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HYDRO TESTING AND FINITE ELEMENT ANALYSIS OF HIGH PRESSURE CAST CYLINDER FOR RECIPROCATING COMPRESSOR

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ABSTRACT

Compressed air is used for multiple operations in industries. Multistage compressors play a vital role for supplying required compressed air at desired pressure. Reciprocating compressors are typically used where high pressure ratios required per stage without high flow rates, and the process fluid is relatively dry. In reciprocating compressor, cylinder subjected to internal pressure due which stresses like resultant stresses, von misses stresses and deformation occur at cylinder. This work describes stress analysis of SG Iron cylinder for high pressure application to determine whether stresses produced in cylinder are within limit of allowable stress. Also the Hydraulic test has been experimented on cylinder to determine strength and durability over period of time. Cost of cast cylinder is also compared with Forged Cylinder. A finite element model is built and stress analysis of this cylinder is carried by using ANSYS.

***Keywords:* ANSYS, Creo 3.0., Cylinder, Material Properties, Stress Analysis.**

I.INTRODUCTION

Compressor is a device which is used to increase the pressure of a fluid on the expense of work energy supplied. Compressors are often some of the most critical and expensive systems at a production facility, and deserve special attention. Gas transmission pipelines, petrochemical plants, refineries and many other industries all depend on this type of equipment. Various compressors are found in almost every industrial facility. The cylinder is a vital part of high pressure compressors. Cylinders are usually subjected to high pressure and temperatures which may be constant or cycling. It’s complex shape, further influenced by the fact that it is working under high pressure pulsating gaseous forces, often leads to cylinder failures due to sever non uniformity of stress distribution. With increasing demand from industrial processes for higher operating pressures and higher temperature, new technologies have been developed to handle the present day specialized requirements. Hence a precise structural analysis accounting all properties of material is needed in order to make a full use of load carrying capacity of material and ensure safety with respect to strength of cylinder.

There are three terms related to pressure- working pressure, design pressure and hydrostatic test pressure. The maximum working pressure is that which is permitted to cylinder in operation. It is the pressure required for the processes that are carried out inside the pressure vessel. The design pressure is the pressure used in design calculations for such quantities as the thickness and also in the design of other attachments like crankcase, cylinder covers. The design pressure is taken as 1.1 times the maximum working pressure. The cylinder is finally tested by hydro3static test. The hydrostatic test pressure is taken as1.5 times the maximum working pressure. For high pressures industries use cylinders made with forging process but for these process is having drawbacks like high production cost and high residual stresses, to overcome this problem instead of forging, casting process can use for manufacturing. By using casting we can reduce the cost of cylinder manufacturing process like machining time, material cost.

II.MATERIAL SELECTION

Table 1. Material Properties

Material	SG 400/15 IS1865 [11]
Young's Modulus	1.325e5 MPa
Poisson's Ratio	0.27
Ultimate Tensile Strength	400 N/mm^2
Proof Strength	(0.2%)= 250 N/mm^2
Density	7200 Kg/cm^2

SG Iron is selected for casting cylinder because of its mechanical properties like High Tensile Strength, High Compression Strength. For this cylinder SG 400/15 material is selected because it is having better corrosion resistant and also wear and heat resistant.

III.ANALYTICAL METHOD

Cylinders are usually subjected to high pressure and temperatures which may be constant or cycling. This cylinder is subjected to cyclic stresses. For calculating allowable stresses of this cylinder we use endurance limit criteria. So that ultimate tensile strength reduction factors are calculated as follows.

Endurance limit (S_e) = $K_a. K_b. K_c. K_d. K_e. K_f. S'_e$

Where ka represents the surface condition modification factor, kb represents the size modification factor, kc represents the load modification factor, kd represents the temperature modification factor, ke represents the reliability factor, kf represents any other miscellaneous effects, and S'_e is the endurance limit stress of a cylinder subjected to reversed bending stress.

1. Surface condition modification factor

$K_a = a.Sut^{b}$ (1)

$a = 2.70 \quad b = -0.265$

$K_a = 0.9205$

2. Size modification factor (2)

$K_b = 1$ (for axial loading)

3. Load modification factor (3)

$K_c = 0.85$ (Bending)

4. Temperature modification factor

$K_d = S_T / S_{RT}$ (4)

$K_d = 1$ for temp. 200 ^{0}c

5. Reliability factor

$K_e = 1 - 0.08\ Z_a$ (5)

For reliability 99% , $Z_a = 2.326$

$K_e = 1 - 0.08\ (2.326) = 0.814$

6. Other miscellaneous effect

$K_t = 1.5 \quad q = 1$

$K_f = q\ (K_t - 1) + 1$ (6)

= 0.5 +1

= 1.5

Stress concentration Factor $(1/k_f)$ = 0.666

7. Reduction Factor

$S_e = 0.9205*1*0.85*1*0.814*0.666*0.35*$ (7)

$S_e = 0.153$

Hence endurance limit at 200^0 c = Reduction factor * Sut (8)

Maximum allowable stress = 61.4MPa (8.9 ksi)

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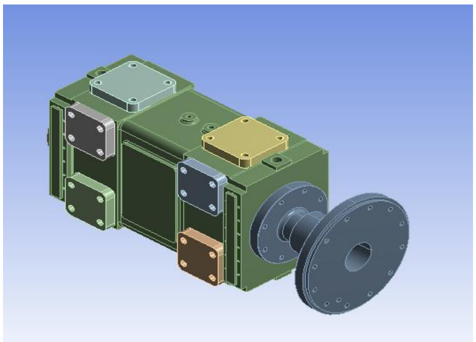
IV.FINITE ELEMENT ANALYSIS

4.1 3D Modeling and Meshing

While theoretically calculating stress values in a given mechanical components, we make assumption that element is uniform, there is no discontinuity, Stress concentration is not there, etc. In such a case we are not in a position to get accurate result. In our case the compressor cylinder geometry is complex composed of different cavities for suction of air, compression, cooling water. There are various features like holes, chamfer, and irregularity in geometry due to that it becomes essential for us to consider effect of these features into account. In ANSYS it's very difficult to model the part with parametric modeling as compared with the available modeling software such as CATIA and Creo. To create a 3D model of cylinder with all intricate geometric details Creo 3.0 software is used. HP SG Iron Cylinder is an assembly of following parts – 1. Cylinder Block 2. Intermediate Plate 3. Front End Cover The created 3D model of cylinder is as shown in figure (1).



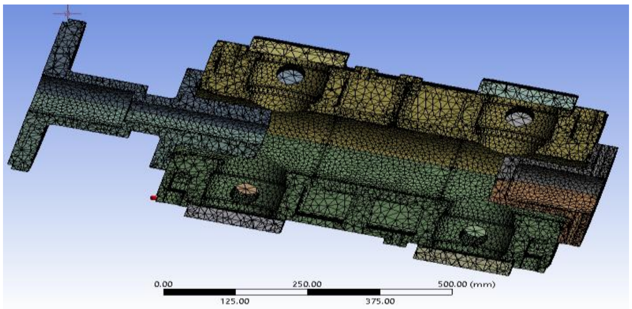


Fig.1. 3D model of hp cylinder

Fig.2. meshed hp sg iron cylinder

Created 3D model is saved in part.step file format Fig.1, as this file format is suitable during importing this model in ANSYS software. For meshing of HP SG Iron Cylinder we have implemented the adaptive mesh option in ANSYS Workbench and have chosen relevance centre as fine with relevance of 30 and smooth transition inflation in Fig.2. For proper mesh generation at the face and the edges we used the option of face and edge sizing.

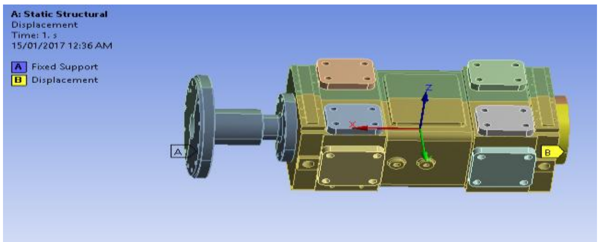
Table 2. Meshing details of HP SG Iron cylinder

1	Relevance Centre	Fine
2	Relevance	30
3	Inflation option	Smooth Transition
4	Element size	10 mm
5	Number of elements	237882
6	Number of nodes	408177

4.2 Boundary Conditions

In our case the cylinder is the assembly of Cylinder block, Intermediate plate, and Front end cover. In this for simplicity we have carried out analysis of whole assembly. Resultant stress due to contact and inside delivery pressure is applied. Pressure inside the cylinder keeps on varying from suction pressure to delivery pressure. For safety we have considered maximum pressure differential condition for analysis. All pressures applied are normal to the surface.

In Fig.3. Fixed support is provided at the both ends of cylinder which is connected to distance piece and cover plate. Cylinder is subjected to air and water pressure. Air pressure is exerted on cylinder internally which is 49 kg/cm^2 And pressure exerted due to circulating cooling water is 11 kg/cm^2 shown in Fig 4.



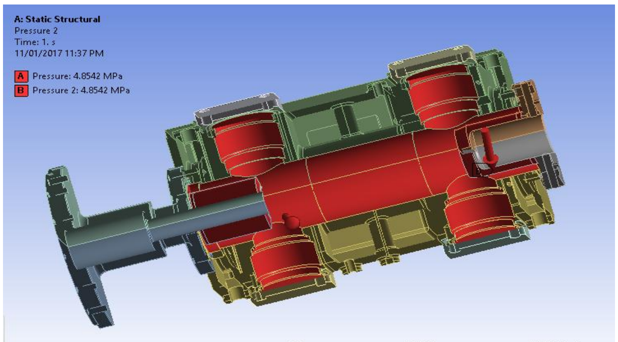
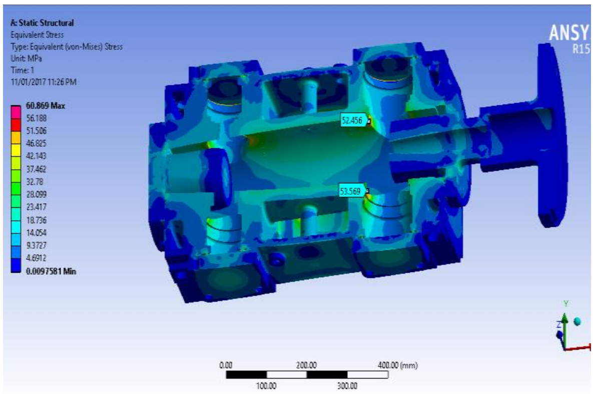


Fig.3. boundary condition for hp sg iron cylinder Fig.4.loading condition (water and air pressure)

4.3 Post processing of Results

Simple mathematical model can be solved analytically, but more complex model requires use of numerical methods. FEA is one the numerical method used to solve complex mathematical problem. The entire solution domain must be discretized into simply shaped sub domain called as elements. ANSYS Workbench software is used for analysis of SG Iron cylinder, which is based on the FEA method. In Fig.5 Von Misses stress for HP cast cylinder is in range of 0.0097581 N/mm^2 to 60.869 N/mm^2 from analysis point of view Von misses stress in cylinder bore is critical as this part subjected to maximum pressure differential. Location of Maximum Von Misses Stress is at the circumference of delivery valve of cylinder which is 54.74 MPa as in Fig.6. Maximum stress has occurred at plates at the waterside pressure. Location of minimum von misses stress is at end of cylinder body.



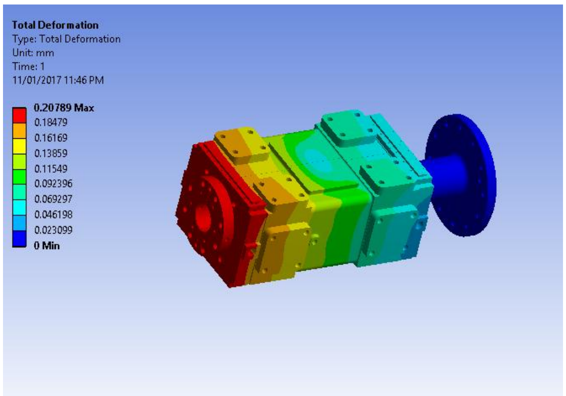


Fig.5.maximum principal stress for hp SG iron cylinder Fig.6. total deformation for hp sg iron cylinder

Total deformation is varying from 0 mm to 0.20789 mm. From analysis point of view total deformation is at outer side of the cylinder. The maximum deformation occurred at the plate of cylinder which is indicated by red color in Fig.6. Deformation at the intermediate plate is 0.2 mm which is less. Deformation is zero at front end cover.

V.HYDRO TESTING

Hydraulic testing is a way for pressure vessels such as plumbing's, pipelines, boilers, gas cylinders and fuel tanks to be tested for leakage and strength. The test involves filling the boat or piping system with a liquid, usually water that can be painted to apply pressure to the visual leak detection and specific test pressure. The pressure tightness can be tested by checking whether the supply valve is closed and whether there is a pressure loss. If the location of a leak contains a water colorant, it can be more easily identified visually. Durability is tested by measuring the continuous deformation of the container. Hydraulic testing is the most common method and best way for testing pressure vessels and pipelines. The use of this test helps protect the safety standards and durability of a ship over time. Newly manufactured parts are initially qualified by hydraulic testing as shown in Fig.7. It is very important to test pressure vessels for the transport and storage of gases as these vessels may explode under pressure.

5.1 Experimental Procedure

Hydraulic testing is carried out using the American Petrochemical Institute (API-618) standard. According to the API standard, the ship is filled with almost uncompressible, usually test or pressurized water or oil, and is inspected for leaks or permanent changes in some way. Red or fluorescent paints are added to make the leak easier to see. The test pressure is always higher than the operating pressure to give a safety factor. This safety factor is typically 166.666%, 143% or 150% of the working pressure designed, depending on the regulations applied.

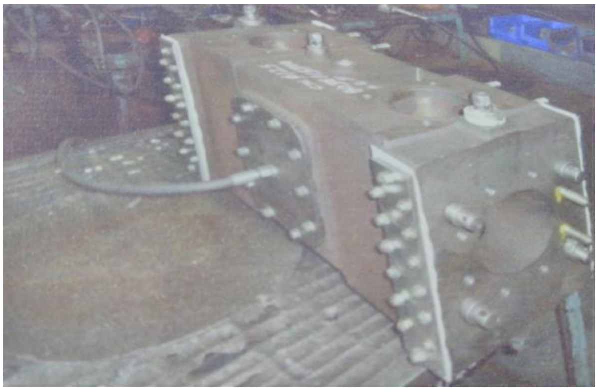


Fig.7. hydro testing set up

Fig.8. hydro testing pump

Water is often used because it is cheaper and it is readily available .Testing is often used because it is inculpable to the system which is to be tested as described in Fig.8. Hydraulic fluids and oil can be specified when water contamination can cause problems. These fluids are almost incompressible, so they need comparatively little work to develop high pressure, and therefore release a small amount of energy in the event of failure. If the container is empty, only a small volume will escape under high pressure. If the high-pressure gas expands with compressed volume, the explosion will occur and there is also a risk of personal injury. This is the risk you are designed to relieve the test.

5.2 HP SG Iron Cylinder Hydro Testing Details:

1. Fluid Used: water
2. Pressure Air Side: 74.5 kg/cm^2
3. Pressure Water Side: 11 kg/cm^2
4. Loading time: 30 Minutes
5. Result: No Leakages were found
6. .Motor used: 3HP
7. Pump Drive: Belt Drive
8. Plunger: Single Plunger
9. Pump (rpm): 350 (Electric Motor Driven)
10. Pressure: 0-211 Kg/cm^2

VI. COST ANALYSIS

In cost analysis of HP SG iron Cylinder, it contains material cost, fabrication cost. The cost of Hp SG Ion Cylinder is economical as compared to forged steel cylinder. Here we have compared cost of both cast and forged cylinder.

Table 3. Cost comparison of cylinder

Part	Forged Cylinder (INR)	SG Iron Cylinder (INR)
Forging Block	60000	-
Casting Cylinder	-	31500
19 Plates	4062	-
Welding	960	-
Total	**65022**	**31500**

1. 1. Material Saving : 33522 Rs. per cylinder
2. Saving in Machining (for 10 hrs): 6000 Rs.
3. Total Saving : 39522 Rs. per cylinder
4. Net saving (considering 60 pieces per annum) : 23.71 Lakhs

VII.CONCLUSION

SG 400/15 material is selected for manufacturing of cylinder which is having high tensile strength. The cost of manufacturing is less as compared to other manufacturing processes. It is clear from theoretical calculation and Finite Element Analysis that the high pressure SG Iron Cylinder is safe for given working parameters. During hydraulic test, no leakages were found. So that cylinder is safe over period of time. From cost analysis it is clear that the cost of HP Cast cylinder is much less than any other cylinders**.** In future we can also do thermal analysis for high pressure cylinder manufactured by casting.

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