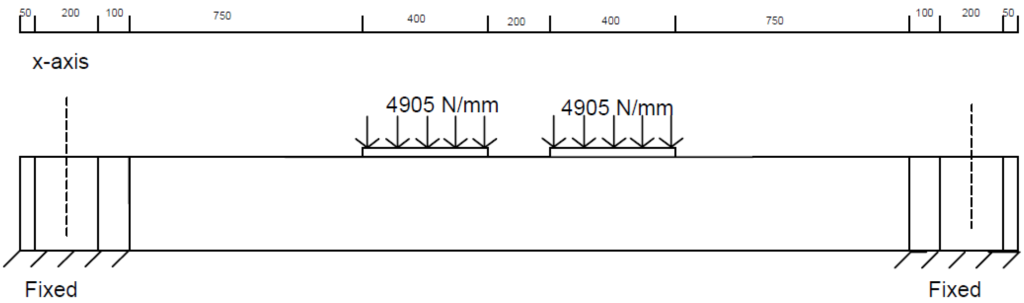


Figure 48: Free-body-diagram of lower beam on x-axis.

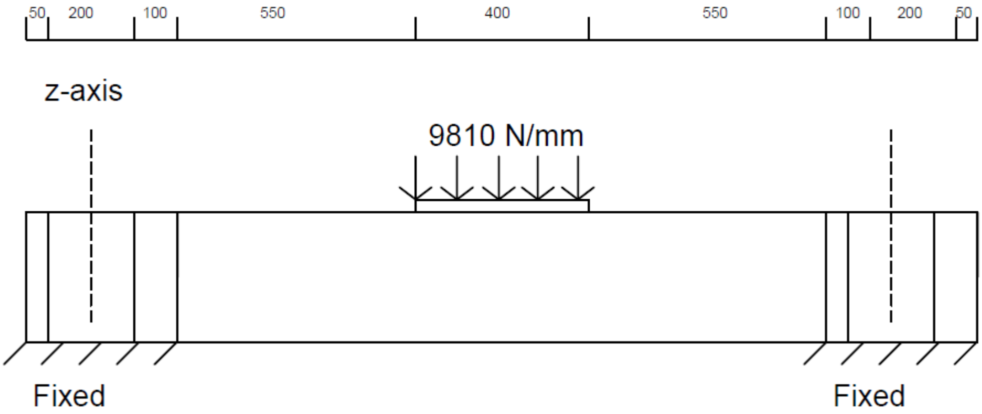


Figure 49: Free-body-diagram of lower beam on z-axis.

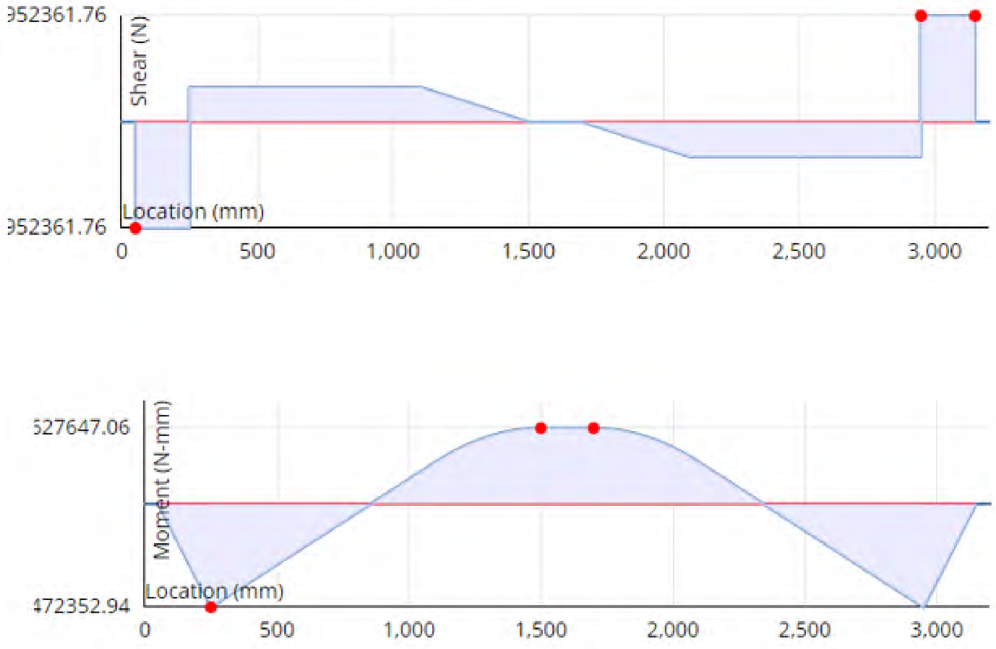


Figure 50: Shear force and moment diagram of lower beam on x-axis.

As can be seen from moment diagram of x axis, maximum bending moment occurs at point 1500mm and 1700mm with magnitude of -1190472352 N.mm.

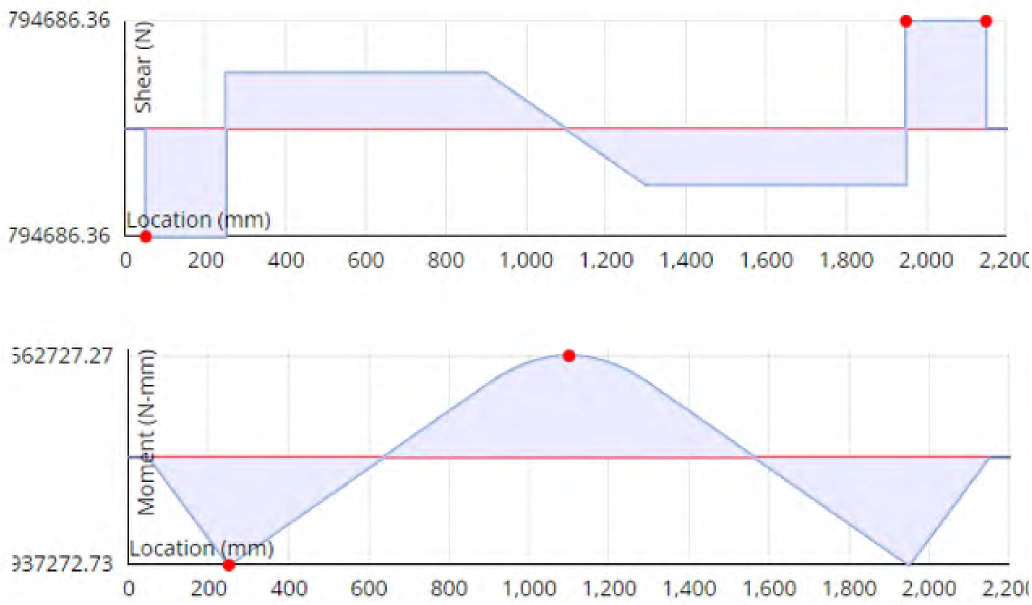


Figure 51: Shear force and moment diagram of lower beam on z-axis.

As can be seen from moment diagram maximum of z axis, bending moment occurs at point 1100mm with magnitude of -758937273 N.mm.

Also, heigh of the lower beam is design to be 500mm to lower the center of mass. So, y value is 500/2 = 250 mm.

So, along x axis:

$$\frac{(1.19 \times 10^9)(250)}{I_{zz}} = \frac{450MPa}{2.0}$$

$$I_{zz,min} = 1.32 \times 10^9 \; mm^4$$

Along z axis:

$$\frac{(7.59 \times 10^8)(250)}{I_{xx}} = \frac{450MPa}{2.0}$$

$$I_{xx,min} = 8.43 \times 10^8 \; mm^4$$

Also, minimum vertical section area can be computed as before:

$$\frac{F}{A_{min}} = \frac{\sigma_{ys}}{S_f} \rightarrow \frac{(400 \times 10^3 \; kg)(9.81 \, {}^{m}/{}_{s^2})}{A_{min}} = \frac{450 \; MPa}{2.0}$$

$$A_{min} = 17440 \; mm^2$$

The lower beam can be designed according to these parameters. In addition, since the hydraulic press has only one point of contact with the ground, ground fasteners should also be drawn. The images below show a lower beam drawn according to these criteria.

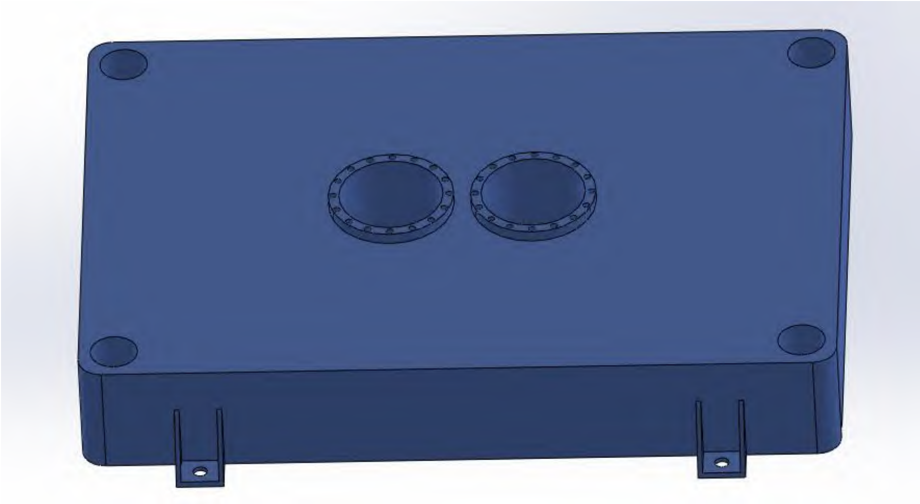


Figure 52: General view of lower beam.

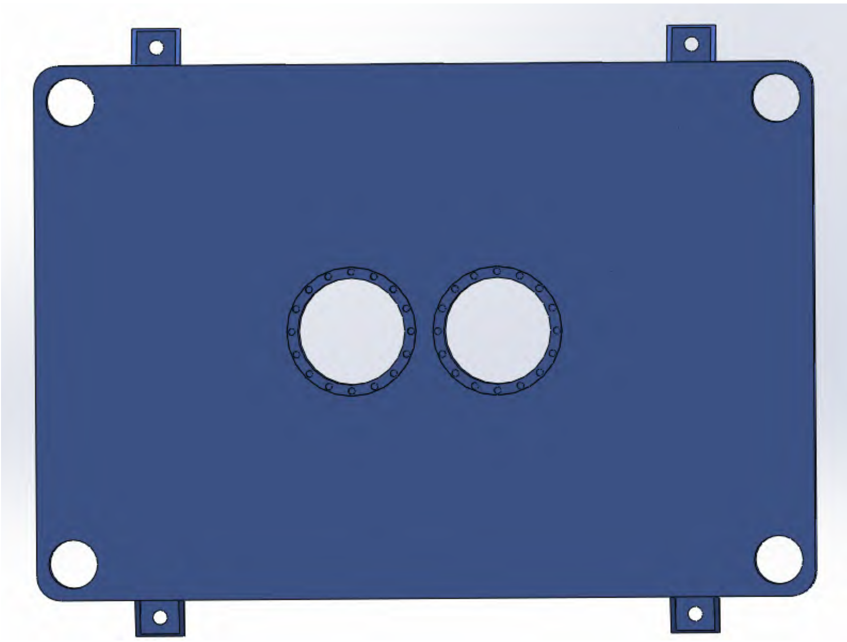


Figure 53: Top view of lower beam.

Since maximum bending moment occurs at 1500mm and 1700mm along x axis, we can take cross section on that points and check it.

```
Alan = 534080.00 milimetre^2

Çıktı koordinat sistemi orijinine göre merkez noktası: ( milimetre )
    X = -738.00
    Y = 0.00
    Z = 150.00

Alanın eylemsizlik momentleri, merkez noktasında: ( milimetre ^ 4 )
    Lzz = 249097481659.73    Lxy = 0.00              Lxz = 0.00
    Lyx = 0.00               Lyy = 18672266666.66    Lyz = 0.00
    Lzx = 0.00               Lzy = 0.00              Lxx = 230425214993.07
```

Figure 54: Moment of inertia value from Solidworks for lower beam on I_{zz} direction.

As can be seen from above figure $I_{zz} = 1.29 \times 10^{11}\ mm^4$ at $x = 1500$mm.

```
Alan = 760000.00 milimetre^2

Çıktı koordinat sistemi orijinine göre merkez noktası: ( milimetre )
    X = 0.00
    Y = -349.00
    Z = 150.00

Alanın eylemsizlik momentleri, merkez noktasında: ( milimetre ^ 4 )
    Lxx = 27033333333.33     Lxy = 0.00              Lxz = 0.00
    Lyx = 0.00               Lyy = 713012666666.67   Lyz = 0.00
    Lzx = 0.00               Lzy = 0.00              Lzz = 685979333333.33
```

Figure 55: Moment of inertia value from Solidworks for lower beam on I_{xx} direction.

As can be seen from above figure $I_{zz} = 2.7 \times 10^{10}\ mm^4$ at $x = 1100$mm.

Minimum area in vertical direction is $2.01 \times 10^6\ mm^2$.

So in summary:

$1.29 \times 10^{11}\ mm^4 > 1.32 \times 10^9\ mm^4$

$2.7 \times 10^{10}\ mm^4 > 8.43 \times 10^8\ mm^4$

$2.01 \times 10^6\ mm^2 > 1.74\ 10^4\ mm^2$

So lower beam design is applicape.

Structural analysis of lower beam

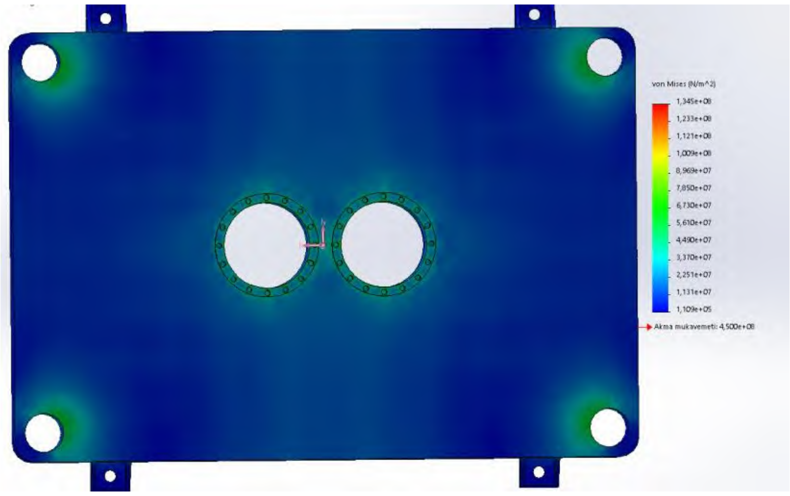


Figure 56: von Mises stress analysis of lower beam.

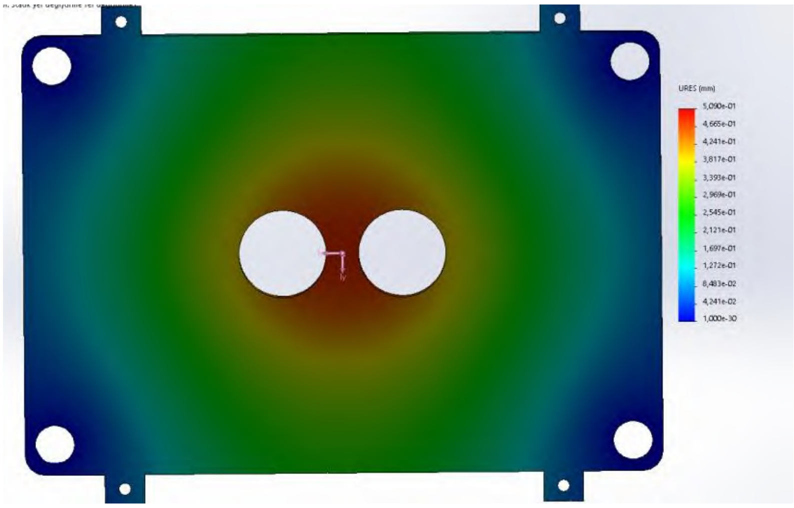


Figure 57: Deformation analysis of lower beam.

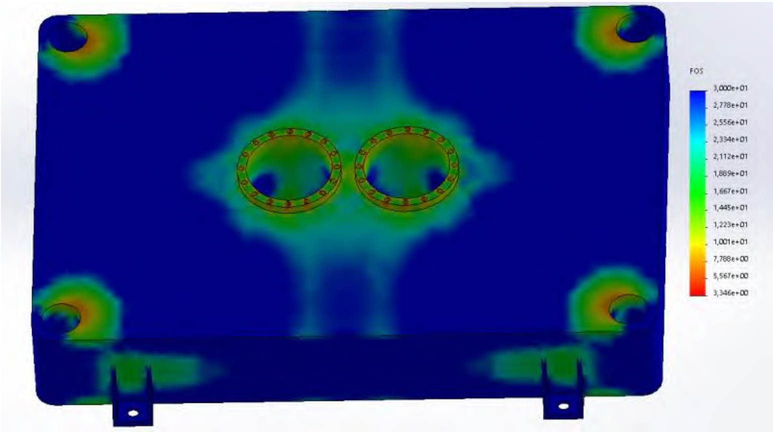


Figure 58: Factor of safety analysis of lower beam.

4.3.6. Hydraulic pump

According to the required parameters, a hydraulic pump with variable displacement power regulation that has a flow rate of 236 lt/min and can reach a pressure of 250 bar should be selected. Normally, a pump with a flow rate of 236 lt/min should be selected. However, considering the losses that may occur in the piping and installation of the system, the pump should be selected by multiplying this value with a safety coefficient of 20% [9].

$Q_{max} = 236(1.2) = 283$ lt/min $= 0.283\ {m^3}/{min} = 0.00472\ {m^3}/{s}$

$P_{max} = 250\ bar = 250 \times 10^5\ N/mm^2$

If the efficiency of the pump is taken as 80%, the power of the motor that should be used is found by the formula below. Also, the speed of the pump was taken as 1900 rpm. And geometrical flow rate can be calculated as:

$D_P = \frac{Q}{n} = \frac{283}{1900} = 0.149$ lt/rev $= 0.149 \times 1000 = 149\ {cm^3}/{rev}$

With %20 safety percentage $149 \times 1.2 = 179\ {cm^3}/{rev}$

$$W = \frac{Q \times P}{\eta} = \frac{0.00472 \times 250 \times 10^5}{0.80} = 148000W = 148kW$$

According to catalogue from Hidropaks Hidrolik A.Ş. K3VL200 hydraulic pump is selected.

AÇIK ÇEVRİM PİSTONLU POMPALAR									
POMPA MODELİ			K3VL28	K3VL45	K3VL60	K3VL80	K3VL112	K3VL140	K3VL200
Kapasite		cc/dev	28	45	60	80	112	140	200
Basınç Değerleri	Sürekli	bar	320	320	250	320	320	320	350
	Pik	bar	350	350	280	350	350	350	400
Devir	Minimum	dev/dak	600						
	Sürekli	dev/dak	3000	2700	2400	2400	2200	2100	1900
	Maksimum	dev/dak	3600	3250	3000	3000	2700	2500	2200
Çalışma Sıcaklığı		°C	(-20, +95)						
Viskozite Aralığı		cSt	(10 – 1000)						
Maksimum Kirlilik Seviyesi			20/18/15 ISO 4406 (NAS 9)						

Figure 59: Open type hydraulic pump catalogue from Hidropaks A.Ş. [21].

4.3.7. Sealing selection

Sealing elements generally control the fluids between two pressure zones in systems; They are used to prevent fluid from passing from one area to another area. A pump, compressor, etc. Force is created by the impact of pressurized fluid on an area. For example, when considering a hydraulic or pneumatic cylinder, work is achieved by the shaft extending outwards or closing inwards. Very high powers can be obtained with the principle of incompressibility of hydraulic fluids. In pneumatic systems, lower powers can be obtained compared to hydraulic systems.

Rod seal and cylinder seal

Pressure level, temperature range, fluid type, movement type, wear and friction, ease of assembly and maintenance, size and tolerances, environmental factors and cost are among the factors that should be taken into consideration when choosing a seal in hydraulic cylinder design. While the height of the pressure level determines the durability of the element, the temperature range affects the elasticity and durability of the material. The fluid type must be compatible with the material of the element, otherwise the fluid may damage the seal.

Depending on the type of movement, a choice must be made between dynamic and static seals. Wear and friction resistance increases element longevity and system efficiency, while ease of assembly and maintenance affects operational processes. While dimensions and tolerances ensure proper fit of the element, environmental factors (dust, dirt, moisture, chemicals) affect durability. Finally, the cost factor must be balanced with performance and durability. Taking these elements into consideration, we selected two seals best suited to our hydraulic cylinder application: laryngeal rod seal and cylinder seal.

Figure 60: K31 Heavy duty rod seal from Kastaş A.Ş. [22].

Below figure shows the design suggestion from Kastaş, for K31 heavy duty rod seal.

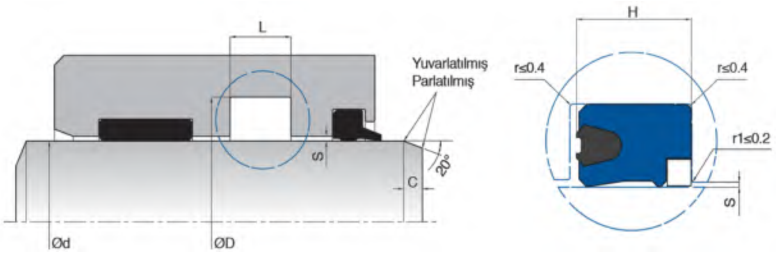


Figure 61: Design suggestion for K31 Heavy duty rod seal from Kastaş A.Ş. [22].

Figure 62: K48 Heavy duty cylinder seal from Kastaş A.Ş. [22].

Below figure shows the design suggestion from Kastaş, for K48 heavy duty cylinder seal.

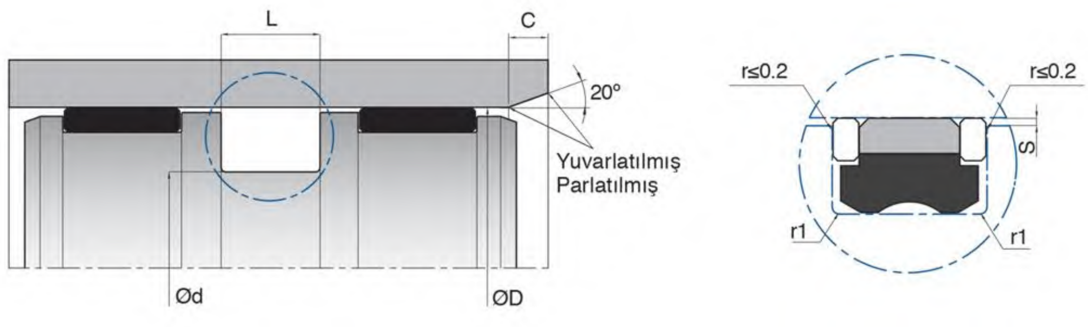


Figure 63: Design suggestion for K48 Heavy duty cylinder seal from Kastaş A.Ş. [22].

Sliding bearing system

It prevents metal to metal contact in the cylinder. It absorbs the lateral loads that occur during work done with a cylinder (load lifting, pressing, etc.). By ensuring concentric operation of the cylinder, it prevents the sealing elements from being crushed and creates a safe working environment. They are manufactured from high-strength material with low deformation and loss of size under load, and they are generally composite in structure.

Note: Bearing elements do not act as a seal in the system. They are manufactured with a cut and helical channel structure that allows the passage of fluid.

Sliding bearing system selection

Factors to be taken into consideration when selecting a bearing element in hydraulic cylinder design include load and load distribution, movement type and speed, environmental conditions, precision and tolerances, wear and maintenance requirements, material and coating, ease of installation, vibration and noise, and cost. While the maximum load that the bearing elements will carry and the uniform distribution of this load reduce wear and deformation, the type of movement and speed it will support affects the selection of the appropriate element. The conditions of the operating environment determine the choice of materials, while precision requirements and assembly tolerances affect the performance of the cylinder.

Elements with high wear resistance and low maintenance should be preferred, and ease of installation and vibration-noise reduction features should also be taken into consideration. Additionally, the cost factor must be balanced with performance and durability. By taking these factors into consideration, you can choose the bearing element that best suits your hydraulic cylinder application.

Figure 64: K79 cylinder rod sliding bearing system from Kastaş A.Ş. [22].

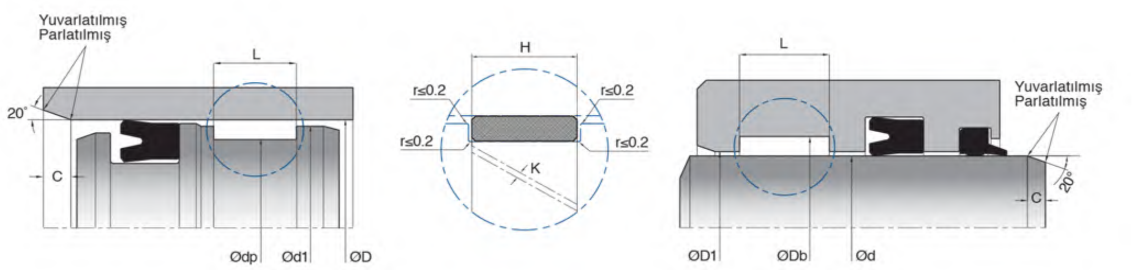


Figure 65: Design suggestion for K79 cylinder rod sliding bearing system from Kastaş A.Ş. [22].

Dust Seal

Dust seal selection in hydraulic cylinder design is of great importance for the performance and life of the system. Dust seals are sealing elements located on the part of the hydraulic cylinder that comes into contact with the external environment and prevent dust, dirt, moisture and other foreign substances from entering the cylinder. The correct selection of these seals reduces the risk of wear and corrosion on the inner surfaces of the cylinder, reducing maintenance costs and increasing the efficiency of the system. Dust seals should be selected from materials suitable for the working environment conditions, the operating temperature and pressure of the cylinder and the type of hydraulic fluid used.

Materials such as nitrile rubber (NBR), polyurethane (PU) and fluorocarbon (FKM) are generally used. Additionally, the geometry and dimensions of the seal must comply with the technical specifications of the cylinder. Therefore, when choosing a dust seal, we made a choice by taking into account the dust content in the working environment, suitability for the operating speed of the cylinder, cost and lifespan.

Figure 66: K708 Dust seal from Kastaş A.Ş. [22].

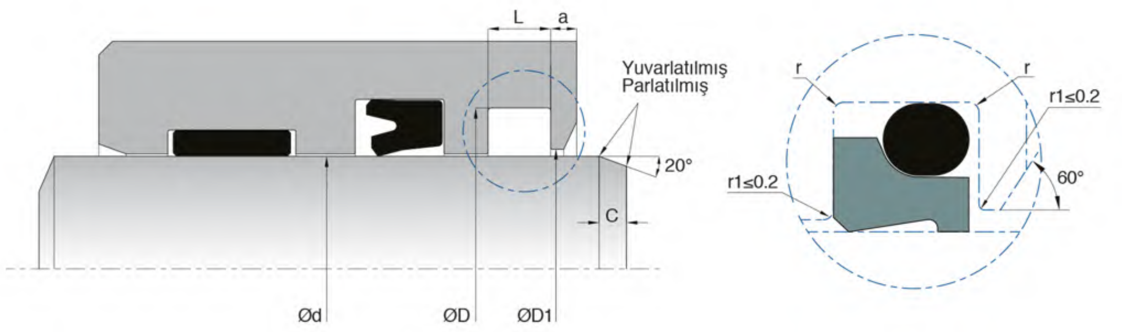


Figure 67: Design suggestion for K708 dust seal from Kastaş A.Ş. [22].

4.3.8. Lubrication and oil selection

Oil also acts as a lubricant, minimizing wear and tear on the system's moving parts. Oil selection may vary depending on the system to be used. As seen in the table below, oil selection varies depending on the operating temperature and the pressure reached.

Pump Type	Temp °C/°F max	Pressure bar/psi	Viscosity ISO VG
Gear	70/158	34.5/500	32/68
	60/140	34.5/500	15/32
Vane	70/158	34.5/500	15/22
	70/158	69/1,000	22/46
	60/140	69/1,000	15/32
	40/104	69/1,000	10/15
Piston	70/158	34.5/500	15/22
	70/158	172.5/2,500	22/46
	60/140	172.5/2,500	32/46
	40/104	172.5/2,500	15/22
	70/158	293/4,250	46/68
	60/140	293/4,250	22/46
	40/104	293/4,250	15/22

Table 4: Oil selection table for given pressure and temperature [23].

The oil in the system heats up because of continuous movements and its properties change. To prevent this, it is necessary to choose the most suitable oil for the system. At the same time, the oil is continuously cooled to ensure that it maintains the desired viscosity value. Considering the criteria in this design, the maximum temperature for oil is 60 degrees. When determining this temperature, the power of the oil cooling system was taken into consideration. At the same time, since the optimum pressure value of the oil generally remains 250 bar so, the most suitable oil for the 1000 ton hydraulic deep drawing press design will be ISO VG 22/46.

Selecting the appropriate amount of oil tank for the hydraulic press is very important to ensure the efficiency, reliability and longevity of the system. The tank must have sufficient capacity; This capacity should generally be 3-5 times the system's pump flow rate per minute. For this system 3 times pump flow rate is selected [7]. Since pump’s flow rate is 200 cc/rev a required oil tank can be calculated as:

$200\ {}^{cc}/_{rev} \times\ 1900\ {}^{rev}/_{min} = 380000$ ml $= 380$ L

So required oil tank capacity is:

$380 \times 3 = 1140$ Liters

Hydraulic piping and hose

For hose selection 7 paremeters should be determined. These parameters are also known as STAMPED. Size, temperature, application, material, pressure, ends or couplings, delivery. Typically, 3 to 5 m/s fluid flow is used in the hose systems. If the flow rate of the system is 283 lt/min. Diameter of the hose can be found as:

283 lt/min $= 4.72 \times 10^{-3}\ m^3/s$

$$\frac{4.72 \times 10^{-3}}{3\ m/s} = 1.573 \times 10^{-3}\ m^2 = 1573\ mm^2$$

$$1573\ mm^2 = \frac{\pi}{4} {d_{hose}}^2 \rightarrow d_{hose,i} = 44.75\ mm$$

The most suitable hose with an inner diameter of 44.75mm should be selected from the figure below. When looking at dash size 24, one of the corresponding diameters in the table, it is seen that the working pressure is 54 bar. Accordingly, it is understood that when we try to increase the pressure of 250 bar with high flow rate, a suitable hose cannot be selected. For this reason, piping must be done manually. For this purpose, steel reinforced pipes will be connected to each other by welding and piping will be made.

Dash Size	DN	ID		OD		WP		BP		BR/r		W
		inch	mm	inch	mm	psi	bar	psi	bar	inch	mm	kg/m
-03	05	3/16	5.1	0.52	13.1	6020	415	24070	1660	3.5	90	0.319
-04	06	1/4	6.7	0.58	14.7	5800	400	23200	1600	3.9	100	0.386
-05	08	5/16	8.2	0.64	16.3	5075	350	20300	1400	4.5	115	0.458
-06	10	3/8	9.8	0.74	18.7	4785	330	19140	1320	4.9	125	0.590
-08	12	1/2	13.1	0.86	21.8	3990	275	15950	1100	7.1	180	0.679
-10	16	5/8	16.2	0.98	25.0	3625	250	14500	1000	7.9	200	0.825
-12	19	3/4	19.3	1.14	28.9	3120	215	12470	860	9.4	240	1.009
-16	25	1	25.9	1.48	37.5	2395	165	9570	660	11.8	300	1.457
-20	31	1.1/4	32.4	1.87	47.6	1815	125	7250	500	16.5	420	2.272
-24	38	1.1/2	38.7	2.13	54.0	1305	90	5220	360	19.7	500	2.620
-32	51	2	51.3	2.63	66.7	1160	80	4640	320	24.8	630	3.381
-40	63	2.1/2	63.5	3.15	80.0	1015	70	4060	280	29.9	760	4.443
-48	76	3	76.2	3.68	93.4	800	55	3190	220	35.4	900	5.459
-64	100	4	101.6	4.67	118.5	725	50	2900	200	46.5	1180	5.887

Figure 68: Hydraulic hose selection chart [24].

To make a handmade piping system tangential and radial stress should be analyzed. To find this values Barlow's Formula [10] can be used. According to Barlow's formula internal pressure can be found as:

$$P = \frac{2\sigma_\theta s}{D} \tag{4.7}$$

Where:

P: Internal pressure

σ_θ: Allowable stress

s: Wall thickness

D: Outside diameter

For piping material AISI 4140 is selected and has a yield strength of 450 MPa.

$$25\ N/mm^2 = \frac{2(450MPa)s}{44.75 + 2s}$$

Wall thickness is 1.3 mm so 1.5mm is selected.

As hydraulic oil leaves the system and cylinders, it increases its temperature due to friction and loading. As the temperature increases, the oil's viscosity changes and loses its properties. For this reason, the oil is kept within a certain value range during the cycle. The inlet and outlet of the oil in the cylinder is controlled by a hydraulic control valve. The heated oil (coming out of the cylinder) is directed to the heat exchanger. and after cooling in this heat exchanger, it becomes pumpable. As seen in the below figure, the tank capacity of the oil sump system is 1140 liters as above. Additionally, filters should be used to ensure a clean oil flow into the cylinders.

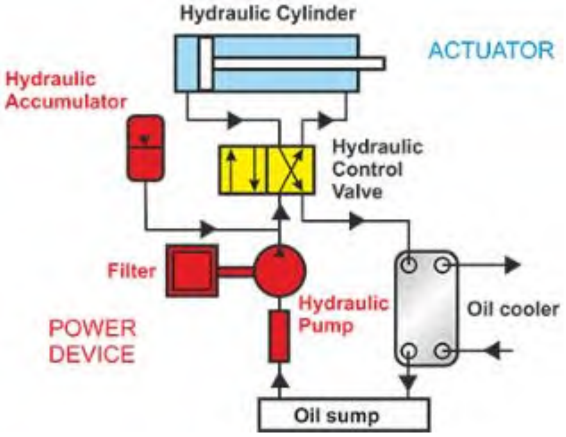


Figure 69: Oil pressurization schematic of hydraulic press [25].

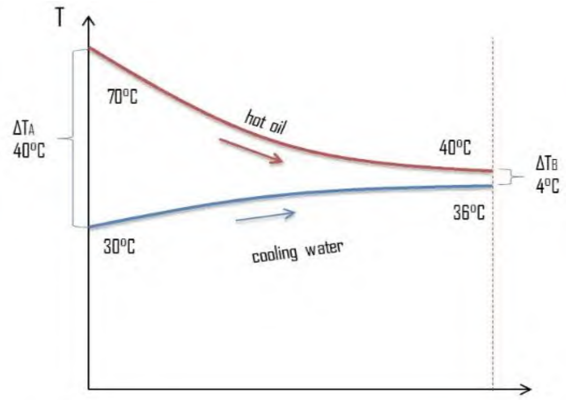


Figure 70: Representation of heat exchanger between oil and cooling fluid [26].

When hydraulic presses used around the world are examined, the optimum operating temperature of the oil is generally taken to be 45◦C. Considering that the ISO VG 22/46 oil used in this design can function at a maximum of 60◦C. Input of the oil entering heat exchanger is 60◦C maximum and leaving oil is 40◦C. For cooling fluid, propylene glycol water will be used. Cooling fluid will be used between 10◦C to 30◦C. So, the required heat exchanger power can be calculated as follows.

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \tag{4.8}$$

$$Q = U \times A \times LMTD \tag{4.9}$$

Q is also:

$$Q = m \times c \times \Delta T \tag{4.10}$$

So, the required heat flow area can be calculated as:

$$A = \frac{Q}{U \times LMTD} \tag{4.11}$$

Where:

T_1: Hot fluid (oil) inlet temperature $= 60 \circ \mathrm{C}$

T_2: Hot fluid (oil) outlet temperature $= 45 \circ \mathrm{C}$

t_1: Cold fluid (cooling) inlet temperature $= 10 \circ \mathrm{C}$

t_2: Cold fluid (cooling) outlet temperature $= 30\ \circ\ \mathrm{C}$

Q: Heat released or absorbed.

U: Overal heat transfer coefficient. (For plate heat exchangers its 2000 $W/(m^2K)$

m: Mass flow rate of fluid

c: Specific heat capacity

ΔT: Temperature difference

$$LMTD = \frac{(60-30)-(45-10)}{\ln\frac{(60-30)}{(45-10)}} = 32.44\ \circ\ \mathrm{C}$$

$$m = \frac{283}{1000lt/m^3}\frac{lt}{min}\frac{1min}{60sec} \times \rho = 4.72 \times 10^{-3}\ m^3/s \times \rho$$
$$= 4.72 \times 10^{-3}\ m^3/s \times 0.855kg/m^3 = 4.03 \times 10^{-3}kg/s$$

$$Q = m \times c \times \Delta T = 4.03 \times 10^{-3}kg/s \times 0.895 \times (60-45) = 0.054kW = 54.1W$$

So:

$A = \frac{54.1W}{2000\ W/(m^2K)\times 32.44} = 8.339\ m^2 = 834\ mm^2$ is needed.

4.3.10 Half-moon part

Half-moon parts ensure that the upper elements do not slide down when the hydraulic press is not working or when it is lifted. The force acting on the half-moon key is shear force. The factor that creates this shear force are upper beam, main cylinder, slider, upper die and the oil insider main cylinders.

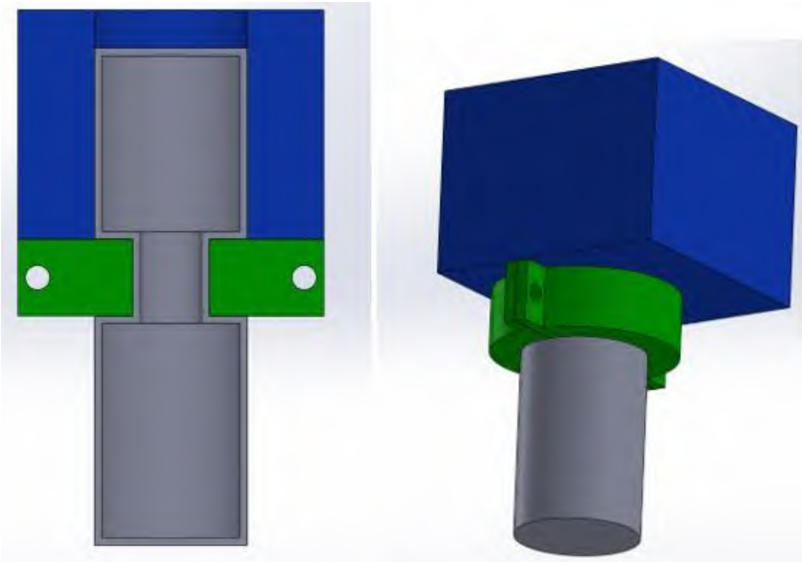


Figure 71: Cross-sectional representation of the half-moon part under load.

As seen in the figure above, the force on the half-moon (green) is visible through the blue part slider. The half-moon part is mounted on the column in two parts. And these parts are joined to each other with screws.

Total force carried by this half-moon can be calculated as:

F_{total} = Upper beam + Main cylinder structure + Slider + Upper Die + Oil

These half-moon parts are general manufactured by AISI 1045 steel. And shear strength of AISI 1045 steel is 450MPa. This total force is divided into 4 half-moon parts. If the factor of safety is taken as 2.0, the minimum required shear stress area is found by the formula below. Shear yield strength can be computer from tensile yield strength:

$$\tau_{ys} = 0.577\sigma_{ys} \tag{4.12}$$

$\tau_{ys} = 0.577 \times 450 = 260\ MPa$

$$\frac{F_{total}}{4 \times A_{min}} = \frac{260MPa}{2.0}$$

$$F_{total} = (9500\ kg\ +\ 3700kg\ +\ 8000kg\ +\ 15000kg\ +\ 350kg) \times 9.81$$
$$= 355612\ N$$

$$\frac{3.56 \times 10^5}{4 \times A_{min}} = \frac{260MPa}{2.0}$$

$A_{min} = 684.62\ mm^2$

The shape of the minimum area found is hallow because a column passes through it. For this reason, the outer diameter of the half-moon part can be found in the formula below.

$$A_{min} = (d_{col})(\pi)(h_{key}) \tag{4.13}$$

$684.62\ mm^2 = (160mm)(\pi)(h_{key}) \rightarrow h_{key} = 1.36\ mm$

Also, other critical parameter is bending stress, for that moment diagram should be analyzed.

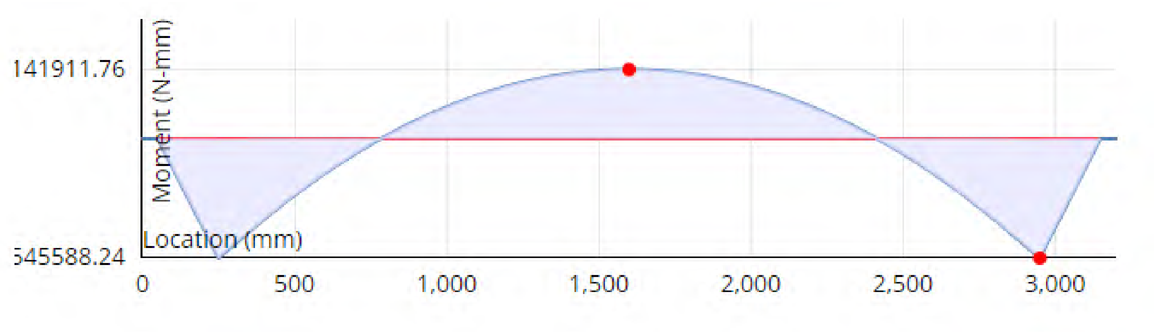


Figure 72: Bending moment diagram on half-moon part.

As can be seen from figure maximum bending moment occurs on inner side of half-moon part with a magnitude of 81545588 N.mm.

So, if bending stress formula writen according to Eq. 4.4:

$$\frac{8.15 \times 10^7 \times y}{I} = \frac{450\ MPa}{2.0}$$

Where:

y: Distance from centerline of object $y = \frac{h}{2}$

I: Moment of inertia of cross section

According to Eq. 4.5 moment of inertia of green cross section can be calculated as:

$$I_{shear\ key} = 2\left(\frac{1}{12}bh^3 + bh\left(d_i + \frac{b}{2}\right)\right) \tag{4.14}$$

d_i: 140 mm

b: horizontal dimension of half-moon

h: height of half-moon

Normally at Eq. 4.14 circular screw holes should be considered but since their effect is relatively small so they are neglected. Since the factor of safety is taken as 2.0 there won't be any problem.

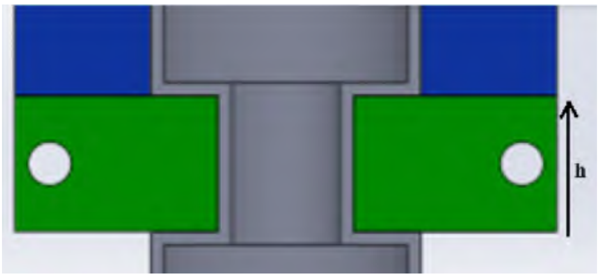


Figure 73: Cross-section view of half-moon element.

To design half-moon a parameter should be assumed so that h is assumed to be 100 mm. Then y becomes 50 mm.

$$\frac{8.15 \times 10^7 \times 50mm}{I} = \frac{450\ MPa}{2.0} \rightarrow I = 1.81 \times 10^7\ mm^4$$

$1.81 \times 10^7\ mm^4 = 2\left(\frac{1}{12}bh^3 + bh\left(d_i + \frac{b}{2}\right)\right) \rightarrow b = 89mm \cong 90mm$ is selected.

So, in summary a half-moon element which has 140 mm inner diameter and $140 + 90 \times$

$\times\ 2 = 320mm$ outer diameter and 100 mm height is enough for this design process.

According to this specification a half-moon part can be designed. Below figure shows the assembly of half-moon part and column. Also torque screws included.

Figure 74: Assembly view of column, half-moon and torque screw.

4.4 Assembly of 1000-Ton hydraulic deep drawing press

First step is assembly is subassembly of hydraulic cylinders. So firstly, sealing elements should be put in place along with bearing and snap ring. Cylinder head are attached to the rod. Cylinder surface and head are lubricated. Cleanliness is prioritized at every step and surfaces are kept clean at every point of the installation and wiped approppriately if necessary. The rod is carefully slid into the tube with the cylinder end first. Cylinder head is welded. After everything is ready, bearings and grease fittings are installed.

Blankholder cylinders are mounted to the lower beam using 16 M30 screws. The rods of the blankholder cylinders are fixed to the lower table using screws. Bedding material is placed in the gaps where the columns will coincide, this sub-assembly is passed through 4 columns and is compressed between the lower beam, half-moon and tension nut, thanks to the tension nuts under the columns. then move on to the upper table. Likewise, the main cylinders are fixed to the upper table from bottom to top using 16 M42 screws. The rods of the main cylinders are mounted to the slider from top to bottom with M42 screws. After the half-moons of the upper part are placed in their places, this part is passed through the columns and compressed by the tension nuts on the top.

The hydraulic power unit is usually placed under the floor where the hydraulic press is located so that it does not take up space, and the necessary valves and tanks are located there. The pipes coming out of the hydraulic pump are welded and installed with 2 inlets each to the main cylinders and 1 inlet to the blankholder cylinders. The reason why blankholder cylinders have one inlet is that they can move downwards thanks to the main cylinder. After the piping operations are completed, the cylinders are filled with oil and the press begins to be tested. It is tested that the security elements are working. Then, after testing on a simple die, the press is delivered.

After these assembly steps are completed, the 1000-ton hydraulic deep drawing press is now ready for use. The image below shows the finished assembly of these assemblies via SolidWorks. Also, a pair of die material is inserted to see its dimensions.

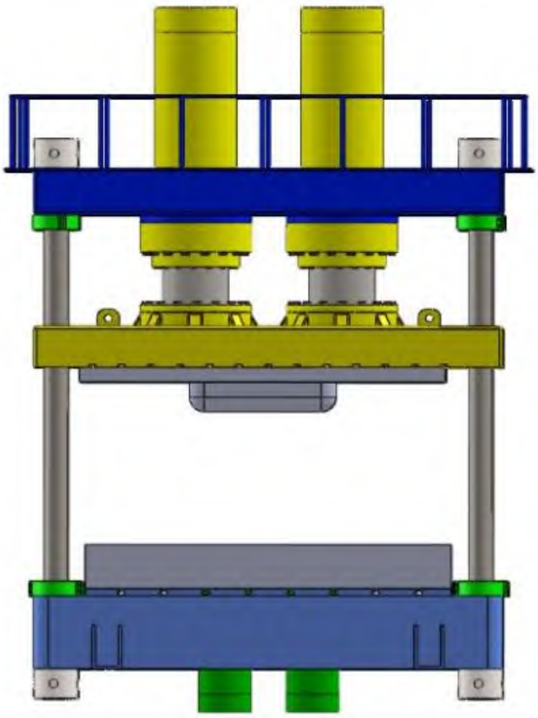


Figure 75: Final assembly view of 1000-ton hydraulic deep drawing press.

4.5 Structural Analysis of Final Assembly

For finite element method analysis, it is first necessary to create a mesh on the assembly. For this purpose, a mesh with a minimum mesh tolerance of 3 mm and element size of 30 mm was selected. The reason for choosing such a small step is sudden rotation and breakage on the parts. The figure below shows the distribution of the mesh with 30mm element length with 3mm tolerance on the assembly. Before meshing, a distributed load of 9810000 N, equivalent to an upward force of 1000 tons, was placed on the lower surface of the slider, and a downward distributed load of 3924000 N, equivalent to 400 tons, was placed on the upper surface of the lower beaming. And the lower surface of the lower beam is made fixed.

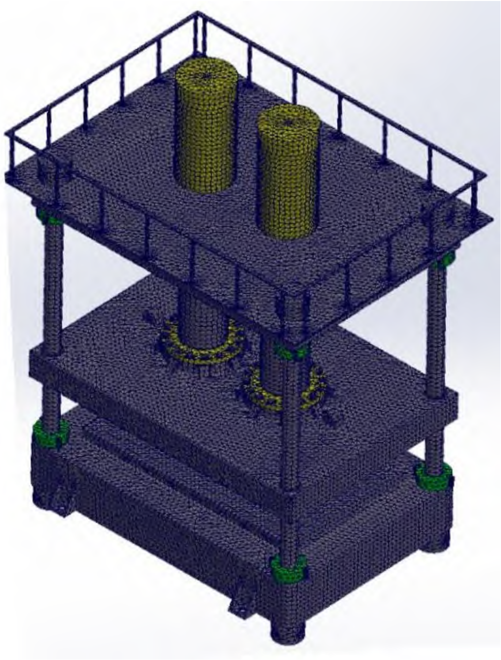


Figure 76: Meshed view of final assembly of hydraulic press.

Static analysis was started according to these parameters. and as a result, it was concluded that the hydraulic press will withstand these loads. The images below are respectively of the 1000-ton hydraulic deep drawing press under these loads; It shows von Mises stress analysis, maximum displacement, strain and factor of safety resistance.

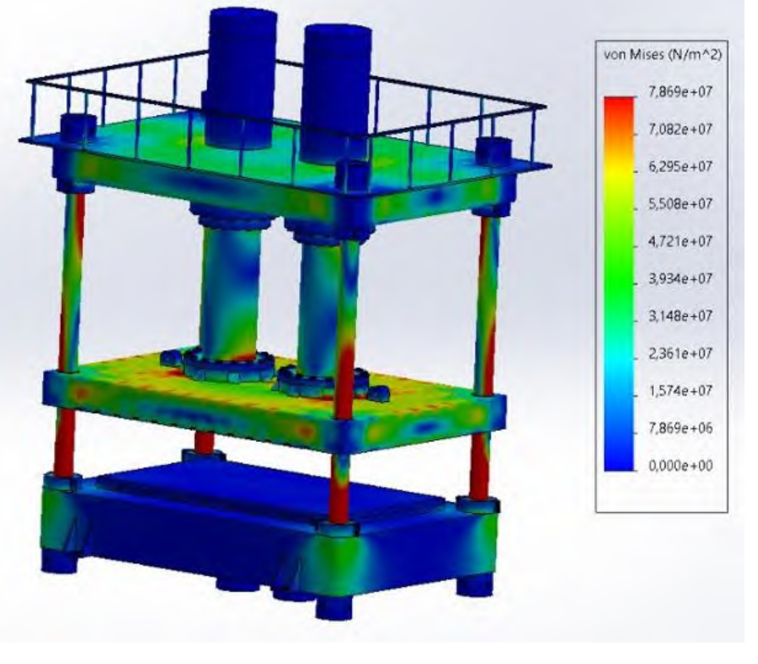


Figure 77: von Mises stress analysis of hydraulic press assembly (undeformed form).

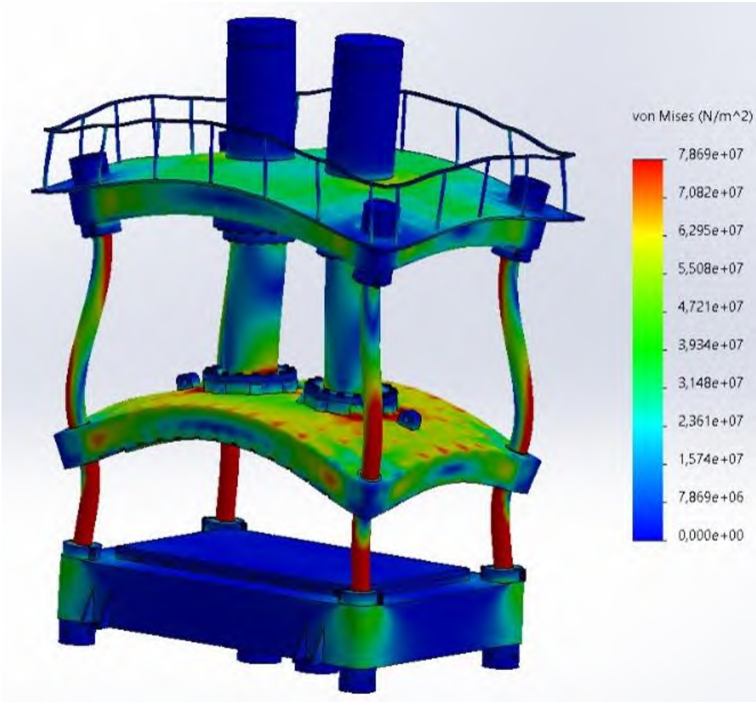


Figure 78: von Mises stress analysis of hydraulic press assembly (deformed form).

According to von Mises analysis maximum stress has a magnitude of $2.87 \times 10^{8}\ N/mm^{2}$. Above figure doesn’t include this magnitude on its scale to see how the stress is distributed along assembly.

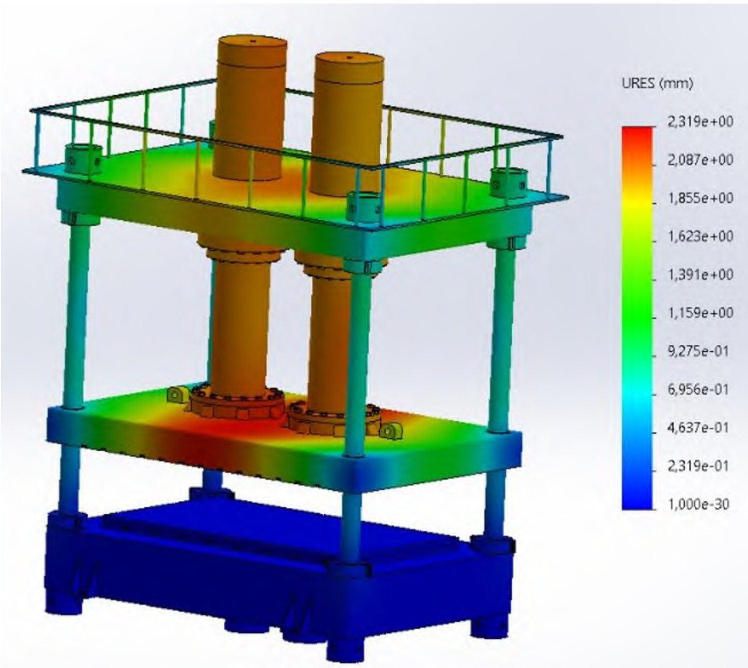


Figure 79: Maximum displacement analysis of hydraulic press assembly.

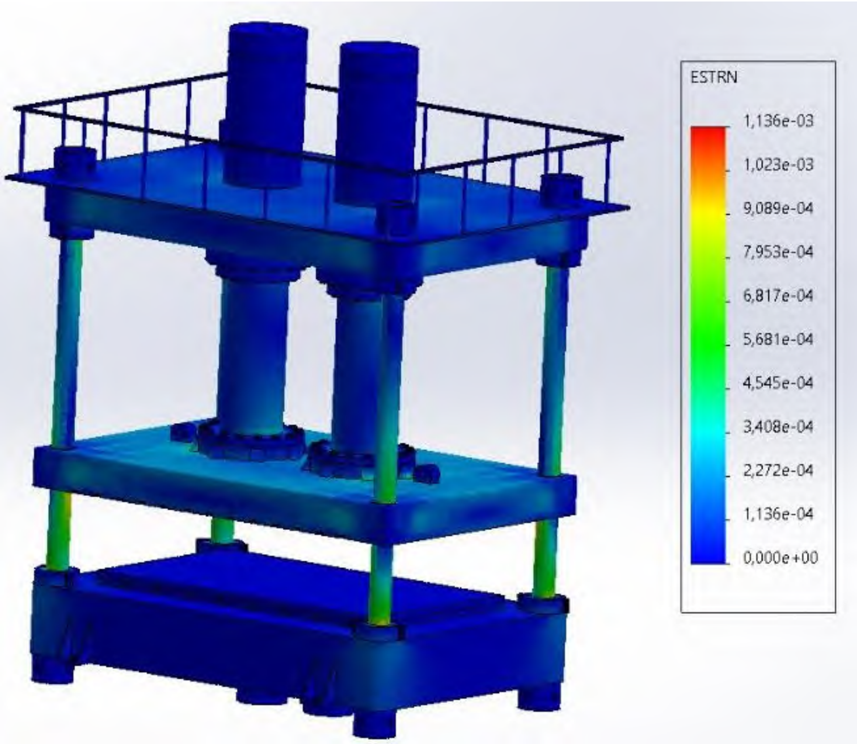


Figure 80: Strain analysis of hydraulic press assembly.

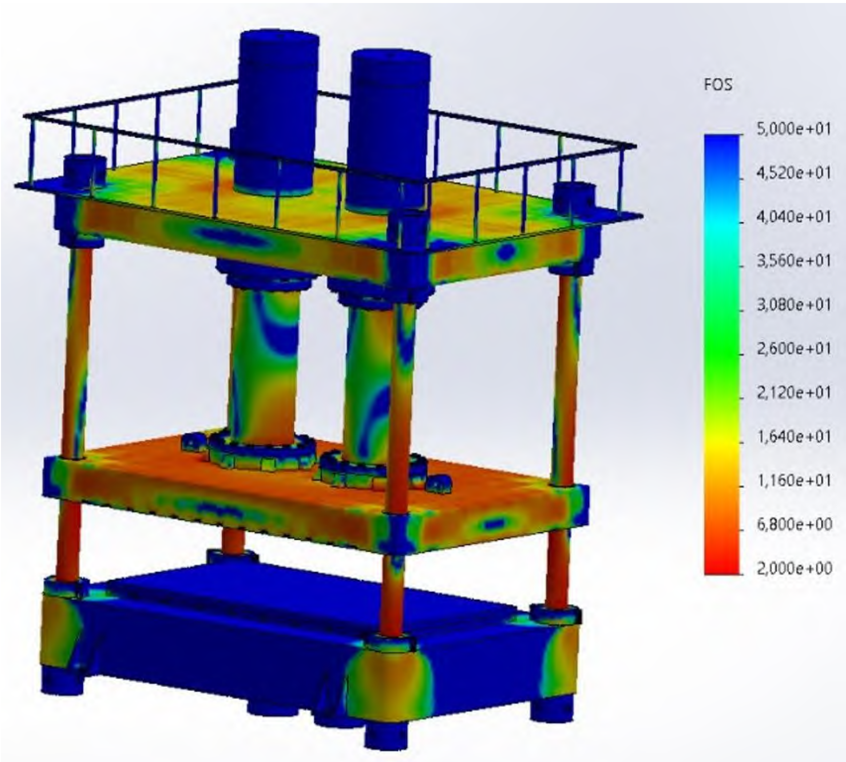


Figure 81: Factor of safety analysis of hydraulic press assembly.

5. COST ANALYSIS

The price analysis is divided into 2 parts. The first is the cost of processing the body materials, and the second is the cost of the hydraulic unit and control groups. The table below shows the processing costs of materials. As seen in the table, unit prices of different materials using the same material type are different. The reason for this is that as the size of the materials increases, the unit prices also increase. According to this table, the weights of the materials were calculated, multiplied by the unit price and the processing cost was added. This processing cost also varies from material to material depending on the process to be performed.

Part Name	Material	Count	Weight (Kg)	Unit Price ($)	Material Cost	Process Cost	Total Cost
Main Cylinder	AISI 1045	2	3800	$3/kg	$22800	$20000	$42800
Blankholding Cylinder	AISI 1045	2	630	$2.5/kg	$3150	$2700	$5850
Lower Beam	AISI 4130	1	16400	$3.5	$57400	$14800	$72200
Upper Beam	AISI 4130	1	9400	$3.5	$32900	$8400	$41300
Slider	AISI 4130	1	8000	$3.5	$28000	$7100	$35100
Column	AISI 4140	4	700	$6	$16800	$3200	$20000
Half-moon	AISI 4145	16	30	$4.5	$2160	$800	$2960
Torque Screw	AISI 4145	8	60	$4.5	$2160	$800	$2960
Sliding Bearing	Bronze	4	15	$10	$600	$200	$800
						Total	$223970

Table 5: Cost analysis table includes material and process costs.

Another cost group is the hydraulic unit and control. These are hydraulic pump, hydraulic unit (piping, valves, etc.), control unit, electrical motor and oil. The table below includes the unit and total costs of these groups.

Unit Name	Count	Unit Price ($)	Total Price
K3VL200 Hydraulic Pump	1	$8000	$8000
Hydraulic Unit	1	$10000	$10000
Control Unit	1	$25000	$25000
185 Kw Electrical Motor	1	$20000	$20000
VG 22/46 Oil	1140	$4.5	$5130
		Total	$68130

Table 6: Cost analysis table includes hydraulic units and control systems.

According to these cost analyses, the total cost of the 1000-ton hydraulic deep drawing press we evaluated was found to be 292100 dollars. This cost does not include die costs and maintenance costs. It only includes the installation cost.

6. FUTURE INNOVATIONS

There are many aspects of hydraulic deep drawing press design that can be improved. In this design, a design was chosen in line with customer requests. The first of these aspects is sustainability. These hydraulic presses are frequently used in the automotive industry. Since the automobile industry is a rapidly competing industry, the production speed of the parts both reduces the cost and ensures competition. For this reason, thanks to a unit that can be built on the lower beam body of this hydraulic press, parts can be produced much more quickly and safely with an autonomous system.

Another issue is die technologies. Throughout this design, blankholder cylinders, which hold the load coming from the main cylinders during the processing of the part and provide shape, were analyzed. However, thanks to new developing technologies, these blankholder cylinders are now becoming unqualified. In the new die technology, the die will provide the function of the blankholder cylinders by creating a reaction force to this force, just like a spring, when a force is applied to it, thanks to the mechanisms within itself. This change eliminates both blankholder cylinders. In addition, this blankholder performs the same function by ensuring that many parts such as hydraulic units, piping and fittings connected to the cylinders are not produced. It also reduces the time required for maintenance [11]. However, it brings an additional cost for each die. This system can be efficient if used in places where there is a lot of production.

Figure 82: New type die technology used in hydraulic deep drawing presses [27].

The image above shows an example of such die technologies. The springs located in the middle on the die create a reaction force at the moment of pressing.

7. CONCLUSION

The design criteria decided and implemented in the previous sections were first subjected to strength analysis as parts. In the report, its compliance with the previously mentioned safety factor has been tested. The parts that did not comply with the specified safety factor were examined one by one and the unsuitable parts were determined. The reasons why these parts were not suitable were determined and made suitable. Afterwards, the edited parts were added to the report. After ensuring the suitability of all parts, the assembly method was determined. The parts were assembled according to the determined assembly method. Then, the assembled and integrated design was subjected to numerical analysis to determine whether it complies with the safety factors. SolidWorks program was used to view and interpret the results of numerical analyses. In this section, no part that does not comply with the safety factor has been identified. From this result, it was seen that the design provides the necessary safety factor. Moreover, it has been observed that the determined design criteria give the desired results.

Afterwards, the production methods required to produce the parts were determined. After researching the prices of the required materials, the most economical materials and production methods were decided. As a result of these decisions, the cost analysis stated in the report was reached. This value shows the installation cost and is 292,100 USD. This price does not include die costs and installation labor. Considering the results, a cost competitive with equivalent designs has emerged. The product, which is designed to provide long-term service both in terms of the economic life of the products used and the quality of the parts used, will pay for itself in a short time with its maintenance costs and trouble-freeness. Designed for the purposes of ease of use, superior performance, long life, low maintenance cost, trouble-freeness and best product output, the press will be superior to its competitors in every aspect, both in terms of market requirements and customer demands.

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8.2 Figure and Table References

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9. Appendices

Cross sectional views of lower beam.

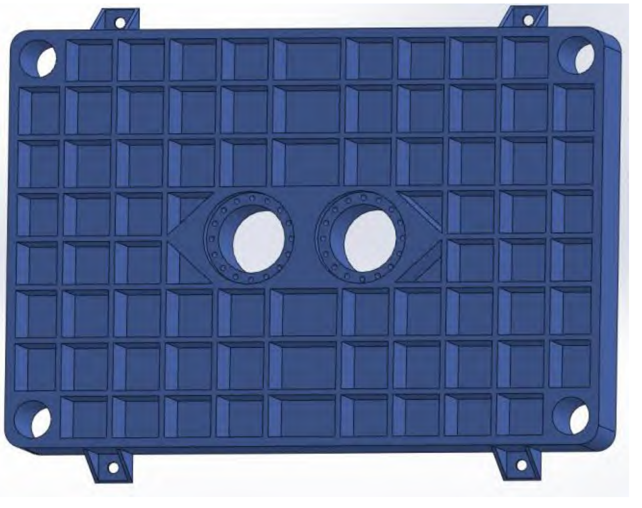

Figure 83: Cross sectional view of lower beam from y axis.

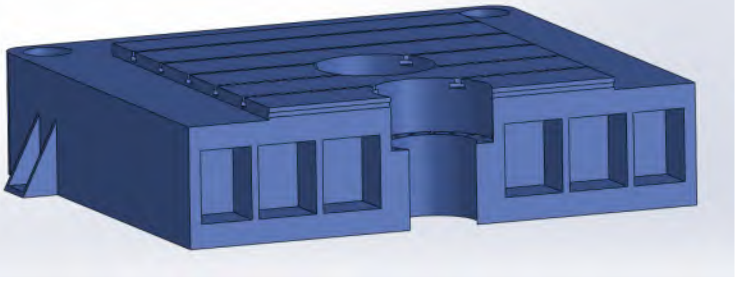

Figure 84: Cross sectional view of lower beam from x axis.

Cross sectional views of upper beam.

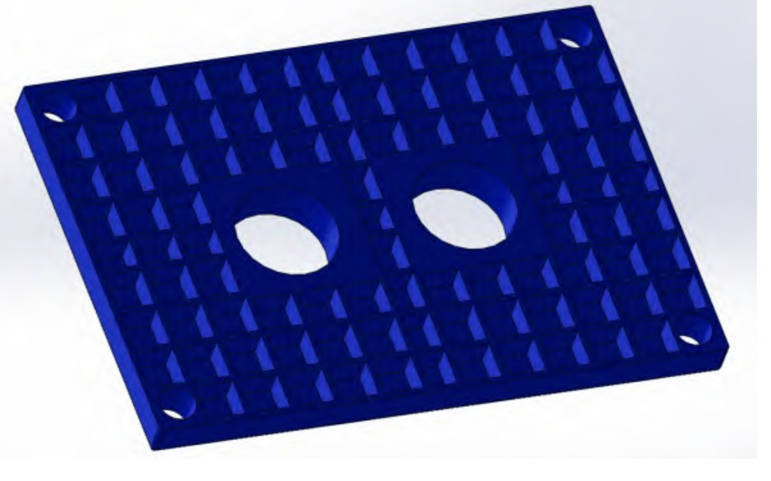

Figure 85: Cross sectional view of upper beam from y axis.

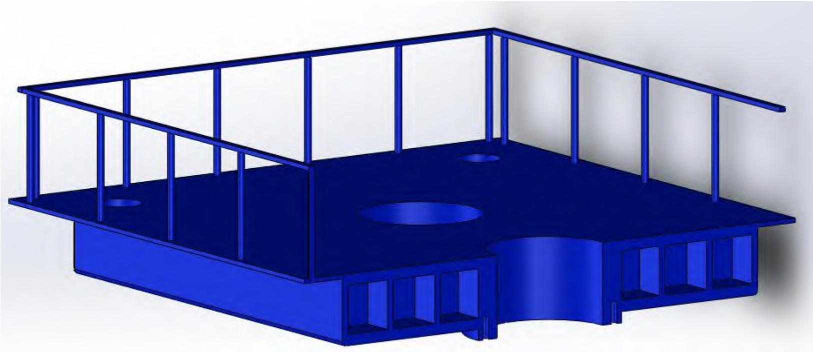

Figure 86: Cross sectional view of upper beam from x axis.

Cross sectional views of slider.

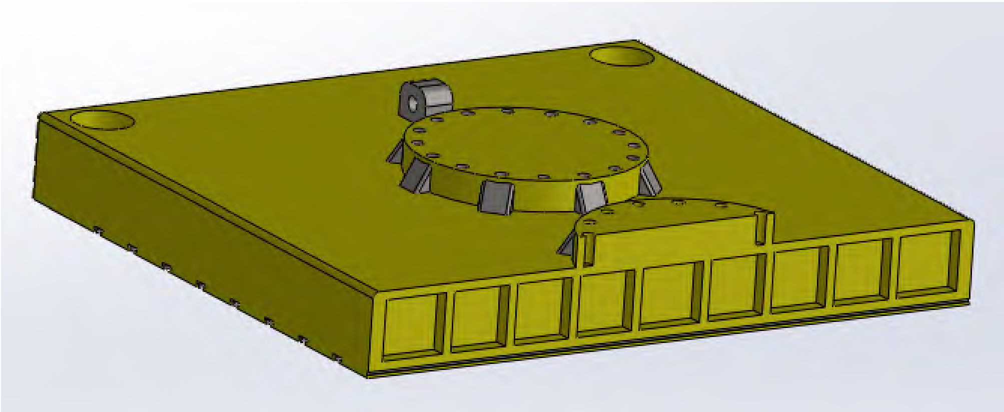

Figure 87: Cross sectional view of slider from z axis.

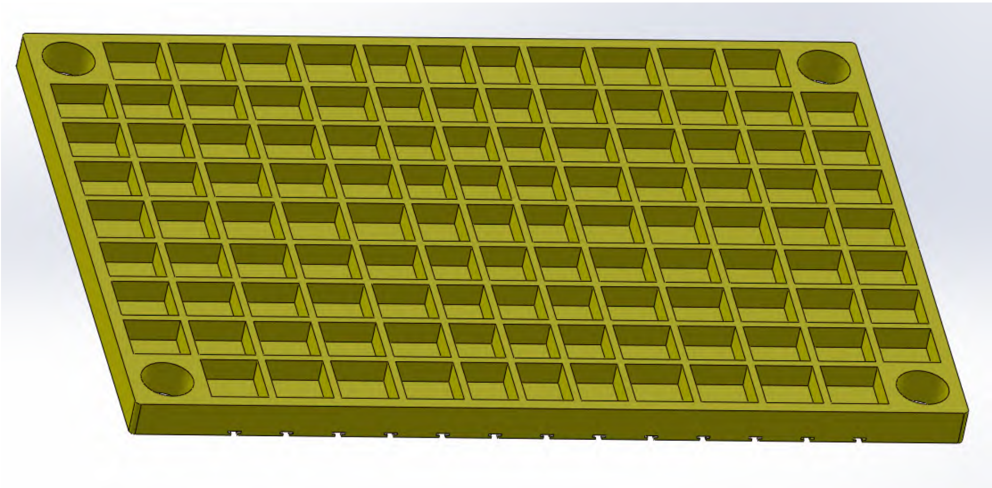

Figure 88: Cross sectional view of slider from y axis.