THICKNESS OPTIMIZATION OF THICK WALLED CIRCULAR CYLINDER BY HEAT TREATMENT

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Abstract - *The hydraulic cylinder are used in chemical industry, military and nuclear power plants, petroleum industries and heavy equipment structures. The cylinder (without heat treatment) is subjected to internal pressure and the internal pressure is incremented in terms of 10MPa till stress equals yield point stress. The thickness of cylinder is determined by using Lame's equation. Further cylinder is subjected to internal pressures in ANSYS APDL 12.0.v. The ANSYS results are compared with analytical results having percentage error less than 2%. The cylinder (with heat treatment) is subjected to internal pressures in ANSYS and pressures are increment in 10MPa till stresses equal yield point stress. The ANSYS results of cylinder (with heat treatment) are compared with ANSYS results of cylinder (without heat treatment). Further the thickness is reduced by 5mm and subjected to internal pressures, the pressure is incremented in 10MPa in ANSYS. The results obtained are compared with cylinder (without heat treatment). Further cylinder (with heat treatment) with thickness reduced is subjected to modal analysis (analytically and numerical). The analytical natural frequencies are compared with numerical natural frequencies with percentage error less than 3%. The working frequencies obtained and compared with analytical and numerical frequencies, the working frequencies are very low hence there is no resonance condition.*

Key words:- Single acting cylinder, heat treatment, Thickness, Mechanical vibrations etc

1. INTRODUCTION

The main component of hydraulic system is the cylinder and cylinders are widely used in petroleum, chemical industries and heavy construction equipments. The cylinder is called thick walled when the ratio of bore diameter to thickness is less than 10. Thick walled cylinders are subjected to high internal pressures which may be cyclic or constant loading condition. The conventional elastic analysis of cylinder subjected to internal pressure is carried out. In order to make full use of loading conditions the radial and hoop stress should be within yield strength of material and ensure safety at such loading conditions. The figure 1 shows the single acting hydraulic cylinder.

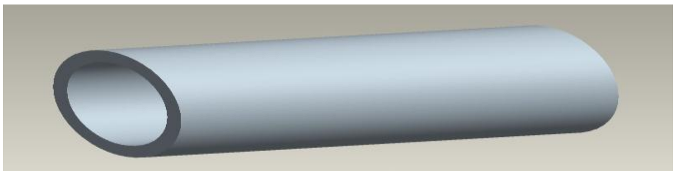

Fig -1: Single acting cylinder

The numbers of theories for prediction of natural frequencies are developed for cylinders. The working conditions of cylinder have different natural frequency according to their usage fields. The large size cylinders require higher force and moment inputs, work generally in lower frequencies and small size cylinder used in sensitive applications fields like testing and measurements systems have higher working frequencies. To study the effect of thickness reduced on heat treated cylinder.

1.1 Heat Treatment on Cylinder

Hardening heat treatment [8] is carried on steels to improve mechanical properties and ductility. The carbon content in medium carbon steel is 45%. Heat treatment is based on iron carbon diagram and heat treated temperature ranges are 800^0C to 850^0C. The improved yield strength is 490MPa and hardness 235HB. The figure 2 shows the iron carbon diagram.

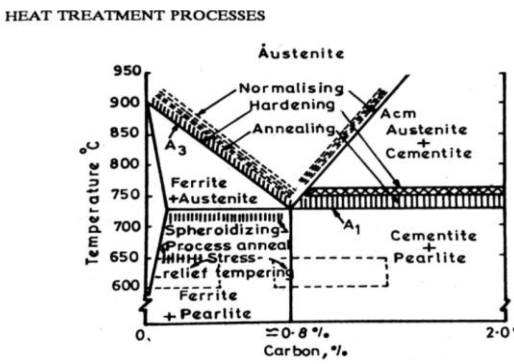

Fig -2: **Heat treating temperatures for carbon steels**

Cylinder with same dimension is heat treated. The thickness of cylinder (with heat treatment) is reduced by 5mm.

1.2 Literature Survey

Qayssar [1] the analysis of thin and thick cylindrical pressure vessels for two different material is carried numerically in C++software and results are obtained for fixed length of cylinder. The two materials used are ductile and brittle materials. For brittle material normal stress theory and for ductile material maximum shear stress theory is used. The variation of internal pressures against the thickness is obtained for both material and thickness of pressure vessel is to be increased if internal pressure is increased. The brittle material is thicker than ductile material for same internal pressures. Talu D. L. Mihai [2] the finite element analysis is carried on hydraulic cylinder by COSMOS software. The stress is obtained for single internal pressure and the 4 mode shapes and natural frequencies are obtained by COSMOS software. Shaun Qiang Xu [3] studied on shakedown analysis of thick walled cylinder subjected to internal pressure with unified strength criterion. He analyzes the cylinder with strength difference and intermediate principle stress effects. The elastic plastic analysis is done and shakedown limit depends on strength difference and intermediate principle stress. Pritish tapare [4] studied the transient dynamic analysis of cylinder using ANSYS software. He analyzes the cylinder for single working natural frequency with two different boundary conditions and obtained the finite element analysis natural frequencies by mode super position method. Pavankumar Shah [5] studied dynamic analysis of hydraulic cylinder of excavator. The cylinder is subjected to two boundary conditions those are cantilever beam and simply support beam type. The deformations are obtained for boundary conditions by finite element analysis. The 6 mode shapes are obtained by finite element analysis with two boundary conditions. R. K. Singhal [6] studied the vibrational behavior of thick walled circular cylinder. He obtained the mode shapes of cylinder by finite element analysis in ADINA software and compared with START experimental modal analysis software for different mode shape on circumferential and longitudinal modes. The analysis carried for natural frequencies ranging from 20Hz to 30KHz. Further the analysis is extended from 20KHz to 30Hz by analytically only. Rakesh Reghunath et al [7] studied stress concentration factor at the vicinity of crack tip in thick walled cylinder. The autofrettage cylinders are used to reduce the stress intensity factor at crack tip causing the reduction of circumferential stresses at vicinity of crack. The work determines the SIF at various crack orientations and predicts which crack fails faster. The SIF of compound cylinder are compared with single cylinder.

The objective of this paper is to find the maximum pressure capacity of cylinder (without heat treated) and cylinder (with heat treated). Further thickness is reduced of cylinder (heat treated). The results are compared with cylinder (without heat treated). The cylinder having maximum pressure capacity is subjected to modal analysis.

2. MATERIAL AND METHODOLOGY

The material used for cylinder [9] is medium carbon steel with carbon content 0.45%. The yield strength of material is 360MPa young modulus E=210 GPa, Poisson ratio μ = 0.3 and hardness 229HB.

The thick walled cylinder (without heat treatment) with closed end is subjected to internal incremental pressures to determine the material stress by analytical and ANSYS APDL 12.0.v. The cylinder (with heat treatment) is subjected to incremental pressures till material stress equals yield point stress. The reduced thickness cylinder subjected to incremental pressures till material stress equals yield stress of material by ANSYS. Further cylinder is subjected for modal analysis.

3. STRESS ANALYSIS

The stress analysis on cylinder (without heat treated) is carried by analytical and ANSYS APDL 12.0.v. For 20MPa internal pressure thickness of cylinder is obtained by Lame's equation. The dimension of cylinder are outside diameter = 320mm, inside diameter = 250mm, thickness = 35mm. The figure 3 shows the thick walled cylinder with dimensions.

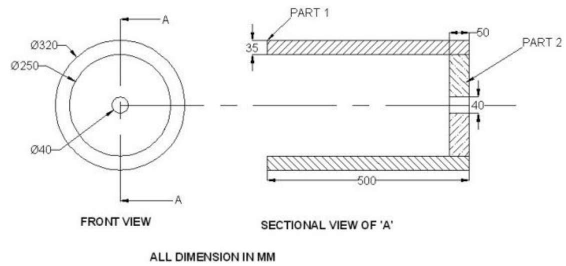

Fig -3: Thick walled cylinder

The von mises yield criteria is chosen and dimensions are fixed. The cylinder is subjected to incremental pressure till material stress equals yield stress of material. The circumferential, radial and longitudinal stresses are obtained by Lame's equation. The circumferential and von mises stresses are obtained for incremental pressures. The cylinder is subjected to incremental pressures and stresses are obtained in ANSYS. The ANSYS results are compared with analytical results as shown in table 1 and table 2. The cylinder is heat treated [8] and subjected to incremental pressures and stresses are obtained till yield strength of material table 3 shows the results of cylinder (with heat treatment). The thickness of heat treated cylinder is reduced by 5mm and subjected to incremental pressures, stresses obtained till the yield point stress. Table 4 shows the results of thickness reduced cylinder (with heat treated). The thickness reduced cylinder (with heat treatment) are compared with cylinder (without heat treatment) to obtain factor of safety. Table 5 shows which cylinder holds good factor of safety.

4. MODAL ANALYSIS

The modal analysis of thickness reduced cylinder (with heat treatment) is done by analytical and finite element analysis with boundary condition (both ends fixed). Considering cylinder as a bar the analytical natural frequency equation is derived based on continuous system of infinite degree of freedom. The analytical natural frequencies are obtained till mode 10. The analytical and FEA natural frequencies are compared as shown in table 6. The working natural frequencies of cylinder (with heat treatment) are in range of 21.5Hz to 45.69Hz.

5. RESULTS AND DISCUSSIONS

The FEA von mises stress of cylinder (without heat treated) subjected to incremental pressures is compared with analytical results. Table 1 shows percentage error of von mises stress with percentage error less than 1% result are in good agreement with analytical result and maximum pressure cylinder can sustain is 80MPa.

Table -1: Percentage error of the von mises stress for different internal pressures

Internal pressure in MPa	Analytical in MPa	FEA in MPa	Percentage error in %
20	88.66	88.39	0.30
30	133.5	132.59	0.68
80	355.6	353.57	0.57
85	377.82	375.67	0.57

The figure 4 shows the graph of von mises stress vs internal pressure and the variation of graph is linear.

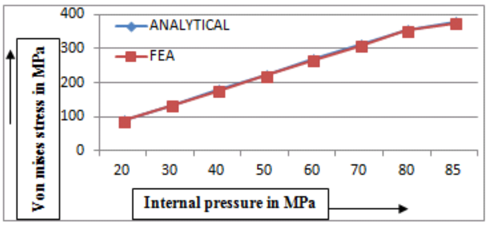

Fig -4: Variation of von mises stress vs internal pressure

The circumferential stress of finite element analysis is compared with analytical results subjected to internal pressures. Table 2 shows the circumferential stress. The maximum pressure cylinder can sustain is 85MPa and percentage error is less than 2%. The maximum pressure cylinder can sustain is 85MPa.

Table -2: Percentage error of circumferential stresses for different pressures

Internal pressure in MPa	Analytical in MPa	FEA in MPa	Percentage error in %
20	82.65	83.48	1
30	123.98	125.22	1
80	330.62	333.93	1
85	351.28	354.80	1
90	371.94	375.67	1

The figure 5 shows the circumferential stress vs internal pressure and the graph is linear.

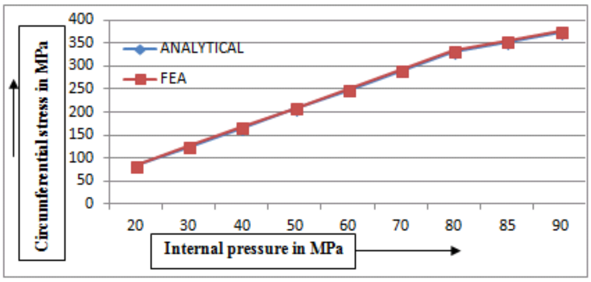

Fig -5: Variation of circumferential stress vs internal pressures

The circumferential and von mises stress of cylinder (with heat treatment) subjected to same internal pressures.

Table 3 shows circumferential and von mises stress of cylinder (with heat treatment). The stresses are obtained till it equals yield strength of material. The maximum pressure cylinder can sustain is 110MPa.

Table -3: Circumferential and von mises stress

Internal pressure in MPa	Circumferential stress in MPa	Von mises stress in MPa
20	83.48	88.39
30	125.22	132.59
100	417.41	441.96
110	459.15	486.16
115	480.02	508.26

This cylinder (with heat treated) showed improved result from cylinder (without heat treated). The thickness of cylinder (with heat treated) is reduced by 5mm and subjected to similar internal pressures and results are obtained.

Table 4 shows the circumferential and von mises stress of thickness reduced cylinder (heat treated) subjected to internal pressures. The maximum pressure cylinder can sustain is 90MPa.

Table -4: Circumferential and von mises stress

Internal pressure in MPa	Circumferential stress in MPa	Von mises stress in MPa
20	101.65	98.96
30	152.47	148.44
80	406.60	395.85
90	457.42	445.33
100	508.25	494.81

Table 5 shows the factor of safety of cylinder (without heat treated) and thickness reduced cylinder (with heat treated). The thickness reduced cylinder (with heat treated) showed better factor of safety for same internal pressures compare to cylinder (without heat treated). For pressure 85MPa cylinder (without heat treated) fails where thickness reduced cylinder (with heat treated) has 1.16 factor of safety.

Table -5: Factor of safety for cylinders (without heat treated) and cylinder (with heat treated)

Component	Cylinder		Modified cylinder	
Internal pressure in MPa	Von mises stress in MPa	Factor of safety	Von mises stress in MPa	Factor of safety
20	88.39	4.07	98.96	4.95
30	132.59	2.71	148.44	3.30
80	353.57	1.01	395.85	1.23
85	375.67	Fails	420.59	1.16

The modal analysis of thickness reduced cylinder (with heat treatment) is carried out. Table 6 shows the finite element analysis and analytical natural frequencies and mode shape till 10 modes are obtained. The FEA results are compared with analytical results having percentage error less than 3%.

Table -6: Comparison of natural frequency

Mode shape	Analytical frequency in Hz	FEA frequency in Hz	Percentage error in %
1	163.14	166.55	2.04
2	326.28	321.21	1.57
3	489.43	489.69	0.05
4	625.57	624.16	0.22
5	815.71	814.55	0.14
6	978.86	977.34	0.15
7	1142	1144	0.17
8	1305.14	1305	0.01
9	1468.29	1468	0.01
10	1631.53	1633.7	0.13

The working frequencies of cylinder are in range 21.49Hz to 45.69Hz. The working natural frequencies are compared with table 6 natural frequencies. The working natural frequencies are less Hence there is no resonance condition for thickness reduced cylinder (with heat treatment).

6. CONCLUSIONS

The analytical stress analysis of thick walled cylinder subjected to internal pressure 20MPa for cylinder (without heat treatment). The von mises criterion is chosen and validation of analytical results is done with finite element analysis circumferential and von mises stress with fixed boundary condition. The result showed good agreement with percentage error less than 1%.

The cylinder is heat treated to temperature between 800^0C to 850^0C. Further the cylinder (with heat treatment) is subjected to internal pressures, circumferential and von mises stresses are obtained. The results of cylinder (with heat treatment) are compared with cylinder (without heat treatment) for same internal pressures. This cylinder showed better results with maximum pressure 110MPa.

Thickness is reduced by 5mm of cylinder (with heat treatment) subjected to similar internal pressures. The maximum pressure capacity of cylinder is 90MPa which is better than cylinder (without heat treatment) with same internal pressures.

The modal analysis of thickness reduced cylinder (with heat treatment) is done with fixed boundary conditions. The finite element analysis natural frequencies are compared with analytical natural frequencies and result is in good agreement with percentage error less than 3%. The working natural frequency range is 21.51Hz to 45.69Hz. The working natural frequencies are compared with table 6. Hence there is no resonance condition for thickness reduced cylinder (with heat treatment).

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