

Design and Analysis of Piercing Tool with Special Purpose Hydraulic Press

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Abstract: The modern manufacturing industries are highly focused towards increasing productivity with very less investment on new tooling and machines. This paper discusses about design of press tool with press to be setup in line production, where component usually transferred stage by stage for performing sequence of operation. Deep drawing is the metal forming operation used to form cups from flat sheet metal, in order to assemble the component holes are required and usually produced by secondary operation using piercing tool. The below sections describe about the design of piercing tool for deep drawn component with hydraulic press for piercing operation. The design challenges involve understanding and identification of various uncertainties involved in process and troubleshooting them through virtual prototyping by using FEM and other simulation software and facilitate the design that supports risk free manufacturing environment, with minimum overall cost of production.

Keywords: Piercing Tool Design, Shape Optimization, Finite Element Analysis, Hydraulic Press Design, Hydraulic Circuit Design

1. Introduction

Deep drawing is the metal forming operation, in which cup shape is formed from flat sheet metal. The limitation in the operation is any metal cutting operations such as trimming, piercing etc has to be carried out as a secondary operation in order to maintain geometry relation. As the deep drawing operation is carried out in plastic deformation stage any holes previously pierced in sheet metal before drawing will get affected, as the material flow during drawing operation. Using a stage tool for piercing as a secondary operation holes produced in deep drawn component [1]. A custom design of press tool along with hydraulic press with appropriate hydraulic circuit is discussed in this paper. The hydraulic press designed and analysed with Ansys and solidworks simulation to ensure high stiffness, low cost and compact. The hydraulic circuit is designed, simulated and functionality is verified using Automation studio 6.0

2. Problem Statement

Press tools are commonly used in hydraulic, pneumatic, and mechanical presses to produce components at high volumes. The press tools are classified into stage tools and progressive tools. In progressive tools many operations on sheet metal are carried out in a sequence by progressing the continuous sheet metal into the tool. eg: Initially piercing in first stage followed by piloting in next stage followed by blanking. In stage tool only one stage of operations will be carried out either only piercing or only blanking or only trimming. In general stage tools are categorized by the type of operation being performed using the tool, such as blanking is performed using blanking tool, piercing operation is performed using piercing tool etc [2]. The paper describes about design of piercing tool for piercing diameter 8mm x 4 holes at PCD 47 mm using a stage tool in a pre deep drawn cup. The suitable hydraulic press design to accommodate the tool to perform piercing operation at low cost was also

covered. The Figure 1 shows deep drawn component without piercing and after piercing with dimensions.

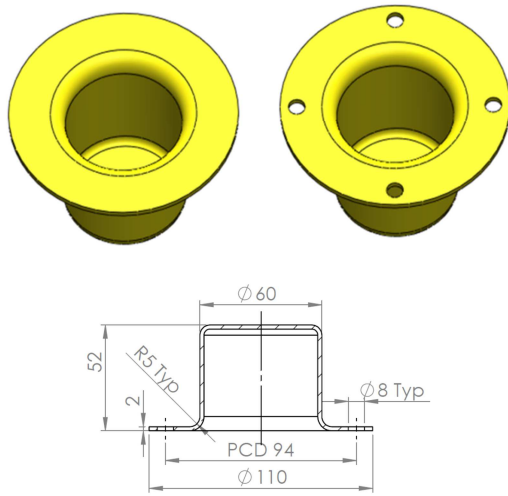


Figure 1. Component dimensions showing with and without pierced condition.

3. Design of Piercing Tool

The general press tool construction will have following elements:

- **Shank:** It is used to locate the press tool in press for alignment purpose.
- **Top Plate:** It is used to hold top half of the press tool with press slide.
- **Punch Back Plate:** This plate prevents the hardened punches penetrating into top plate.
- **Punch Holder:** This plate is used to accommodate the punches of press tool.
- **Punches:** To perform cutting and not cutting operations either plain or profiled punches are used.
- **Die Plate:** Die plate will have similar profile of the component where cutting dies usually have holes with land and angular clearance and non cutting dies will have profiles.
- **Die Back Plate:** This plate prevents the hardened Die inserts penetrating into bottom plate.
- **Guide Pillar & Guide Bush:** Used for alignment between top and bottom halves of the press tools.
- **Bottom plate:** It is used to hold bottom half of the press tool with press slide.
- **Stripper plate:** It is used to strip off the component from punches.
- **Strip guides:** It is used to guide the strip into the press tool to perform the operation.

Piercing tool design purely depends on the shape and size of the component, therefore custom design of tool is must. As the standard press may be of higher capacity or of lower capacity, tends to produce low or high press force then the requirement therefore limited to select only the higher capacity press with high press force though the requirement can be met with less force then the selected press. In order to

reduce the cost invested on the press, a special purpose press is designed to meet the requirement. For the design of press tool the following design calculations are carried out.

4. Component Details

Material: AISI 340 stainless steel

Maximum shear strength of AISI 304 stainless steel= 290 MPa

Finding cutting clearance between punch and die plate

$$C_c = C \times S \sqrt{\frac{\tau_{\max}}{10}}$$

Sheet thickness of material to be pierced = 2 mm

Therefore cutting clearance = $0.005 \times 2 \times 5.38$
= 0.053 mm / side

Therefore the diameter of piercing punch should be of 8 mm and the diameter of piercing hole in die is 8.106 mm [3].

Finding the required cutting force

$$C_F = L \times S \times \tau_{\max} [3]$$

For circular holes the cut length = πD

Cut length of single hole = 25.13 mm

Cut length of 4 holes = 100.53 mm

Therefore cutting force = $100.53 \times 2 \times 290$

$$= 58307.4 \text{ N} = 50.30 \text{ kN}$$

Finding press force

$$P_F = C_F + S_F [3]$$

Stripping force = 11.66 kN

Therefore press force = 62 kN

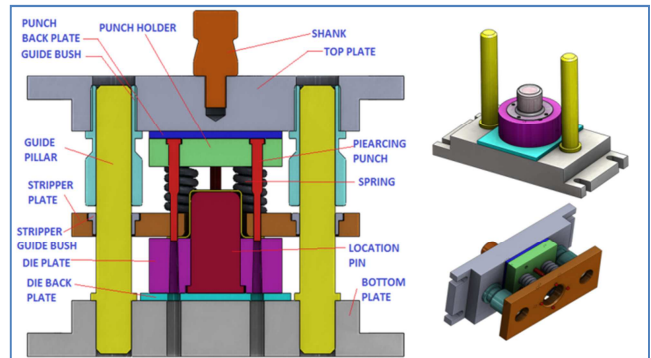


Figure 2. Piercing Tool Design.

5. Arriving Appropriate Structure of Press Frame Using Shape Optimization

Shape optimization is the form of layout optimization performed in Ansys, helps to find the best use of material for press frame structure. To carry out the analysis no optimization parameters was defined. The material distribution function over a body is the optimization parameter. The goal is maximize the energy of structural compliance and the design variables are pseudo- densities assigned to each finite element. The value range from 0 to 1,

were 0 is for material to be taken away and 1 is for material to be kept. In below Figure 3 the portion shown in red has zero pseudo densities of 0, those region can be removed off and the portions shown in gray has pseudo density of 1 therefore those are the functional region the material has to be retained in those regions. For the shape optimization problem, initially a cube is created considering overall span for the frame and

the problem was defined as linear, elastic and isotropic. The small region were the frame is supported was provided with fixed constrain at the four corners of the cube. The region of cylinder mounting, which exhibit the reaction force at the top face of cube the force was applied. The analysis was carried out for the above boundary conditions. [4]

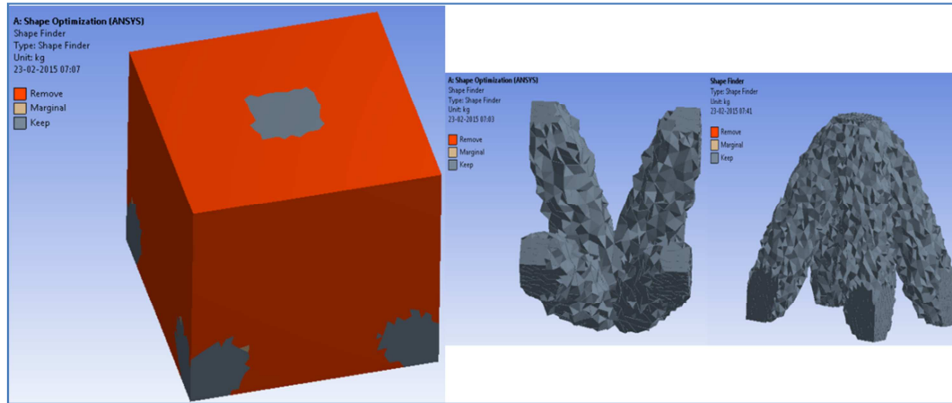


Figure 3. Shape Optimization Results.

6. Design of Press Frame

Based on the shape optimization result it is difficult to implement the shape as it is as per the result, as the software will not consider the manufacturing constrains therefore considering the manufacturing feasibilities appropriate shape of the frame was arrived. As the press is designed for force magnification through hydraulic, by considering the space for accommodation of reservoir, power pack etc the final design is arrived as shown in Figure 4 below.

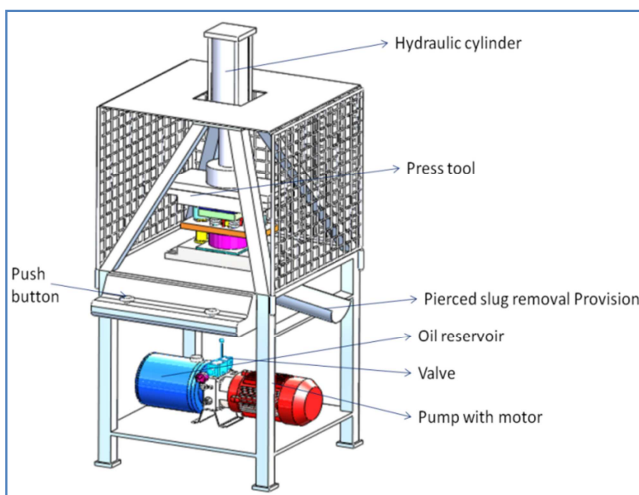


Figure 4. Final design of Press with Press Tool.

7. Finite Element Analysis of Press Frame

Finite Element Analysis is an engineering analysis technique which is widely used in various field of

engineering, implemented to identify behaviour of complex structures for which no exact solutions exist. The basic concept of finite element analysis is to convert the complex problem into a simple form by discretising the structure into many small parts called elements. Each elements has nodes which has degree of freedom and it enables to solve the complex problem easily, by finding the solution to all small parts and the sum of behaviours of all parts are assembled into one solution for the overall problem. [5] For conducting finite element analysis initially mesh was generated with idealization as shown in Figure 5. As the stiffness of press tool and hydraulic power pack was not focused therefore the whole structure is idealized as 0D mass element with equivalent mass connected to frame using 1D rigid links, the force generated by cylinder applied on the frame, the fixed constrain was provided in the region of frame is grouted and the acceleration of gravity is considered.

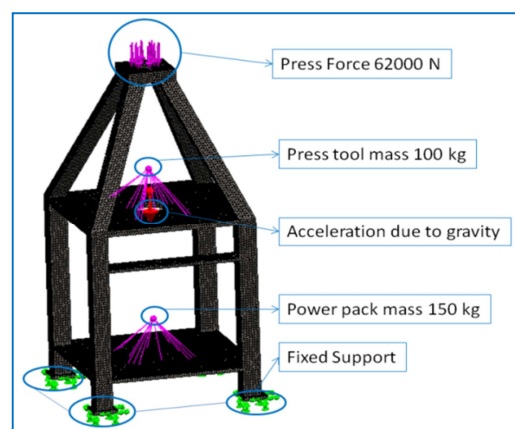


Figure 5. Boundary Condition for Static Analysis.

The finite element analysis involves three stages the first is pre processing involves creation of finite element model,

than processing involves matrix generation, solving and evaluating the result. The post processing involves viewing of deformation, stress results. Initially for the frame structure static analysis was conducted using Solidworks simulation, for the boundary conditions shown in Figure 6 The maximum

deformation observed in frame is 0.076 mm and maximum von Mises stress observed in the frame is 18.2 MPa. As the AISI1040 material has minimum yield strength of 350 MPa therefore the structure has FOS 19.2.

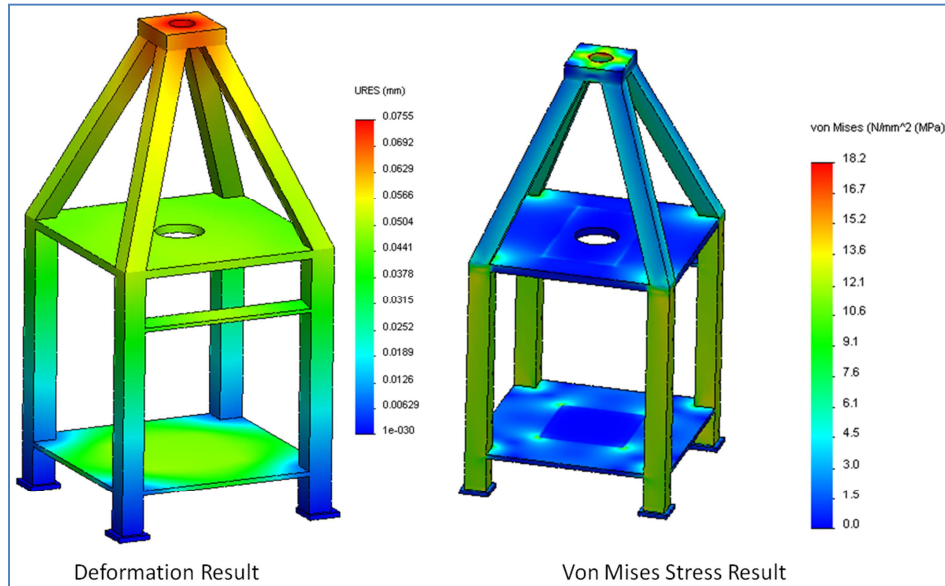


Figure 6. FEM Static Analysis Deformation and von Mises Stress Result.

8. Modal Analysis

Modal analysis is conducted in order to ensure the structure doesn't undergoes resonance. The analysis was conducted to understand the dynamic response of the frame

structure during excitation. The analysis was also ensures the structural natural frequencies are not matching with the forced frequencies. The Boundary conditions for analysis is as shown in Figure 7.

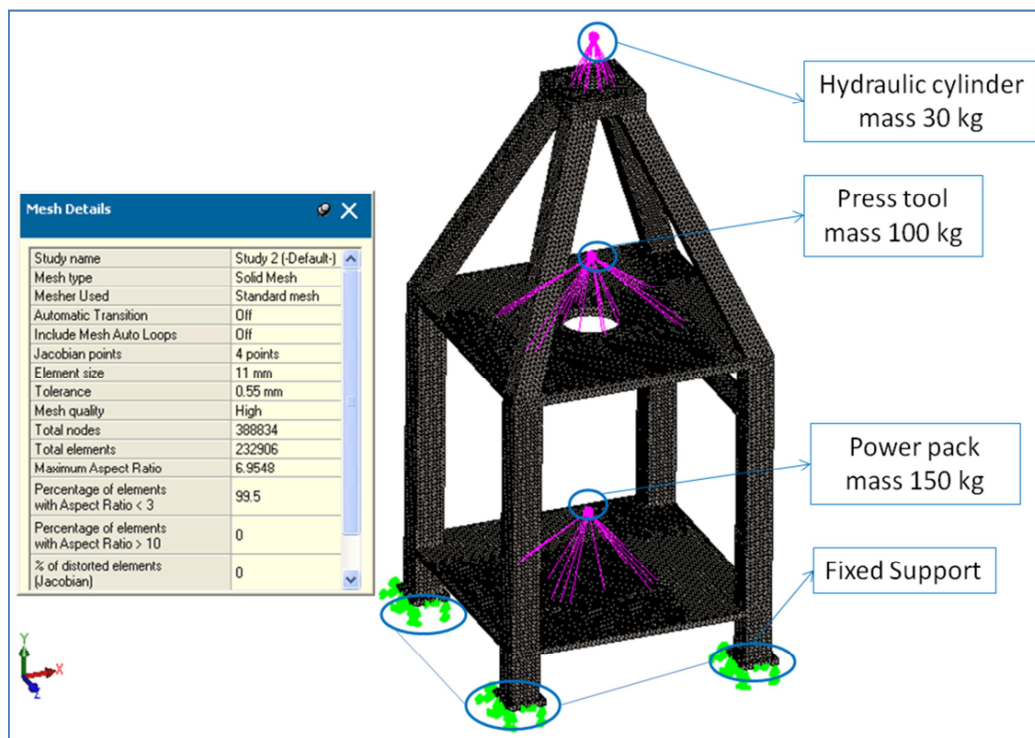


Figure 7. Boundary Condition for Modal Analysis.

List Modes			
Study name: Study 2			
Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	183.76	29.246	0.034192
2	185.17	29.471	0.033931
3	398.25	63.383	0.015777
4	505.07	80.384	0.01244
5	699.47	111.32	0.0089827

Figure 8. Natural Frequencies Result of Press Frame.

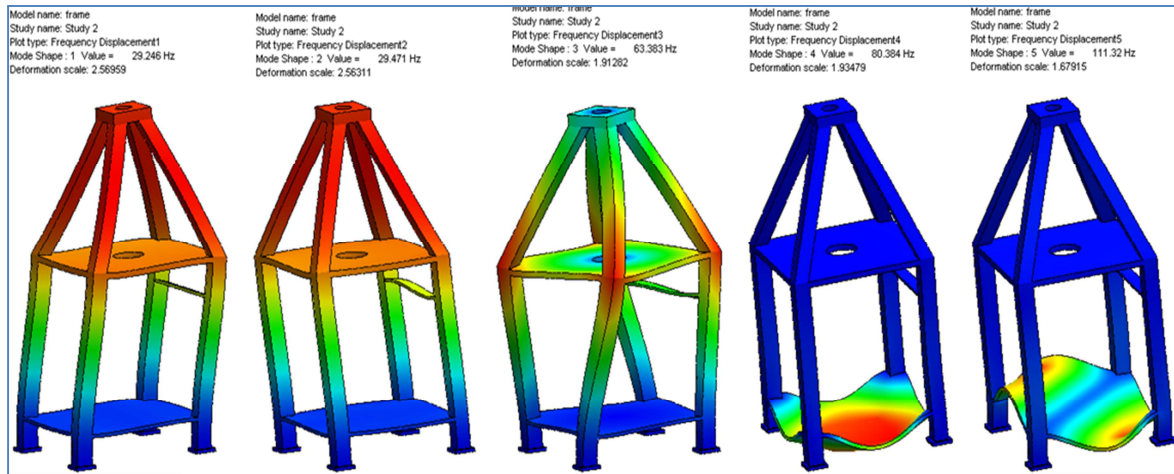


Figure 9. Mode Shapes at First Five Natural Frequencies.

To find the solution to a finite element analysis problem the solver must solve simultaneous equations, for solving the problem the FFE plus method was used with convergence criterion 1×10^{-4} , this method is iterative. It will first approximate certain parameters in order to solve the equations and calculate a solution, it will then increment those estimated parameters and calculate a new solution. By comparing the two solutions it can identify if the solution is diverging or converging. As it converges the answer will get

closer and closer to the real answer. for the most accurate result the finer the convergence criteria has to be set and the software will run more number of iterations which in turn increases the solving time. As for this analysis the convergence criterion 1×10^{-4} was set, therefore the software will set a limit to determine when the change in solution between one iteration to the next is small enough to meet the criterion, it will stop computing and accept that as the solution with minimal error.

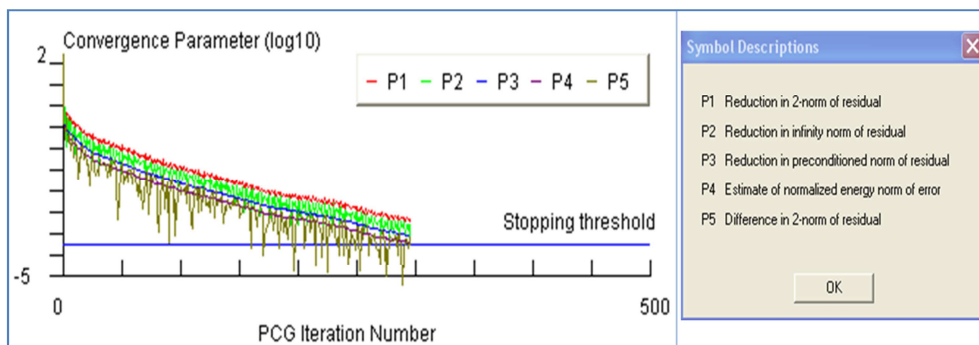


Figure 10. Convergence Graph of FEM Analysis.

9. Hydraulic Circuit Calculation

For developing the hydraulic circuit the required calculations was carried out initially to select appropriate elements to generate hydraulic circuit. As the required press

force was found using that as input the calculations was carried out. [6]

The required press force = 62 kN = 6320 kgf

Working pressure of fluid (P) = 50kg/cm²

Oil viscosity (γ) = 68cst mm²/sec

Oil density (ρ) = 890 kg/m³

a. Finding the cylinder diameter calculation:

$$P = F/A$$

Therefore area required for cylinder considering pressure and press force is = 126.4 cm²

$$\text{Diameter of cylinder} = 126.86 \text{ mm} = 130 \text{ mm}$$

b. Finding required fluid flow rate:

$$Q = A V$$

$$= 12640 \text{ mm}^2 \times 20 \text{ mm/s}$$

$$= 252800 \text{ mm}^3/\text{s}$$

$$= 252800 \times 60 / 1 \times 10^6$$

$$= 15.16 \text{ l/m}$$

Therefore pump with fluid flow rate of 16 l / m is considered.

c. Electrical motor calculation:

$$P_w = Q \times P / 600 \times \xi$$

$$= 15.16 \times 50 / (600 \times 0.9)$$

$$= 1.45 \text{ kW} = 1.97 \text{ hp}$$

Therefore the motor with 2 hp is considered.

d. Calculations for Tank Capacity:

To provide uninterrupted supply of hydraulic fluid and to prevent vacuum inside the tank, capacity is taken as 2.5 times of the pump capacity.

$$\begin{aligned} \text{The tank capacity is taken as} &= 2.5 \times 15.16 \\ &= 37.9 \text{ l/min.} \end{aligned}$$

Therefore the tank with 40 liters is considered.

10. Hydraulic Circuit Design

The hydraulic circuit for press consist of an interconnected set of discrete components that transport hydraulic oil. The pictorial symbolic representation shows how fluid is controlled to get desired output. The hydraulic circuit design and simulation was carried out in Automation Studio to actuate the cylinder for piercing operation, while designing a special purpose press the safety of the operator also needs to be taken care. The press is designed such that when the operator presses two push button at a time together the piercing operation takes place to ensure that operators both hand is outside of the press during operation. In hydraulic circuit an And value was used to execute this function. The various elements used in circuit is shown in below Figure 11. The function of various elements used are as follows

- Tank: Reservoir or tank is portion at which the hydraulic oil is stored and circulated within the circuit during operation
- Filter: The fluid before enters into the variable displacement pump gets filtered by suction filter placed before pump
- Variable displacement pump: The variable displacement pump is used to generate pressure in hydraulic oil
- Pressure relief valve: The pressure relief valve is used in the circuit to ensure the safe working pressure is maintained within the circuit, if the pressure exceeds the set limit the pressure relief valve gets connected to tank therefore from pump the oil will directly goes back to tank.

- Check valve: The check valve allows the fluid flow in one direction. The check valve is placed above the pump as when power fails the stored energy in accumulator balances the circuit, during which due to back pressure from accumulator to prevent the oil gets diverted to tank through pump.
- Pressure gauge: The pressure gauge is used to identify the system pressure.
- Accumulator: Accumulator is used to store the energy while the system is under operation and releases the energy to stabilize the system when power fails.
- 4/2 Solenoid operated direction control valve: The 4/2 solenoid operated DCV is used to control the direction of fluid. The valve consist of 4 ways and 2 positions. It is a normally open valve the hydraulic oil from tank always connected to port B of cylinder and ensures the cylinder is retracted as solenoid S4 is always energised. When 2 push buttons P1 and P2 is pressed together will energise the solenoid S3 and changes the position of valve therefore the port A of cylinder gets connected and cylinder extends. The cylinder stroke is limited up to sensor sen1 position, when cylinder reaches the position sen1 the sensor energise the solenoid s4 and retracts the cylinder.
- Variable flow control Valve: The variable flow control valve is used to adjust the flow of oil enters into the cylinder, therefore piston movement in the cylinder is controlled.
- Double acting cylinder: The double acting cylinder has port A and B, both extension and retraction of cylinder is controlled by hydraulic oil.
- Sensor: The sensor is used to ensure the cylinder has completed its maximum permitted stroke and provide signals to energise the solenoids in DCV. [7]

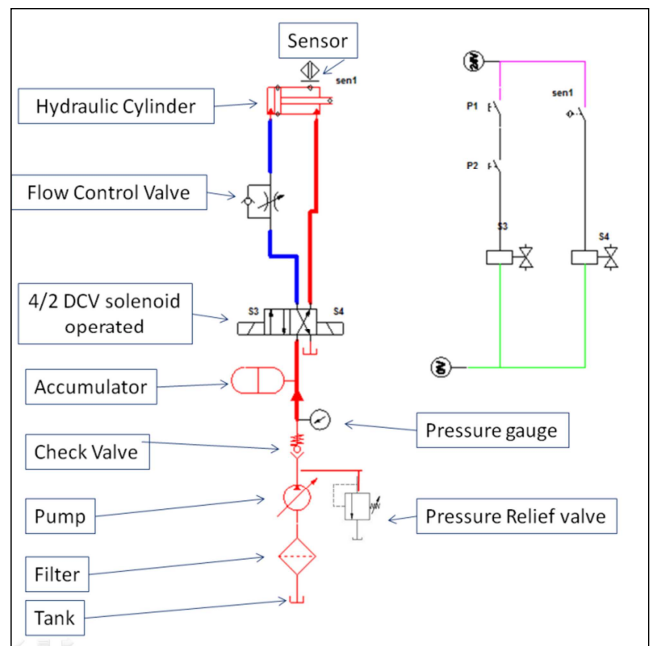


Figure 11. Hydraulic Circuit Simulation.

11. Results and Discussion

The paper describes the step by step methodology involved in design and analysis of piercing tool with hydraulic press design. Based on design calculations the piercing tool design was developed. By arriving the overall bounding dimension of press frame the shape optimization was conducted to design the structure with minimal mass. With reference to the shape optimization result final concept was generated and verified using FEM. The static analysis ensuring that von Mises stress is within elastic limit with high factor of safety and deformation observed is within permitted level. From modal analysis result the structure was ensured that the structure will not undergo resonance, as the first natural frequency of structure was well beyond the maximum operating frequency. The hydraulic circuit calculation ensures that the elements selected in hydraulic circuit is convincing, by simulating the circuit the functionally was verified.

12. Conclusion

The objective of designing the cost effective piercing tool with hydraulic press for specific component was briefed. The design calculations required to design press and press tool was carried out. The design validation using virtual FEM software shows the design is safe and by simulating the hydraulic circuit the circuit design was verified. The elements sizing for hydraulic circuit was carried out using analytical calculations.

Nomenclature

C = Constant 0.005 to be considered for very accurate component

P = Pressure applied in kg/cm²

S = Sheet thickness of material to be pierced

F = Output force required in cylinder in kgf

τ_{\max} = Maximum shear strength of material to be pierced

A = Area of cylinder in cm²

L = Cut length in mm

Q = Rate of flow

D = Diameter of hole to be pierced

V = Velocity of piston movement

S_F = Stripping force, usually 20% of C_F

P_w = Power in kW

C_c = Cutting clearance between punch and die plate

ξ = Efficiency

C_F = Cutting force V_o = Required volume

P_F = Press force

P = Working pressure of fluid

γ = Oil viscosity

ρ = Oil density

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