Modification of piston and hydraulic system using taguchi response surface optimization

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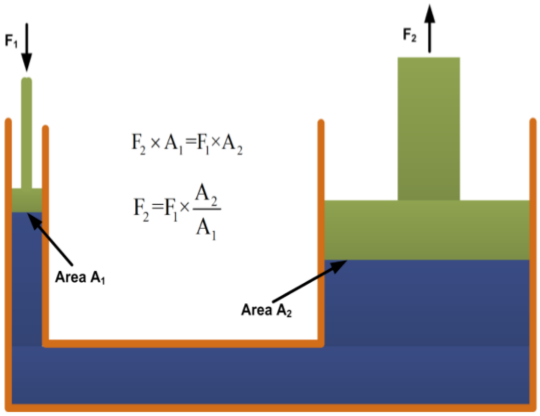
Abstract- *A hydraulic cylinder is a mechanical actuator that uses pressurized hydraulic fluid to generate linear force or motion. It consists of a cylindrical barrel, a piston that moves back and forth within the barrel, and hydraulic fluid which is used to transfer the force from one end of the cylinder to the other. . The choice of cylinder depends on the specific application and the desired performance requirements. The hydraulic system encompasses piston rod and piston. In the current research, the piston and rod mass are minimized using response surface optimization techniques. The design of piston, piston rod is developed and analyzed in ANSYS. The CAD model is developed and static structural analysis is conducted using ANSYS structural software. The responses of optimization variable are captured using 3D response surface plots and 2D linearized curves. The sensitivity plots of different variables are also generated. The optimization is conducted using central composite design scheme and design points are evaluated on the basis of stresses and deformation generated.*

Keywords- Hydraulic, FEA, Optimization.

I. INTRODUCTION

Various operations in industries demands controllable movement of parts in order to perform specific tasks. The controlled movements can be achieved with the use of certain components like screw jack, lever, rack and pinions. However, the fluids (compressed way) can be used in enclosed systems to generated both rotator as well as linear systems. The hydraulic system can be used to generated high magnitude of force using Pascal law.



Finite Element Method

The finite element method (FEM) is a “numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization. Domain of interest is represented as an assembly of finite elements”. The nodal values are determined for physical fields. The physical problem which is continuous are converted in to discredited problem (elements and nodes) where in the nodal values are unknown.

Two features of the FEM are:

1) By using simple approximation functions, the good precision of physical problem can be achieved.
2) The use of sparse equations can rectify the problem of unknown nodal variables.

Applications of FEM

1. **Mechanical engineering:** In automobiles component design, machine component designand other tool design.
2. **Geotechnical engineering:** The geotechnical engineering involves soil stability, soil structure and fluid solid interaction. The analysis involves heavy structures like tunnels, dams etc.
3. **Aerospace engineering:** The aerospace engineering involves use of FEA in air craft design, shuttle design.

The type of analysis involves vibration and structural type.

4. **Nuclear engineering:** The safety and performance of nuclear reactor is investigated. The analysis of reactor involves steady state and transient state.

II. LITRATURE REVIEW

S.M.Bapat and Dessai Yusufali et al have conducted numerical analysis on 30 ton hydraulic machine using ANSYS software. The hydraulic press investigated is used in metal forming process. The structural failure on hydraulic machine due to high compressive or tensile stresses is investigated. The design of hydraulic system is optimized which enabled to reduce weight and reduce stress.

Malachy Sumaila et.al. has conducted experimental investigation of 30-ton hydraulic press which has 150mm piston diameter so as to withstand 10KN load. The stresses generated and deformation was well within the limits and with good safety factor.

Neville Saches et al has conducted numerical and experimental studies on hydraulic machine and the parameters fatigue life, stress concentration factor are investigated. Then findings have shown that loads causing machine failure are combination of torsion, bending.

P.E. Uys, K. Jarmai, J. Farkas et al has worked on developing cost effective design of hydraulic system to be used for farming purpose. The design of hydraulic system is optimized to minimize fatigue failure using different types of algorithms. The “gradient-based method, requiring no explicit line searches, is a proven robust and reliable method, being relatively insensitive to local inaccuracies and discontinuities in the gradients”.

Mohamad M. Saleh et al has conducted FE simulation on hydraulic machine manufactured by ENERPAC. The design of hydraulic machine is then optimized to reduce weight and cost. The simulation results obtained from analysis are in close agreement with experimental results and design is optimized with 12% weight reduction.

Sinha and Murarka et al has conducted a simplified type of numerical analysis on hydraulic press. This simplified type of method is simplified plane stress FEM model. The conventional method generates higher number of elements which is time consuming also and the new advanced method enabled to improve design of hydraulic press using specific set of guidelines.

Muni Prabaharan and V.Amarnath et al has worked on innovative product design of 5ton hydraulic press using ANSYS FEA software. The topological optimization technique used in weight minimization with new improved design of hydraulic press.

LeRoy Fitzwater, Richard Khalil, Ethan Hunter et al has worked on improving design of hydraulic press using topological optimization technique. These advantages provide a strong argument for integrating this technology into the standard design procedure for enhancing the functionality of engineering goods. Topological optimization methods have several advantages, including the ability to visualize load paths, reduce weight, expand the design space of a system, enhance ballistic protection, and reduce fatigue. There are several more advantages of using topological optimization methods. In the diagram below, we see the several steps taken throughout the optimization process.

III. METHODOLOGY

2Design of the cylinder

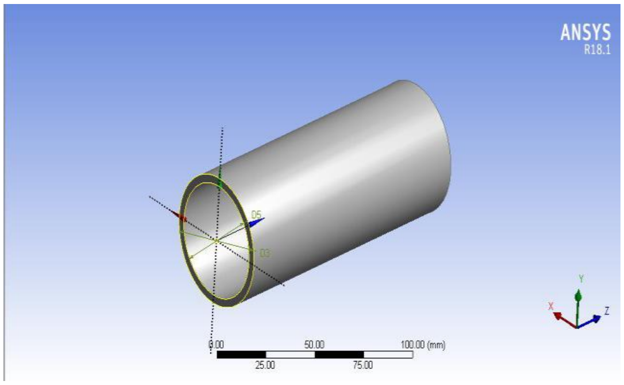
When it comes to the design of hydraulic cylinders, the tube thickness of a cylinder barrel is a very crucial issue to consider. The thickness of the cylinder tube's wall directly correlates to the strength of the structure. Because of the potential dangers to both personnel and equipment posed by a cylinder that is either too thick or too thin, the wall thickness of the tube that makes up the cylinder must be carefully selected. [27].It is possible to determine the necessary wall thickness for the cylinder by using the formula found in equation

Thickness (t)

Where: OD, is the cylinder external diameter, 55mm and small “d” is the piston seal diameter

(cylinder internal diameter), 48mm.

t = Thickness (t) = 3.5mm



ANSYS design modeller is used to generate the computer-aided design (CAD) model of the cylinder. With ANSYS design modeller, modelling a hydraulic cylinder is accomplished with the help of the sketch and extrude tool. The CAD model that was created is developed in the manner that is seen up above in figure 4.2.

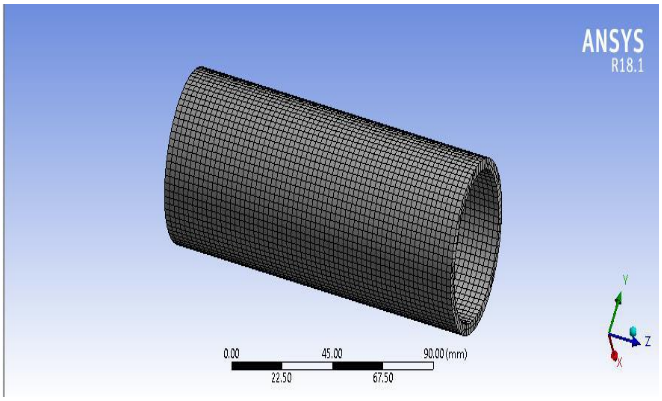


Figure 2: Meshed model of cylinder

3 Design of the piston

The hydraulic cylinder is designed to be double acting and double ending, the force of the pressure acts on both sides of the rod. Hence, the area that the force of the pressure is acting on may be calculated as (A-a). The generated force is given as:

F=P(A-a)

“Since the piston and the piston rod are circular in nature, therefore area of the pressurized part is given by

A-a $=\pi D2/4-\pi d2/4$(4)

Where: F = force = assume force * factor of safety (3) = 11000 * 3 = 33 * 103N
P = pressure, 200bar = 200 * 105 Pa
D = diameter of piston
d =diameter of piston rod, 12mm = 0.012m

By substituting the above value into those equations, we have, m Hence diameter of piston required d = 47 mm.

Finally, for other calculations and construction, the diameter of the piston is taken to be48mm. Because from Bay Hydraulics Corporation catalog of metric rod wipers and piston seals, the nearest standard rod seal diameter is 48mm”.

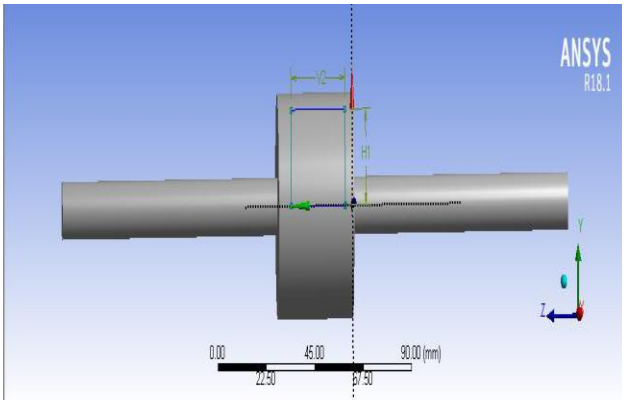


Figure 3: CAD model of piston and piston rod with internal sketch for mass removalusing revolve tool.

III. RESULT AND DISCUSSION

Structural Analysis Results of Cylinder

For the purpose of determining deformation and equivalent stress, the structural analysis of the cylinder is carried out. The plot of the overall deformation reveals that the most significant deformation occurs in the middle of the cylinder and has a magnitudeof.0178mm.The deformation is minimum on free end of cylinder as shown in figure 5.1below.

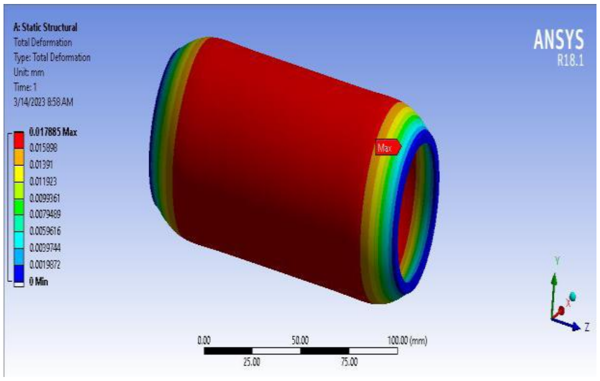


Figure 4: Deformation plot of cylinder

The equivalent stress plot reveals that the amount of the stress is greatest near the cylinder's perimeter, as can be seen in figure 5.2 below. The investigation led to the discovery of avalue of 229.49MPa for the maximal equivalent stress.

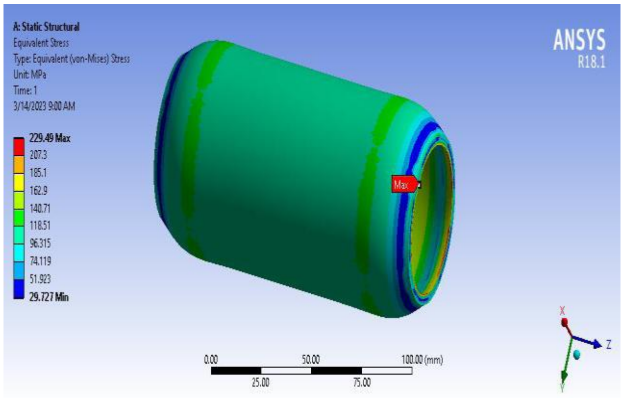


Figure 5: Equivalent stress on cylinder

Structural Analysis Results of Piston and Piston rod

In order to calculate deformation and equivalent stress, a structural study of the piston and the piston rod must first be carried out. The plot of total deformation reveals that the most significant amount of deformation occurs near the end of the piston rod and has a magnitudeof.049mm.

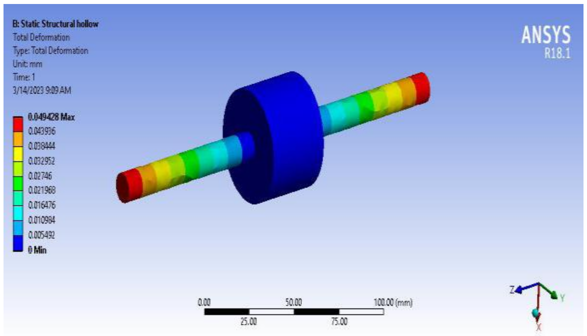


Figure 6: Total deformation of piston and piston rod

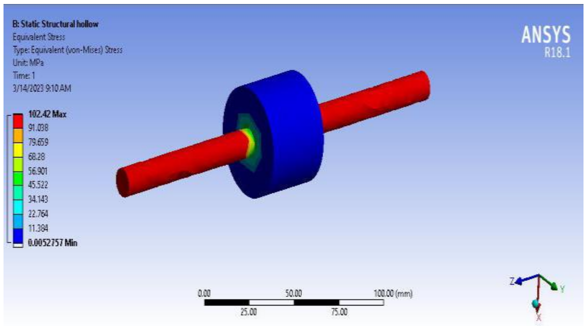


Figure 7: Equivalent stress plot of piston rod and piston

The equivalent stress plot displays the greatest magnitude at the junction of the piston and the piston rod, as well as on the piston rod itself. As can be seen in the preceding figure 5.18, the study resulted in a maximum equivalent stress of 102.42 MPa being determined. The corresponding stress of 56.9 MPa can be seen at the point of junction between the piston rod and the piston. Figure 5.19 depicts the safety factor plot that was produced for the piston and the piston rod, and the safety factor that was calculated by analysis was 2.44.

IV. CONCLUSION

1. The FEA analysis is conducted on hydraulic cylinder and piston with piston rod. The equivalent stress, deformation and safety factor of both components are determined. The response surface optimization of cylinder and piston is conducted to determine range of values for which the output parameters is maximum or minimum. The sensitivity plot, 3Dresponse surface plot and sensitivity plot of each variable vs output parameter is generated. The detailed results are:
2. From design of experiments conducted on hydraulic cylinder, the maximum and minimum values of different parameters are obtained. The minimum equivalent stress is 159.54MPa while maximum equivalent stress is 639.33MPa. The minimum mass is 0.179Kg and maximum mass is 1.6565Kg.
3. The greatest safety factor that can be obtained from the design of the trials that were carried out on the piston and the piston rod is 2.47, and the lowest safety factor that can be achieved is 2.42. The least equivalent stress that was measured was101.17MPa, while the highest equivalent stress that was measured was 103.27MPa.
4. For safety factor, the if r and if h shows positive sensitivity for safety factor. The positive sensitivity signifies that increasing these variables the output parameters also increases and decreasing these variables, the output parameters also decreases. The ifrshows 39.66 sensitivity percentage while if h shows 28.96% sensitivity percentage which shows that if r has higher effect on safety factor as compared to if h.

V. FUTURE SCOPE

The piston and piston rod is crucial components used in hydraulic systems. The materialused in these parts significantly affects the strength and deformation of hydraulic systems. Therefore, the feasibility of new composite materials on hydraulic systems needs to be investigated.

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