Hydraulic Forging Press for Pattern-Welded Damascus Steel

Bob The Bladesmith [1] [2]

***Abstract*—The paper describes an attempt to build a budget and relatively small Hydraulic Forging Press whose main usage is forge welding Pattern-Welded Damascus Steel and drawing out the material quickly and effectively.**

The article includes preliminary assumptions, initial calculations, steps taken to implement the project, and the final results with practical examples.

Experimental results show that a press with limited pressure force and speed can still effectively perform the intended tasks well enough.

***Index Terms*—Hydraulic Forging Press, Damascus Steel, Pattern-Welded Steel**

I. Introduction

The hydraulic press is a versatile and powerful tool widely used in various industries for shaping, forming, and assembling materials through the application of controlled force. In the realm of blacksmithing and metalworking, hydraulic presses have become indispensable for forging operations, particularly in the creation of pattern-welded Damascus steel and the efficient drawing out of material. This paper aims to guide readers through the detailed process of designing and constructing a hydraulic press tailored specifically for these demanding applications, focusing on key components, engineering principles, and practical considerations.

The construction of a hydraulic press involves integrating several mechanical and hydraulic components to create a cohesive and functional system. At its core, a hydraulic press operates based on Pascal's principle, which states that pressure applied to a confined fluid is transmitted undiminished throughout the fluid. This principle allows for the amplification of force, enabling the hydraulic press to exert significant pressure with relatively small input forces.

The primary objective of this hydraulic press is to facilitate the forging of pattern-welded Damascus steel, a process that requires precise control and significant force to achieve the intricate patterns and superior strength characteristic of this material. Additionally, the press will be designed to quickly draw out metal, enhancing efficiency and productivity in the forging process.

This paper provides a comprehensive overview of the essential components required to build a hydraulic press, including the frame, hydraulic cylinder, pump, electric motor, control valve, and reservoir.

Each component is discussed in terms of its function, selection criteria, and integration into the overall system. Additionally, we will delve into the calculations necessary to determine the appropriate specifications for achieving desired performance metrics, such as force output and piston speed.

II. Design

A. Hydraulic Forging Press Parameters

There are three main parameters to consider when designing a hydraulic forging press:

- Force
- Speed
- Stroke

*1) **Force**:* The force exerted by a hydraulic press is one of the most critical factors in its design, especially for forging applications such as pattern-welded Damascus steel. The required force is determined by the material properties and the specific forging processes to be performed. For Damascus steel, a force in the range of 20 to 30 tons is typically necessary to achieve proper shaping and pattern formation. Calculating the required force involves understanding the pressure capabilities of the hydraulic system and ensuring the hydraulic cylinder can generate sufficient force based on its diameter and operating pressure.

*2) **Speed**:* The speed at which the hydraulic press operates impacts both the efficiency and quality of the forging process. Speed is primarily influenced by the flow rate of the hydraulic pump and the capacity of the hydraulic system to move fluid quickly. For forging, a balance between speed and control is essential. Too high a speed can lead to poor material deformation, while too low a speed can reduce productivity. Typically, a speed of 2 to 3 cm/s for the piston movement is suitable for forging operations. This ensures that the material is deformed at a controlled rate, allowing for precision and reducing the risk of defects.

*3) **Stroke**:* The stroke length of the hydraulic cylinder determines the range of motion available for the forging process. For a hydraulic press used in forging, a sufficient stroke length is necessary to accommodate the full range of material deformation and drawing operations. A stroke length of at least 200 mm is recommended for versatile forging tasks. This allows the press to handle a variety of workpieces and perform multiple forging steps without the need to reposition the material frequently. Ensuring an adequate stroke length also provides flexibility in the types of dies and tools that can be used with the press.

B. Components

*1) **Frame**:* The frame is the main structure of the hydraulic press, providing support and stability. It is usually made of heavy-duty steel to withstand the high pressures and forces generated during operation. The frame ensures proper alignment and secures all other components in place.

*2) **Hydraulic Cylinder**:* The hydraulic cylinder is the core component responsible for generating the pressing force in the hydraulic press. It converts hydraulic energy into linear mechanical force and motion. The cylinder is connected to the hydraulic system, where pressurized fluid pushes the piston, creating a powerful force that drives the ram downward. The cylinder's diameter and stroke length determine the maximum force and the working range of the press.

*3) **Hydraulic Pump**:* The hydraulic pump generates the flow of hydraulic fluid needed to create pressure in the system. It is driven by an electric motor and comes in various types, such as gear pumps, vane pumps, and piston pumps. The pump's displacement and efficiency determine the system's flow rate and pressure capabilities.

*4) **Electric Motor**:* The electric motor powers the hydraulic pump. Its specifications, such as power (kW) and rotational speed (rpm), are chosen based on the requirements of the hydraulic system. The motor's efficiency and reliability are critical for the overall performance of the press.

*5) **Reservoir**:* The reservoir stores hydraulic fluid and supplies it to the pump. It also allows for the dissipation of heat generated during operation and helps remove air and contaminants from the fluid. The size and design of the reservoir depend on the system's capacity and cooling requirements.

*6) **Hydraulic Fluid**:* Hydraulic fluid transmits power within the hydraulic system. It also lubricates moving parts, reduces wear, and helps dissipate heat. The choice of hydraulic fluid depends on factors like operating temperature, pressure, and the specific requirements of the press.

*7) **Control Valve**:* The control valve regulates the flow and direction of hydraulic fluid within the system. It allows the operator to control the movement and force of the hydraulic cylinder. Common types include directional control valves, pressure relief valves, and flow control valves.

*8) **Piping and Hoses**:* Piping and hoses connect various components of the hydraulic system, allowing hydraulic fluid to flow between the pump, cylinder, reservoir, and control valves. They are designed to withstand high pressures and are often reinforced with materials like steel braiding.

*9) **Pressure Gauge**:* The pressure gauge measures the hydraulic pressure within the system. It provides real-time feedback to the operator, ensuring that the press operates within safe and optimal pressure ranges. Accurate pressure monitoring is essential to prevent overloading and potential damage.

*10) **Safety Devices**:* Safety devices, such as pressure relief valves, overload protection, and emergency stop buttons, are critical for ensuring the safe operation of the hydraulic press. These components protect both the operator and the equipment from accidental damage and hazardous situations.

These components work together to create a functional hydraulic press capable of generating the high forces needed for forging and other pressing operations. The schema of hydraulic press is presented in Fig 1. Each component's selection and design are crucial for the overall performance, efficiency, and safety of the press.

C. Components Selection

The selection of components to achieve desirable press parameters described in section II-A requires basic calculations. The most important factors are:

- piston diameter,
- piston stroke,
- pump pressure,
- pump displacement,
- electric motor power.

*1) **Force**:* The force (F) produced by a hydraulic press is determined by the hydraulic pressure (P) and the area of the piston (A). The relationship between these factors is described by the formula:

$F = P * A$

where:

- F is the force in Newtons (N),
- P is the pressure in Pascals (Pa),
- A is the area of the piston in square meters (m^2).

Factors impacting force are:

1) **Hydraulic Pressure** - The pressure exerted by the hydraulic fluid in the system. Higher pressure results in greater force. The pressure is usually measured in bars or Pascals (1 bar = 100,000 Pascals).
2) **Piston Diameter** - The diameter of the hydraulic piston affects the piston area, which in turn influences the force. A larger diameter piston has a greater area, resulting in more force for the same hydraulic pressure. The area of the piston is calculated using the formula for the area of a circle:
   $A = \pi(d/2)^2$ where:
   - d is the diameter of the piston.
3) **Electric Motor Power** - Higher pressure requires higher motor power. More information about Electric Motor Power is provided in section II-C2.

Fig 2 shows how the force changes with varying piston diameters at different pressures. Increasing the diameter of the piston also increases the force exerted by the hydraulic press. The force increases non-linearly with the piston diameter due to the area being proportional to the square of the diameter ($A = \pi(d/2)^2$). By observing where the pressure lines intersect the red horizontal line at 20 tonnes, we can determine the minimum piston diameter required to achieve 20 tonnes of force at each pressure level. For example, at 100 bar, a much larger piston diameter (about 160 mm) is needed compared to achieving the same force at 300 bar (about 90 mm).

Fig 3 illustrates how the force exerted by the hydraulic press varies with different hydraulic pressures and piston diameters. This diagram helps in understanding how changes in hydraulic pressure and piston size impact the overall force generated by the press. The force increases linearly with pressure for each piston diameter, as indicated by the straight lines. This linearity is due to the direct proportionality between pressure and force in the equation $F = P * A$. Similarly to the previous diagram, we can observe that a smaller diameter piston requires much

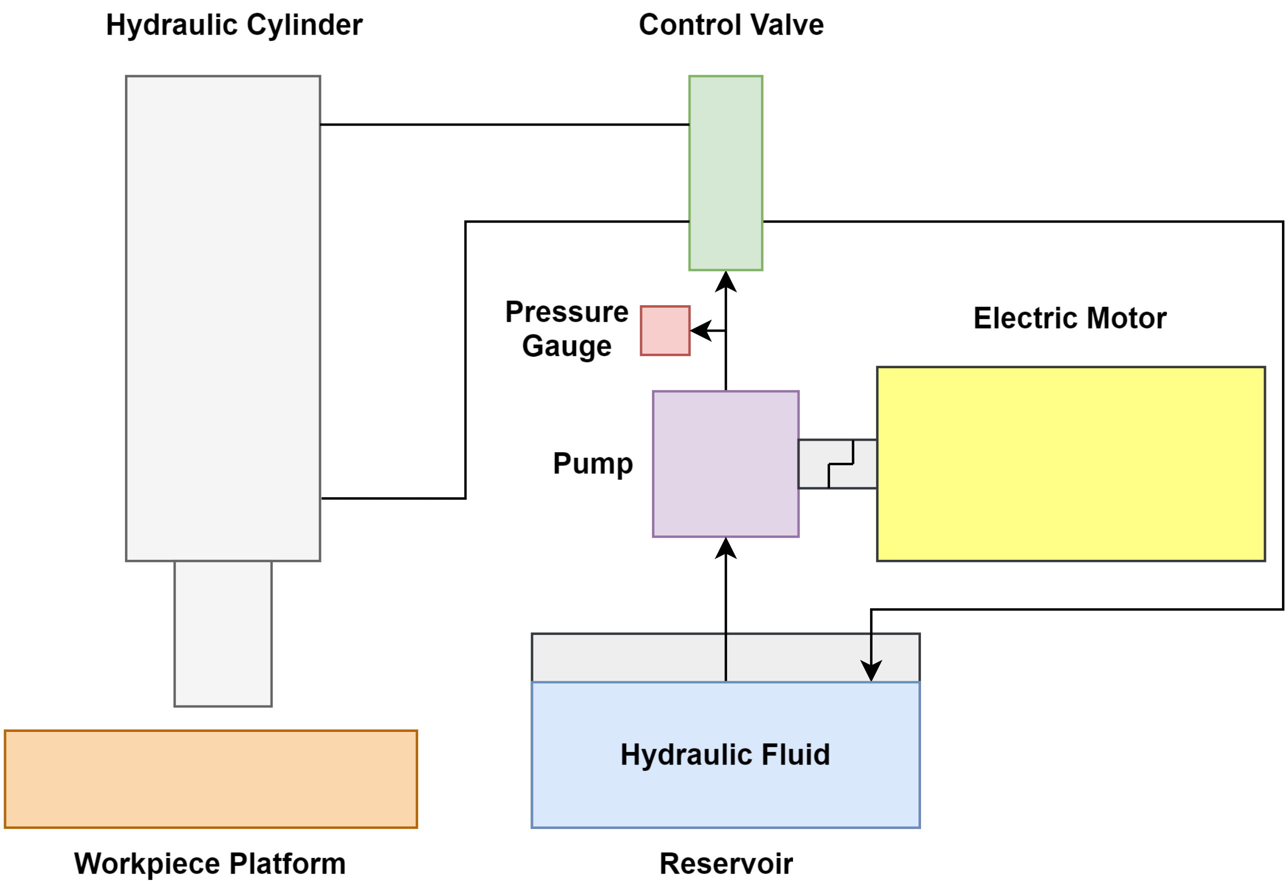

Fig. 1. Hydraulic Press Schema

higher pressure compared to a larger diameter piston to achieve the same force. For example for a piston diameter of 125 mm just about 150 bars is enough to reach 20 tonnes of force, but for an 80 mm piston diameter, it's about 400 bars.

*2) **Speed**:* The speed parameter in a hydraulic press system is primarily determined by the flow rate of the hydraulic fluid and the cross-sectional area of the piston. The relationship between these factors is described by the formula:
$Speed = \frac{FlowRate}{PistonArea}$.
Factors impacting speed are:

1) **Piston Diameter** - The diameter of the hydraulic cylinder's piston affects the speed of movement. Larger diameters require more fluid to fill the cylinder, which can slow down the piston speed for a given flow rate.
2) **Pump Displacement** - Pump displacement, usually measured in cubic centimeters per revolution (cm^3/rev), influences the amount of fluid the pump can deliver per revolution. Higher displacement pumps provide more fluid, thereby increasing piston speed.
3) **Flow Rate of the Hydraulic Pump** - The flow rate of the hydraulic pump, usually measured in liters per minute (L/min) or gallons per minute (GPM), is the primary determinant of the speed of the hydraulic cylinder. A higher flow rate results in a faster piston movement. The flow rate depends on the pump displacement and the pump RPM (revolutions per minute), as described by the formula: $FlowRate = PumpDisplacement * PumpRPM$. The pump RPM, in turn, depends on the engine speed, as the engine drives the pump.
4) **Electric Motor Power** - The power required to operate the press increases with both the pressure and the pump displacement, indicating that higher motor power is necessary to achieve greater force and faster piston speeds.

Fig 4 illustrates the relationship between piston speed, piston diameter, and pump displacement. Fig 2 shows that as the piston diameter increases, the force generated by the press also increases, allowing for greater forging capabilities. However, this comes at the cost of piston speed, which decreases significantly with larger diameters. Consequently, while a bigger piston diameter can enhance the press's capacity to exert force, it also results in slower operation, highlighting the **trade-off between speed and force in hydraulic press design**.

The power versus pressure diagram (Fig 3) illustrates that as pressure increases, the required power rises significantly, emphasizing the need for a more powerful engine to handle

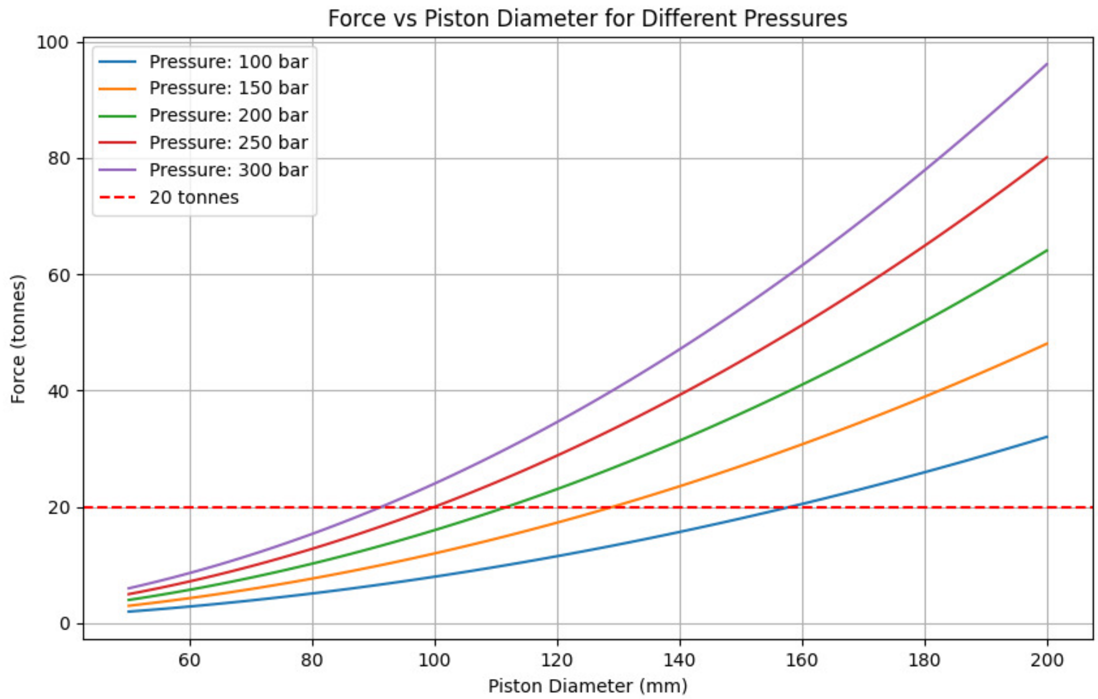

Fig. 2. Force vs Piston Diameter

higher operational pressures. Similarly, the power versus displacement diagram (Fig 6) shows that larger pump displacements require increased engine power to maintain optimal performance.

When choosing the engine, it is essential to consider the maximum expected pressure and pump displacement to ensure the engine can deliver sufficient power for the desired performance. This selection process guarantees that the hydraulic press operates efficiently and reliably under varying load conditions.

*3) **Stroke**:* The stroke parameter in a hydraulic press system is primarily determined by the cylinder length and the system design.

Factors impacting stroke are:

1) **Cylinder Length** - The diameter of the hydraulic cylinder's piston affects the speed of movement. Larger diameters require more fluid to fill the cylinder, which can slow down the piston speed for a given flow rate.
2) **System Design** - The overall design of the hydraulic press, including the frame and the mounting position of the cylinder, impacts the effective stroke length.
3) **Hydraulic Fluid** - A longer stroke may require more hydraulic fluid to operate effectively, which can increase the overall fluid capacity needed in the system. Additionally, having an adequate amount of hydraulic fluid is essential to prevent overheating during operation. Sufficient fluid not only helps to maintain optimal temperature levels but also ensures smooth and efficient movement of the piston, contributing to the longevity and reliability of the hydraulic press. The typical amount of hydraulic fluid required for an average hydraulic forging press ranges from 20 to 40 liters, providing adequate cooling and preventing overheating during operation.

The cylinder stroke should be kept to a minimum, just long enough to meet the requirements. For forging applications, a stroke length of 300 mm is typically more than sufficient. It's also important to consider that the frame of the hydraulic press can limit the maximum achievable stroke. The design of the frame must support both the cylinder length and the required stroke while ensuring the overall stability and rigidity of the press.

D. Calculations

When designing a hydraulic press, it is crucial to find a balance between the required parameters and the overall cost. More powerful components, such as higher capacity pumps and engines, often come with significantly higher costs. Therefore, careful calculation and consideration of the press's operational needs are essential to ensure both efficiency and cost-effectiveness. By optimizing the balance between force, speed, and stroke, we can achieve a well-designed hydraulic press that meets the requirements without incurring unnecessary expenses.

To keep the design relatively inexpensive, We decided to aim for a pressure capacity of around 20 tonnes, a piston speed of approximately 2 cm/s, and a stroke length of at least 20 cm.

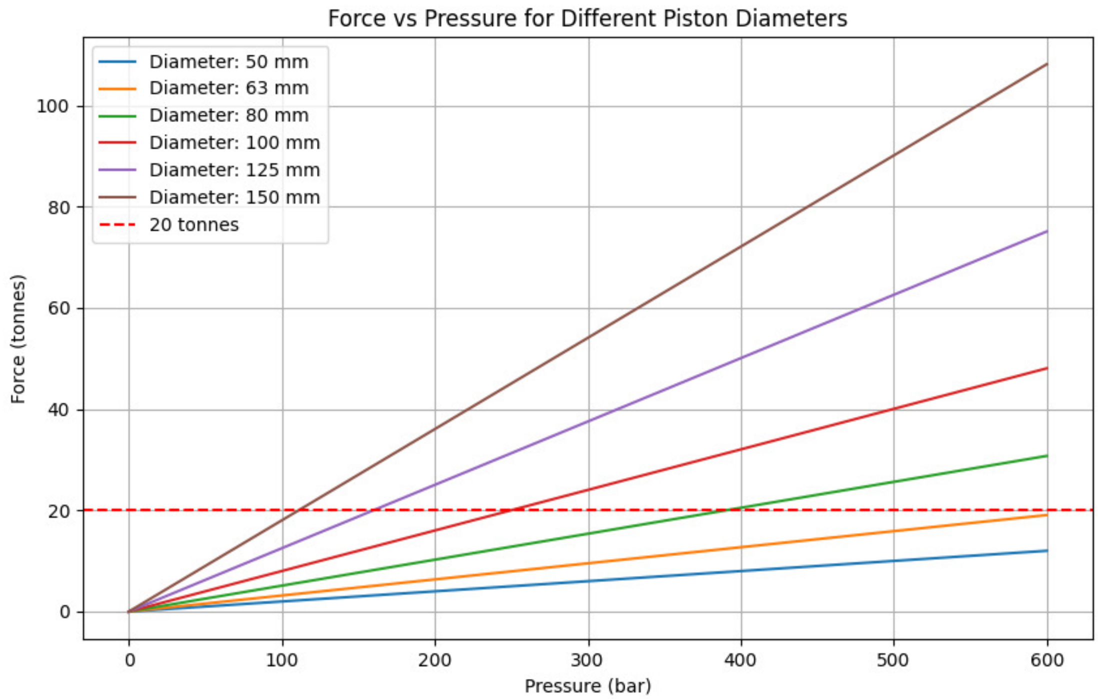

Fig. 3. Force vs Pressure

The selection of components to achieve desirable press parameters described in section II-A requires basic calculations.

To achieve a pressure capacity of 20 tonnes, the required pressure for various piston diameters can be calculated using the formula:

$$Pressure(P) = \frac{Force(F)}{PistonArea(A)}$$

where:

- $Force(F)$ is the required force in Newtons (N)
- $PistonArea(A)$ is the cross-sectional area of the piston in square meters (m^2)
- $Pressure(P)$ is the pressure in Pascals (Pa), which can be converted to bars by dividing by 10^5, (1 bar = 100,000 Pa).

First, convert the force from tonnes to Newtons:

$$F(\mathrm{N}) = \text{Force (tonnes)} \times 9{,}806.65 \times 1000$$

Next, calculate the piston area:

$$F(\mathrm{N}) = \text{Force (tonnes)} \times 9{,}806.65 \times 1000$$

Finally, the pressure in Pascals can be calculated as:

$$P(\mathrm{Pa}) = \frac{F(\mathrm{N})}{A(\mathrm{m}^2)}$$

To convert Pascals to bars:

$$P(\mathrm{bar}) = \frac{P(\mathrm{Pa})}{10^5}$$

Example Calculation for a 20-tonne force and a 100 mm diameter piston:

1. Diameter:

$$d = 100\,\mathrm{mm} = 0.1\,\mathrm{m}$$

2. Area:

$$A = \pi \left(\frac{0.1}{2}\right)^2 = \pi \times 0.0025 = 0.007854\,\mathrm{m}^2$$

3. Force:

$$F = 20 \times 9{,}806.65 \times 1000 = 196{,}133\,\mathrm{N}$$

4. Pressure in Pascals:

$$P(\mathrm{Pa}) = \frac{196{,}133}{0.007854} = 24{,}984{,}203\,\mathrm{Pa}$$

5. Pressure in bars:

$$P(\mathrm{bar}) = \frac{24{,}984{,}203}{100{,}000} = 249.84\,\mathrm{bar}$$

So, the required pressure for a 100 mm diameter piston to achieve a 20-tonne force is approximately 250 bar.

For ISO-compatible piston diameters of 50 mm, 63 mm, 80 mm, 100 mm, 125 mm, and 150 mm, the required pressures are as follows:

- $d = 50$ mm, $P \approx 999$ bar
- $d = 63$ mm, $P \approx 631$ bar
- $d = 80$ mm, $P \approx 390$ bar
- $d = 100$ mm, $P \approx 250$ bar

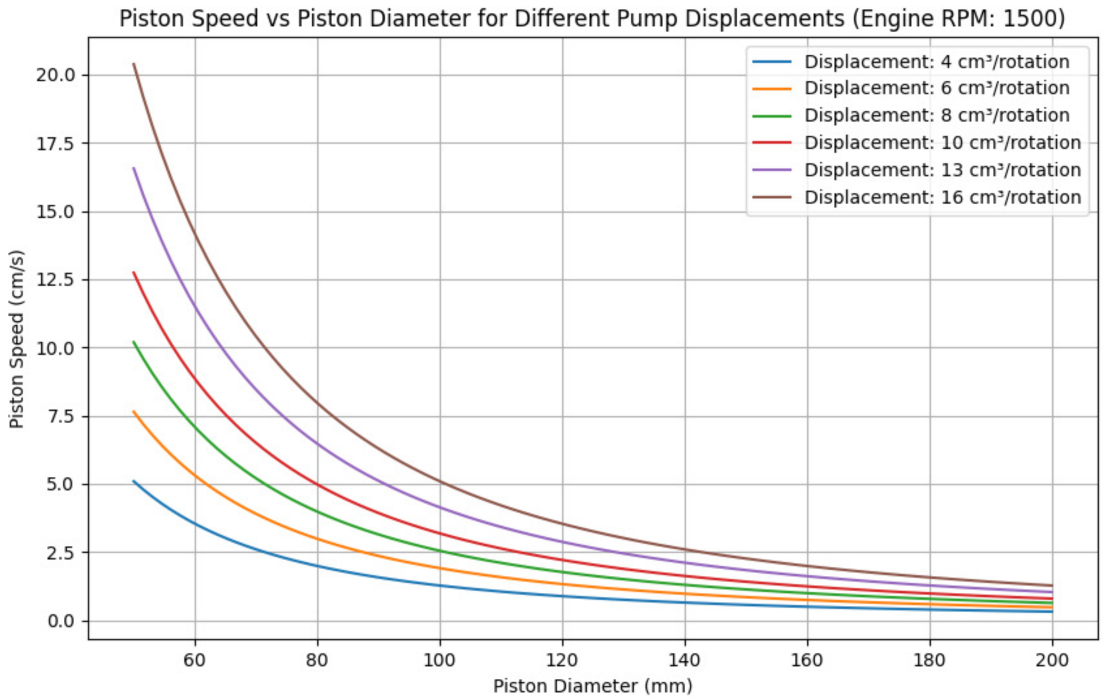

Fig. 4. Speed vs Diameter

- $d = 125$ mm, $P \approx 160$ bar
- $d = 150$ mm, $P \approx 111$ bar.

For a home workshop, safety is a top priority. While pressures around 390 bars are certainly achievable with modern hydraulic systems, they can be risky if not properly managed. Higher pressures also demand more robust equipment and rigorous safety measures. Given the safety and practical constraints, we consider two piston diameters: 100 mm and 125 mm. These sizes balance the need for adequate force with manageable pressure levels, ensuring a safer and more practical setup for a home workshop. Finally, we have chosen a 125 mm piston diameter. This diameter not only requires lower pressure, enhancing safety but also provides flexibility to increase the force if needed. With this size, there remains a substantial margin before reaching the maximum safe pressure limit, ensuring a safer and more adaptable design. However, a larger diameter comes with a speed reduction as presented in Fig. 4.

Knowing the piston diameter we can calculate the required pump displacement. To determine the required pump displacement for a speed of 2 cm/s, we use the following formula:

$$V_{\text{pump}} = \frac{Q}{N}$$

where:

- Q is the flow rate (in liters per minute, L/min)
- N is the engine speed (in revolutions per minute, RPM)

Engines commonly available on the market typically operate at around 1500 RPM, and this speed is generally compatible with many hydraulic pumps. Therefore, we will use this RPM value in our calculations.

Given:

- Piston diameter $d = 125\,\text{mm} = 0.125\,\text{m}$
- Piston speed $v = 2\,\text{cm/s} = 0.02\,\text{m/s}$
- Engine speed $N = 1500$ RPM.

1. Calculate the piston area:

$$A = \pi \left(\frac{d}{2}\right)^2$$

$$A = \pi \left(\frac{0.125}{2}\right)^2 = \pi \times (0.0625)^2 = 0.01227\,\text{m}^2$$

2. Calculate the Flow Rate in Cubic Meters per Second

$$Q = \text{Piston Speed} \times \text{Piston Area}$$

$$Q(\text{m}^3/\text{s}) = 0.02\,\text{m/s} \times 0.01227\,\text{m}^2 = 0.000248\,\text{m}^3/\text{s}$$

Convert this flow rate to liters per minute:

$$Q(\text{L/min}) = 0.000248\,\text{m}^3/\text{s} \times 1000\,\text{L/m}^3 \times 60\,\text{s/min} = 14.88\,\text{L/min}$$

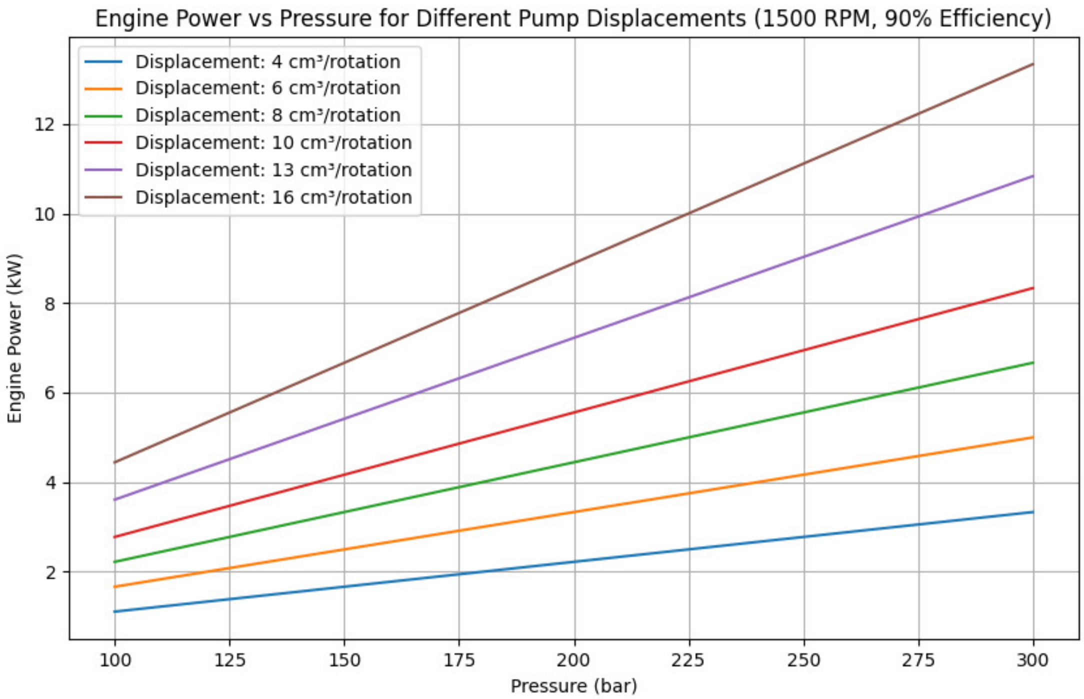

Fig. 5. Power vs Pressure

3. Calculate the Required Pump Displacement

$$V_{\text{pump}} = \frac{Q(\text{L/min})}{N} = \frac{14.88\,\text{L/min}}{1500\,\text{RPM}} = 0.00992\,\text{L/rev}$$

Convert the displacement to cubic centimeters per revolution:

$$V_{\text{pump}} = 0.00992\,\text{L/rev} \times 1000\,\text{cm}^3/\text{L} = 9.92\,\text{cm}^3/\text{rev}$$

For a 125 mm piston diameter and an engine speed of 1500 RPM the pump with a displacement of approximately **10 cm³/rev** is required to achieve the desired piston speed of 2 cm/s.

Knowing the pump pressure (**160 bars**) and pump displacement (**10 cm³/rev**) we can calculate the required engine power. To determine the required motor power for a hydraulic press, we use the following formula:

$$P = \frac{Q \times p}{600 \times \eta}$$

where:

- P is the motor power (in kilowatts, kW)
- Q is the flow rate (in liters per minute, L/min)
- p is the pressure (in bar)
- η is the efficiency (typically around 0.9)

1. Calculate the Flow Rate Needed
As determined previously, the flow rate Q is:

$$Q = 14.88\,\text{L/min}$$

2. Determine the Required Motor Power
Given a pressure p of 160 bar and an efficiency η of 0.9, calculate the motor power:

$$P = \frac{Q \times p}{600 \times \eta} = \frac{14.88 \times 160}{600 \times 0.9} = \frac{2380.8}{540} \approx 4.41\,\text{kW}$$

For a 125 mm piston diameter, a piston speed of 2 cm/s, an engine speed of 1500 RPM, and a pressure of 160 bar, the required motor power is approximately **4.41 kW**.

The stroke length is primarily determined by the cylinder stroke and does not directly impact other parameters such as force or speed. Therefore, the main consideration is to select a cylinder that offers a stroke length of **20 cm** or more.

It's important to note that the stroke length affects the overall length of the cylinder. A longer stroke requires a longer cylinder, which in turn impacts the construction and design of the frame. The frame must be able to accommodate the full length of the cylinder while maintaining stability and rigidity.

In summary, while the stroke length is a critical parameter for determining the operational capacity of the press,

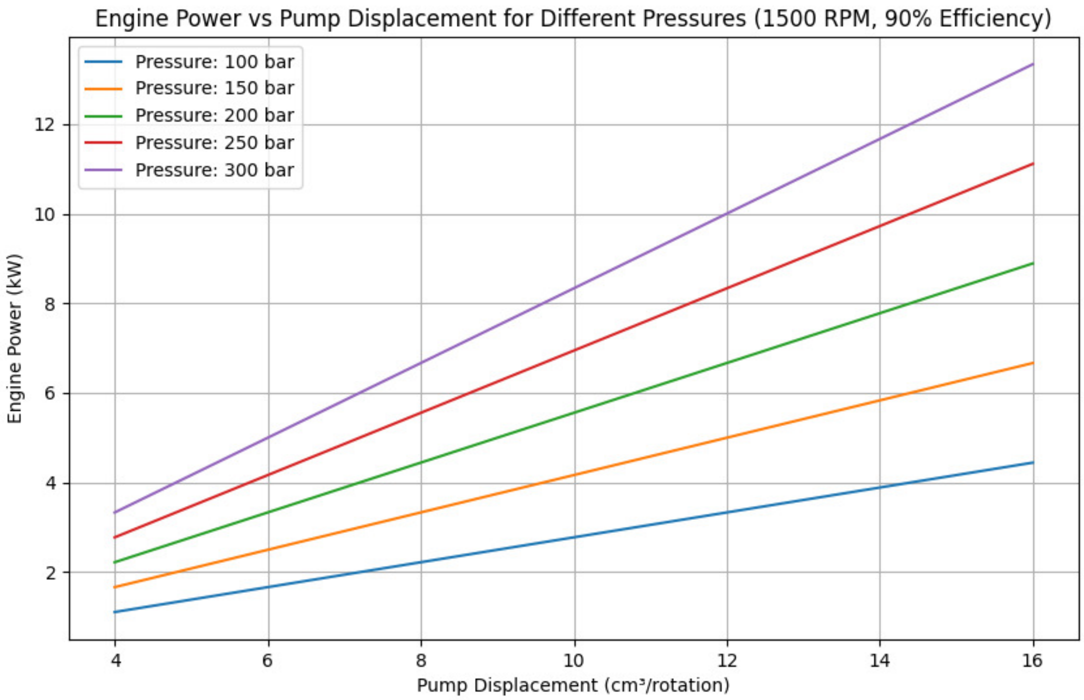

Fig. 6. Power vs Displacement

its primary influence is on the dimensions and structural requirements of the press frame.

Based on the detailed calculations and considerations, the following components have been chosen for the hydraulic press:

1) **Bidirectional Cylinder:** A cylinder with a 125 mm diameter and a 600 mm stroke. The reason for choosing a 600 mm stroke is due to the unavailability of shorter cylinders or the significantly higher price of those that were available.
2) **Pump:** A pump with a 10 cm^3/rotation displacement and a working pressure of 160 bars.
3) **Engine:** An engine with a speed of 1470 RPM and a power rating of 4 kW. This is slightly below the calculated requirement of 4.41 kW, which may result in a slightly lower force and/or speed. However, it should still meet the overall design requirements satisfactorily.

E. Mechanical Construction

The mechanical construction of the hydraulic press involves designing and building several key components to ensure stability, functionality, and safety. The design is based on practical experience and intuition, aiming to balance robustness, ease of construction, and cost-effectiveness. The main components of the hydraulic press construction include:

- Base Table
- Frame
- Hydraulic Fluid Reservoir

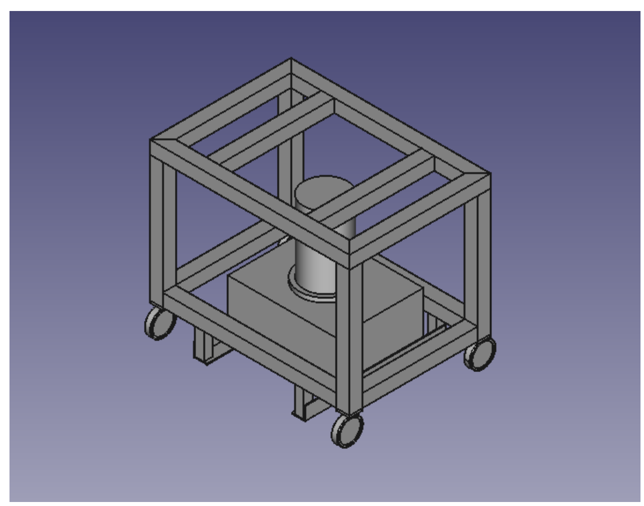

Fig. 7. Base Table

1) ***Base Table****:* The base table serves as the foundation for the entire hydraulic press, providing a stable and level surface on which the frame can be mounted. The dimensions of the base table are designed to accommodate the frame and other components while ensuring stability during operation. In addition to supporting the frame, the base table is also designed to house the hydraulic fluid reservoir and the engine below it, optimizing space usage and maintaining a compact footprint. To enhance mobility, the base table is equipped with wheels, allowing the entire press to be moved easily if required. A simplified model of the base table, including the placement of the reservoir and engine, is presented in Fig. 7.

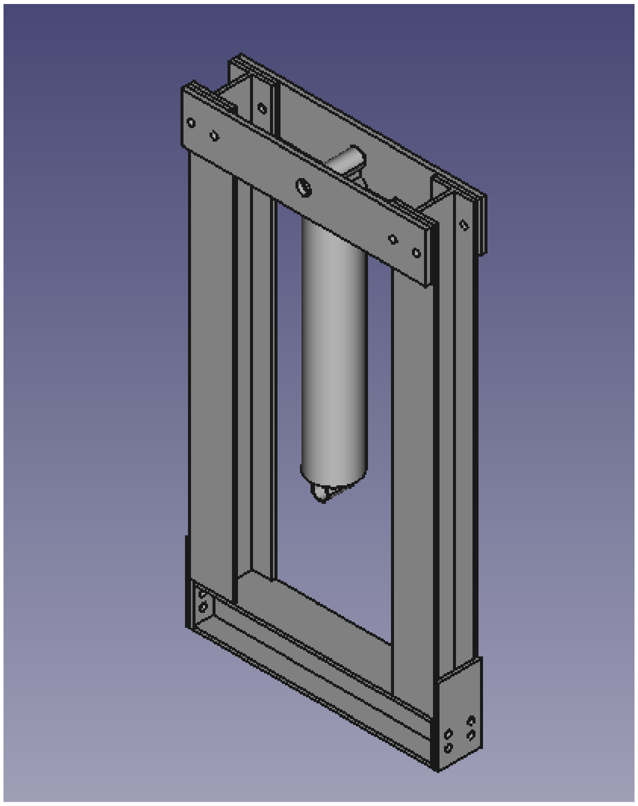

Fig. 8. Frame

*2) **Frame**:* The frame is the structural component that houses the cylinder. It must be designed to withstand the forces generated during operation and ensure the press operates safely and effectively.

There are typically two types of frames used in hydraulic presses: H-frame and C-frame. H-frame presses offer greater stability and can handle higher loads due to their symmetrical design. C-frame presses, on the other hand, provide better accessibility and ease of operation but may not be as stable under high loads.

For our hydraulic press, we have decided to use an H-frame design. This choice ensures the necessary stability and strength to handle the 20-ton pressure, while still providing a straightforward and robust construction. The frame design was adjusted to accommodate the shape and length of the cylinder we purchased. A simplified model of the frame with mounted cylinder is presented in Fig. 8.

*3) **Hydraulic Fluid Reservoir**:* The hydraulic fluid reservoir stores the fluid required for the press operation. With a capacity of 20 to 40 liters, it ensures sufficient hydraulic fluid to prevent overheating during use. The reservoir is designed to house a filter and pump inside the fluid, which helps limit noise during operation. Additionally, the engine is mounted on top of the reservoir to save space and simplify the overall design. The placement of the reservoir is presented in Fig. 7.

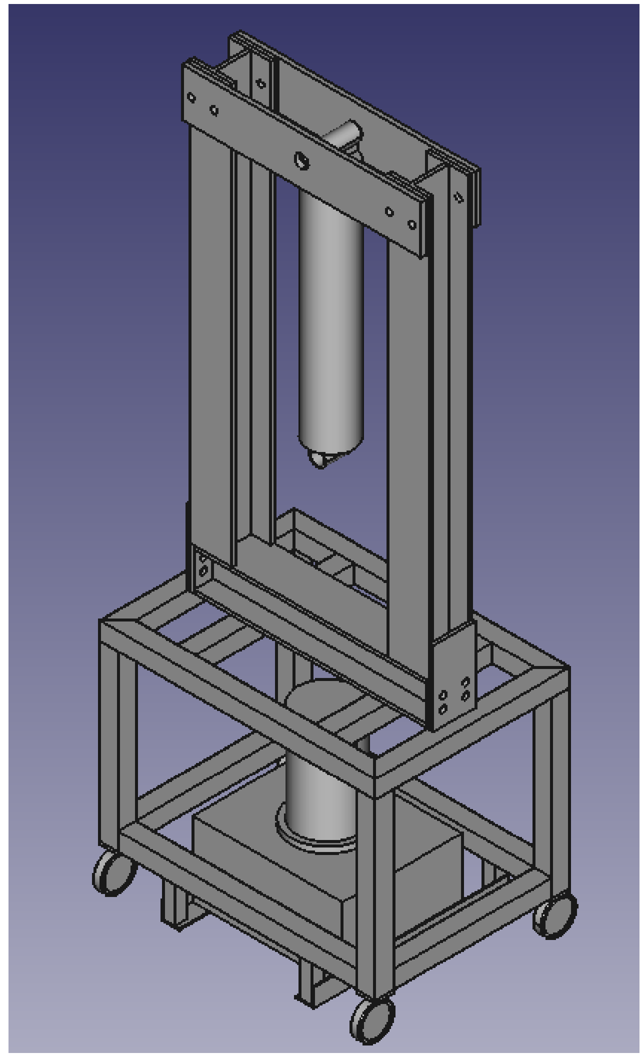

Fig. 9. Mechanical Construction

The mechanical construction of the hydraulic press has been designed with several key considerations in mind. The design aims to minimize the required space, as the workshop has limited free space. To facilitate mobility, the base table is equipped with wheels, allowing the press to be easily moved when needed. Additionally, the construction incorporates numerous screw connections, making it relatively straightforward to disassemble and reassemble the press if required. This approach ensures that the press is both practical and adaptable to changing workshop conditions. The overall simplified mechanical construction design is presented in Fig. 9.

*4) **Anvil Mount and Replaceable Anvils**:* In addition to the core components of the hydraulic press, a crucial aspect of the mechanical design is the anvil mount. The anvil is the surface against which the workpiece is pressed, and having the ability to easily replace the anvil is essential for different forging tasks.

The anvil mount is designed to allow for quick and secure attachment of various anvil shapes. A modular design was chosen, enabling the use of different anvils, such as flat, rounded, or custom shapes, depending on the specific requirements of the forging process. The mounting system includes a series of bolts and locking mechanisms that ensure the anvils remain firmly in place during operation but can be replaced without significant effort when needed.

Different anvil shapes serve specific forging purposes:

- Flat Anvil: Ideal for tasks like forge-welding, where a large, stable surface is needed to evenly press the material together. This shape helps to maintain uniform pressure over the entire surface area.
- Rounded Anvil: More suited for drawing out material, as it allows the metal to spread more evenly and elongate when pressed. The rounded shape concentrates the force in a smaller area, making it easier to manipulate the workpiece into a longer, thinner shape.

By incorporating interchangeable anvils, the hydraulic press becomes much more versatile and adaptable for various forging tasks. This flexibility allows the operator to switch between processes such as forge-welding and drawing out material with minimal downtime. The anvil system was designed to be robust enough to handle the press's maximum force while remaining easy to use and adjust as necessary.

This addition further enhances the overall practicality of the press, ensuring it meets the demands of a wide range of forging operations.

III. Assembly

The assembly of the hydraulic press involves bringing together the various components in a systematic manner to ensure proper functionality and safety. This section describes the assembly process.

A. Preparation

Before assembling the hydraulic press, it's important to gather all necessary components, materials, and tools. This section outlines the key elements required for the assembly process.

Components:

- Hydraulic cylinder
- Hydraulic pump
- Hydraulic fluid filter
- Engine
- Control valve and hydraulic lines
- Manometer

Materials:

- Steel profiles for the frame and base (e.g., square or rectangular steel tubing)
- Steel plates for mounting components
- Steel plates for constructing the reservoir
- Fasteners (bolts, nuts, washers) for assembling the frame and securing components
- Hydraulic fluid

Tools:

- Welder (for assembling the steel frame, base table, and reservoir)
- Angle grinder (for cutting steel components)
- Drill (for creating mounting holes)
- Wrenches and spanners (for securing bolts and fittings)
- Measuring tools (such as a tape measure, calipers)

This preparation ensures all essential parts and tools are available before starting the assembly, which contributes to a smoother and more efficient process.

B. Mechanical Construction

*1) **Assembling the Reservoir**:* The reservoir is constructed from steel plates, welded together to form a robust and leak-proof container with a capacity of approximately 50 liters (500x400x250). The reservoir not only holds hydraulic fluid but also houses the filter and pump, which are submerged inside the fluid to reduce noise during operation.

Using the materials mentioned in the preparation section, the steel plates were cut to size and welded into a rectangular box. The top of the reservoir includes a mounting area for the engine and the necessary inlet and outlet ports for the pump and hydraulic lines were drilled and threaded. Once welded, the reservoir was tested for leaks before being mounted onto the base table. The connections for the hydraulic lines were made.

*2) **Assembling the Base Table**:* The base table serves as the foundation of the hydraulic press, providing stability and support for the entire structure. It is constructed using square steel tubing and designed to accommodate the reservoir and engine beneath the table to save workshop space. Additionally, wheels were added to the base to allow the press to be moved easily when needed.

The steel profiles were cut to the required dimensions and welded together to create a rectangular base frame. Mounting plates were added to the top surface to securely fasten the frame and reservoir. The wheels were bolted to the base, allowing for easy mobility.

*3) **Assembling the Frame**:* The frame is built in an H-frame design, chosen for its strength and stability during heavy forging operations. The cylinder is mounted vertically in the frame, allowing for the application of force downward during forging.

The steel profiles and plates were cut and joined into a rigid H-frame structure, ensuring that the dimensions accommodate the length and diameter of the hydraulic cylinder. Mounting brackets were welded in place to securely hold the cylinder in alignment with the base table. Additional reinforcements were added to ensure the frame's rigidity under load.

C. Installing the Hydraulic Cylinder

The cylinder was mounted to the upper portion of the H-frame using heavy-duty brackets that were welded in place during the frame assembly. Care was taken to ensure that the cylinder was aligned perfectly vertically to ensure even force application during operation. Misalignment could lead to uneven wear on the cylinder or, in extreme cases, structural failure of the frame. Press frame with mounted cylinder is presented in Fig. 10.

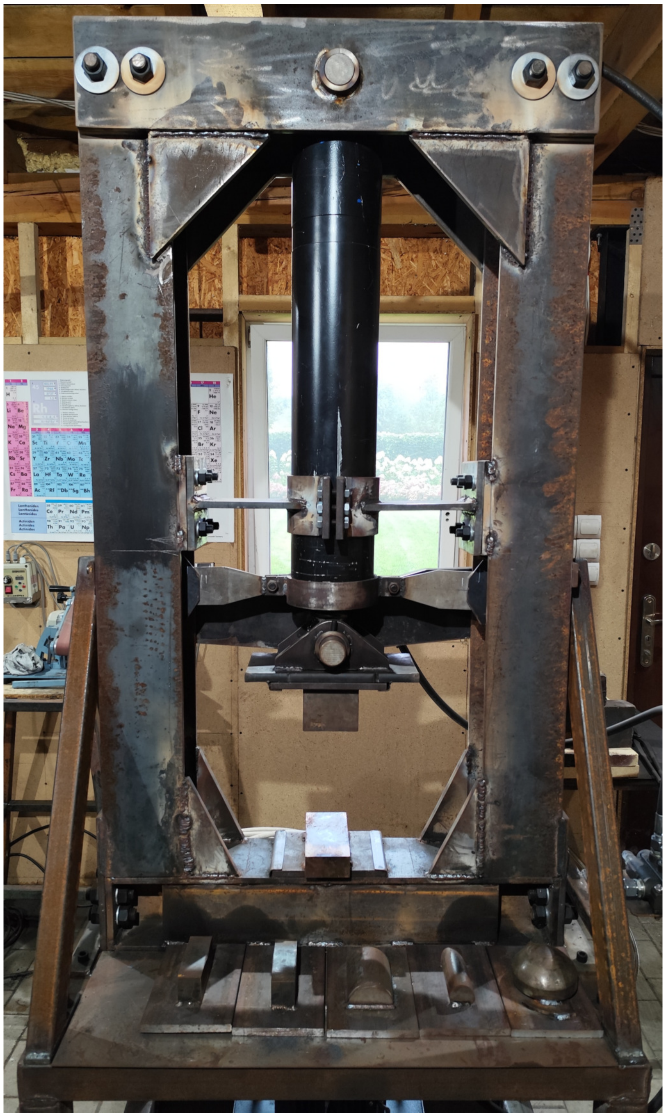

Fig. 10. Press Frame with Cylinder

D. Installing the Pump and the Engine

Before installation, the engine was powered on briefly to check for proper rotation.

The installation process began by securing the pump to the designated mounting bracket on top of the reservoir. The pump was mounted vertically, with its intake submerged in hydraulic fluid. This design helps reduce noise and improves the pump's lifespan by keeping it cool and lubricated. The pump's intake and return lines were fitted with the necessary high-pressure hoses, ensuring proper sealing to prevent leaks.

Next, the engine was mounted on the custom-built platform welded to the top of the reservoir, directly above the pump. The pump and engine were then connected via a flexible coupling to ensure smooth transmission of torque while compensating for any minor misalignment between the two. Proper alignment was checked carefully, as any misalignment could cause premature wear on both the pump and engine shafts. The engine mounted on the top of the reservoir is presented in Fig. 11.

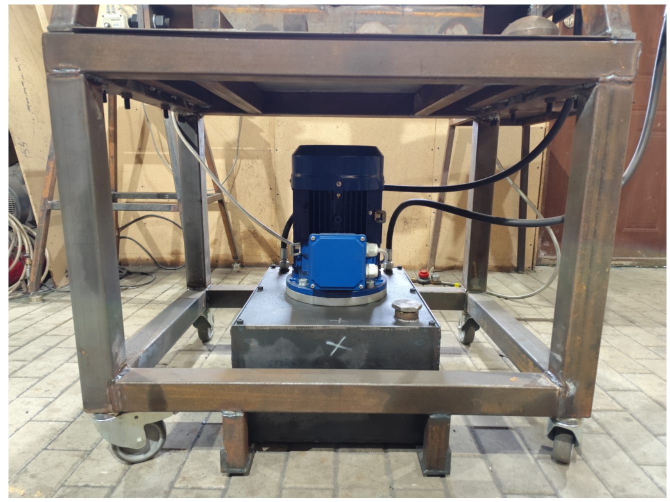

Fig. 11. Reservoir with Engine

E. Installing the Control Valve

The installation of the control valve began by mounting it onto a designated bracket relatively near the pump and cylinder. Its proximity to these components helps minimize the length of hydraulic hoses, reducing the chance of pressure loss and ensuring quicker response times. The control valve was located approximately at hip height for comfortable control. The valve was securely bolted to the frame, ensuring stability during operation.

F. Hydraulic Connections and Mounting the Manometer

With the control valve installed, the next step involved connecting the hydraulic components using high-pressure hoses. The quality and routing of these hoses are crucial to ensure the safe and efficient operation of the hydraulic press, as they carry the hydraulic fluid between key components.

The first connection was made between the pump and the control valve. A high-pressure hose was used to connect the outlet of the pump to the input port of the control valve. Teflon tape was applied to the threads to ensure a proper seal and avoid any fluid leakage. The hose was securely fastened to handle the system's working pressure of up to 160 bars.

Next, two hoses were used to connect the control valve to the hydraulic cylinder. The first hose ran from the extend port on the control valve to the lower port of the cylinder, which controls the upward movement of the piston. The second hose ran from the retract port on the valve to the upper port of the cylinder, responsible for retracting the piston. A tee was included to allow connection of the manometer. These connections allowed for smooth bidirectional control of the cylinder, as commanded by the control valve.

Afterward, a return hose was connected from the control valve to the reservoir. This hose allows excess hydraulic fluid to return to the reservoir after the press has completed its cycle. The reservoir was designed to hold a sufficient amount of hydraulic fluid to avoid overheating, as mentioned earlier.

Finally, a manometer (pressure gauge) was installed to monitor the hydraulic system's pressure. The manometer was mounted to the tee near the control valve for easy visibility. This gauge is crucial for maintaining safe pressure levels, especially when working with high pressures like 160 bars. It provides real-time feedback, allowing the operator to ensure the system operates within safe limits.

Control Valve with manometer and all hydraulic connections is presented in Fig. 12.

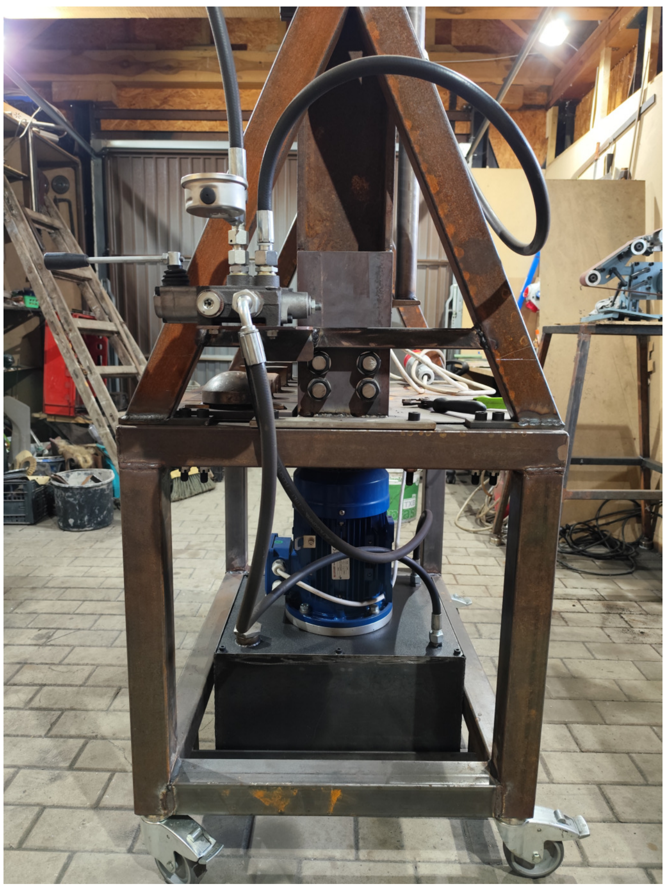

Fig. 12. Control Valve and Manometer

G. Filling the Reservoir with Hydraulic Fluid

With the mechanical and hydraulic components fully assembled, the final step before testing the press was to fill the reservoir with hydraulic fluid.

Before filling, the reservoir was carefully inspected for any debris or contaminants that could affect the system. Ensuring the reservoir was clean is critical to maintaining the longevity of the hydraulic components and avoiding premature wear or damage.

The chosen hydraulic fluid was a high-quality, ISO VG 46 hydraulic oil, known for its stability and good performance under varying temperatures. Approximately 40 liters of fluid were poured into the reservoir, based on the system's requirements and the capacity of the cylinder. The reservoir has a designed capacity of around 50 liters, which allows some headroom to prevent overheating during extended use. It's important not to overfill the reservoir, as the hydraulic fluid expands when it heats up, and there needs to be enough space for the fluid to circulate properly.

The hydraulic fluid was added to the reservoir through the fill port located on top of the tank. A funnel was used to ensure the fluid was poured steadily into the reservoir without spilling. After filling, the fluid level was checked to ensure it was within the recommended range.

This step completed the hydraulic setup, making the press ready for operation. The next phase involved testing the system to ensure everything functioned as intended. A fully assembled hydraulic press is presented in Fig. 13 (front view) and Fig. 14 (side view).

IV. Testing

Once the hydraulic press was assembled and filled with hydraulic fluid, the next critical phase was testing. This phase ensures that all components work correctly and safely, and that the press meets the designed specifications. The testing process is divided into several key steps:

A. Initial System Check

Before operating the press, a preliminary check was performed to ensure that all components were correctly installed and that there were no visible leaks or issues. This included:

- Verifying that all hydraulic connections were secure and free of leaks.
- Checking the fluid level in the reservoir to ensure it was within the recommended range.
- Ensuring the manometer was properly installed and functional.

B. Bleeding the Hydraulic System

To remove any air trapped in the hydraulic system, the following procedure was carried out:

- The pump was run briefly while the hydraulic cylinder was cycled through its full range of motion.
- This process helped to expel air bubbles from the hydraulic lines and the cylinder, ensuring smooth operation.
- The system was monitored for any signs of air pockets, which could cause erratic behavior or affect performance.

Fig. 13. Press - front view

Fig. 14. Press - side view

C. Functionality Testing

The press was tested under various operating conditions to confirm it met performance requirements:

- The hydraulic cylinder was operated to test both extension and retraction.
- The force applied by the press was measured to ensure it matched the design specifications.
- The speed of the piston was checked to confirm it met the desired rate of 2 cm/s.
- The pressure gauge was monitored to ensure the system operated within safe pressure limits.

D. Safety Checks

Safety is paramount in hydraulic press operations. The following safety checks were performed:

- Ensuring mechanical construction is stable enough to handle maximum generated force.
- Verification that all safety guards and emergency stops were functioning correctly.

E. Final Adjustments

Based on the testing results, any necessary adjustments were made:

- Additional reinforcement of the frame structure and cylinder mounts.

The successful completion of these tests confirmed that the hydraulic press was fully operational and met the designed specifications for force, speed, stroke, and safety.

V. Usage and Performance

Example usage of hydraulic press is presented in video *Forging a Damascus Steel Billet: Hydraulic Press Demonstration* [3].

A. Usability and Practical Design

The hydraulic press is designed with usability in mind, ensuring a compact and efficient layout. The engine and reservoir are placed beneath the frame, which helps minimize the required workshop space. The addition of wheels allows the press to be easily moved when needed, making it versatile for different tasks around the workshop.

A significant design feature is the placement of the pump inside the reservoir, which effectively reduces operational noise. This contributes to a quieter, more pleasant working environment, especially during prolonged forging sessions. The overall design balances power, mobility, and compactness, making the press an ideal tool for personal or small-scale forge work.

B. Performance and Efficiency

The press delivers excellent performance, particularly for forging Damascus billets. With a capacity of 20 tonnes and a piston speed of 2 cm/s, it easily handles relatively large billets, such as 140 x 50 mm, making forge welding an efficient process. For example, smaller billets around 100 x 35 mm can be fully forge welded in just two presses. This speed and power ensure that metal can be quickly and efficiently reshaped or flattened without excessive effort.

The 2 cm/s speed is also optimal for preventing the metal from cooling down too quickly during pressing, allowing for effective forging without unnecessary delays. This balance of force and speed ensures that even larger tasks can be completed in a single heat cycle.

C. Challenges and Solutions in Metal Drawing

While the press performs well in most tasks, drawing out material remains a challenging process. Thinner material, such as reducing a bar to 2.5 mm thickness, requires multiple cycles of pressing and reheating. The choice of anvil shape becomes critical here. Rounded anvils are ideal for quickly drawing out thicker material, but if they are too aggressive, it becomes difficult to flatten the metal afterward.

A quick anvil replacement system has been implemented to allow for easy switching between flat and rounded anvils, depending on the task. This flexibility is key to maintaining efficiency during forging operations. Despite the challenges in drawing out material, the press is highly effective when used with the appropriate tools and techniques.

VI. Conclusions

- Proper design and calculations upfront allowed the hydraulic press to be built without major problems. The final performance parameters closely matched the initial design assumptions.
- Incorporating wheels and a compact construction to minimize the required space was a worthwhile decision, especially in small home workshops where space is often limited.
- The press greatly improves efficiency, allowing tasks to be completed faster, which in turn saves on resources like gas. Reducing the need for frequent reheating of metal is another advantage, as it conserves both time and fuel.
- The press excels at forging Damascus billets, making it possible to quickly shape and forge-weld billets, even after multiple cuts and refinements. It's also effective for rapid material reshaping, making it a valuable tool for complex forging tasks.
- The press is less effective for drawing out bars, particularly for achieving thinner sections like 2.5 mm. While it's still faster than manual methods, this task requires multiple cycles and careful selection of the correct anvil shapes. Tools like a power hammer may be more suitable for this specific task.
- The original frame design was insufficiently strong, with the frame bending significantly under the maximum 20 tonnes of pressure. Reinforcements were necessary to improve stiffness, and it is recommended to design a stronger frame from the outset to avoid similar issues.
- Basic tools, such as a simple drill, are sometimes not enough to efficiently complete the tasks needed for building the press. For example, drilling large diameter holes (e.g., 22 mm) in thick metal profiles can be challenging. Access to more advanced tools can be very helpful.
- The length and shape of the hydraulic cylinder have a significant impact on the overall frame construction. The press had to be made larger than necessary due to the cylinder being 90 cm long, despite only needing 60 cm of stroke. A cylinder with a flange may have been easier to mount than the ear type, as it simplifies the attachment of the frame and top anvil.

VII. Future Work

In the future, we plan to upgrade the hydraulic press by replacing the manual control valve lever with a foot pedal control. This modification would allow for more convenient operation, enabling the user to hold the material with both hands while controlling the press with their foot.

To achieve this, an electrically actuated control valve would need to be installed, which can be operated by a foot pedal switch. This upgrade would likely involve replacing the current manual valve with a solenoid-operated valve, connecting it to the hydraulic system, and wiring the foot pedal to control the solenoid. Additional electrical components, such as a control box and safety features, may also be necessary to ensure smooth and safe operation.

References

[1] *https://www.bobthebladesmith.com.*
[2] *bobthebladesmith@gmail.com.*
[3] *https://youtu.be/0vDwvFRIjCc.*