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Design, Analysis & Weight Reduction of Piston of Refrigerator Compressor

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Abstract - *The refrigerator is a device used for cooling purpose. It is one of the home appliances using mechanical vapour compression cycle in its process. Performance of the systems become the main issue and many researches are still ongoing to evaluate and improve the efficiency of any used system. Refrigerator consist of various important part such as, compressor, condenser and evaporator. These all components play main role in efficiency of refrigerator. If such components are having the heavy system then it may decrease the overall efficiency of refrigerator as they consume the more amount of power. Hence in this project we are working on the piston of compressor in refrigerator. As we known that the compressor used in refrigerator is a reciprocating type. Connecting rod is the intermediate link between the piston and the crank shaft. And is responsible to transmit the push and pull from the piston pin to crank pin, thus converting the reciprocating motion of the piston to rotary motion of the crank. The loads acting on this piston and crank shaft are cyclic in nature. Further in this project we will use the modelling and analysis software and ensure the weight reduction and optimisation of piston. The modelling software is CATIA and analysis software is ANSYS.*

***Key Words*: Optimisation, Pressure vessel, Compressor, Efficiency, Piston**

1.INTRODUCTION

The refrigerator is used for cooling purpose. The domestic refrigerator contains the sealed compressor. This compressor is sealed because to avoid the noise. It also consists of crank shaft, connecting rod, piston, etc. In this project the optimization of piston and will be done. This will decrease the weight of the system and also increase the efficiency of the system. Due to the low weight of system like Shell, piston and crank shaft the power consumption of system will be decrease and it will conclude on the increase in the efficiency of the system. This project is unique and very less work is being done on refrigerator compressor.

1.1 Technical Specifications of compressor shell used for study

Thus, Specification of the compressor shell are tabulated below:

Sr No.	Parameters	Values
1	Length	15 mm
2	Diameter	10 mm
3	Thickness	3 mm
4	Power (For the same model in Refrigerator)	163 W
Material Specifications Al Alloys		
5	Density	2800 kg/m3
6	Tensile strength, Ultimate	900 MPa
7	Tensile Strength, Yield	600 MPa
8	Melting Point	1370-1430°C

Table 1.1 – Specifications of existing piston

Fig. 1.1 – Photographic view of existing piston

2. LITERATURE REVIEW

[1] Ashwani Kumar, Shaik Imran Behmad, Pravin P Patil et al The main objective of this research work is to investigate and analyse the stress distribution of piston at actual engine condition. This research work suggests a new type of SiC reinforced ZrB2 composite material that can sustain at higher temperature (1680 K) and pressure (18 MPa).

[2] Jatender Datta, Dr. Sahib Sartaj Singh et al The paper shows the behavior of piston made of Carbon Graphite and Aluminum Alloy 2618 applied heat power value of 200 Watt. The result of Temperature distribution and resultant temperature gradient was found and the main motive is to find the comparison between both of materials of piston.

[3] K Ramesh Babu, G Guru Mahesh and G Harinath Gowd et al In this paper the authors have studied the variation of Isotherms and heat flux with respect to radius, height of piston, liner, cylinder head and thermal analysis. First thermal analysis was done and analyzed the temperature distribution over the convectional engine and copper coated convectional engine. In the second stage structural analysis was carried out using the thermal loads obtained in the first stage. Three different types of materials were taken for analysis.

[4] Dilip Kumar Sonar, Madhura Chattopadhyay et al The authors had studied a piston which is designed using CATIA V5R20 software. Complete design is imported to ANSYS 14.5 software then analysis is performed. Aluminium alloy has been selected for structural and thermal analysis of piston. Results are shown and a comparison is made to find the most suited design.

3. PROBLEM DEFINITION AND METHODOLOGY

A. Problem Definition

We have to reduce the overall weight of the system. The load bearing components like piston and crank shaft are used in refrigeration and are also heavy in assembly. The Shell of the compressor is also heavy. This heavy component decreases the overall efficiency. Due to the heavy weight components the power consumption of system increases and thus it is not good as it increases the running cost of the system. The material requirement also increases as the component is heavy. Hence to overcome all this problem this system should be redesign for optimisation.

B. Objectives

1. To study the current system in detail with its specification and all required considerations.
2. To design & optimize the existing material for compressor shell and piston.
3. To optimize system according to one of the following:
   a) Changing dimensions of system and keeping material same as it is.
   b) Keeping same dimensions and changing material of components.
   c) Changing both material as well as dimensions of component.
4. Modelling of new design with help of CATIA software.
5. To analyse the optimized components to study the stress on the system.
6. To compare existing & optimized piston & shell of compressor.

C. Methodology

The following are important steps for completion of objectives -

1. Check design of various existing components in compressor.

2. Creating geometric model and finite element model of existing components of compressor using CATIA software.

3. Analysis of piston of compressor by using ANSYS software.

4. Optimization of compressor assembly for weight reduction.

5. Comparison between existing and optimized design.

4. DESIGN & ANALYSIS OF EXISTING COMPRESSOR PISTON

Mechanical Efficiency, $\eta = B.P / I.P$
$B.P = 163$ W
$I.P = 163 / 0.8 = 203.75$ W
$I.P = P \times A \times L \times N / 2$
$203.75 = P \times 0.112 \times 0.015 \times 1500/ 2 \times 60$
$P = 203.75 \times 2 \times 60 / 0.112 \times 0.015 \times 1500$
$= 9.70$ Mpa
Max pressure $= 10 \times P$
$= 10 \times 9.70$
$= 97.02$ MPa
Assuming piston material as Aluminum Alloy Steel
Permissible Stress of aluminum alloys is Sut = 900 Mpa
Considering uniformly distributed load & FOS as 2
We have to calculate actual FOS for pressure vessel.
Allowable Stress (σall) = Sut / Fs
$= 900/2$
$= 450$ Mpa.
According to Grashoff's formula
Thickness of piston
$Tc = D \sqrt{(3 \times Pmax / 16 \times \sigma t)}$
$3 = 10 \sqrt{3 \times 97.02 / 16 \times \sigma t}$
$\sigma t = 289$ Mpa

Thus, there is scope to change the material and optimize the system.

Density = Mass/ Volume

Volume of piston = $\prod \times h\ (r_1^2 - r_2^2) + \prod \times r_2 \times t$

$= \prod \times 0.015\ (0.005^2 - 0.00375^2) + \prod \times 0.00375 \times 0.0025$

$= 2.99527E\text{-}05\ m^3$

mass of piston = $V \times \rho$

= 0.083 Kg

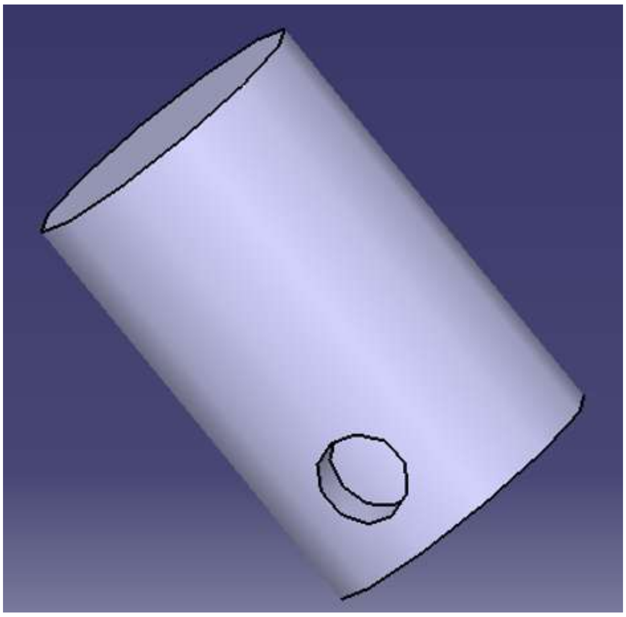

Fig. 4.1 – Geometric model of piston

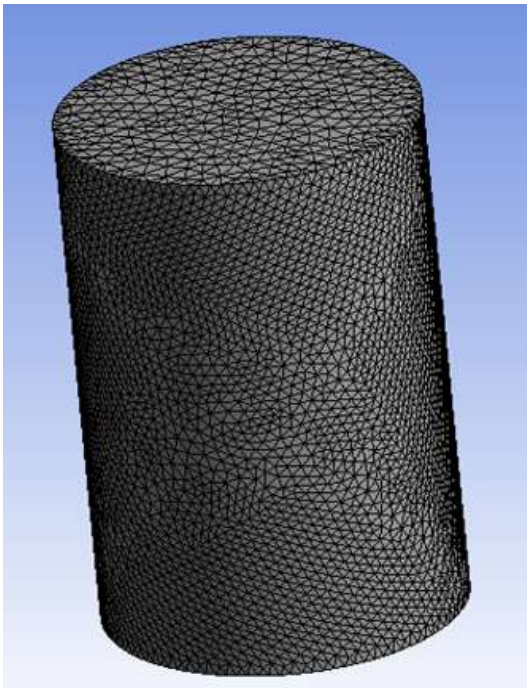

Fig. 4.2 – Meshing of piston

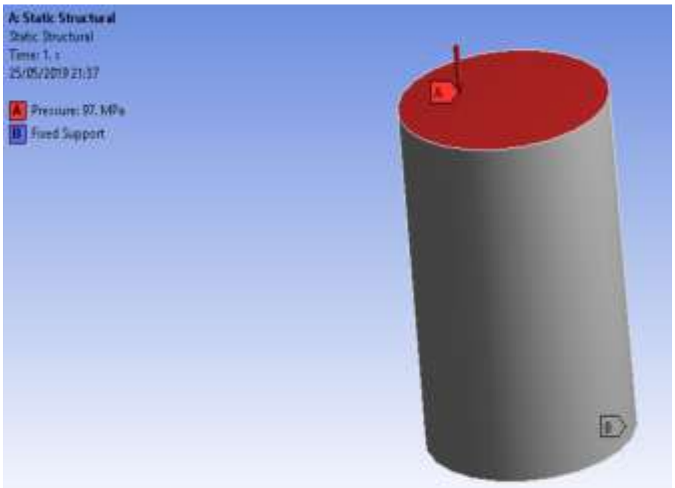

Fig. 4.3 – Boundary conditions for piston

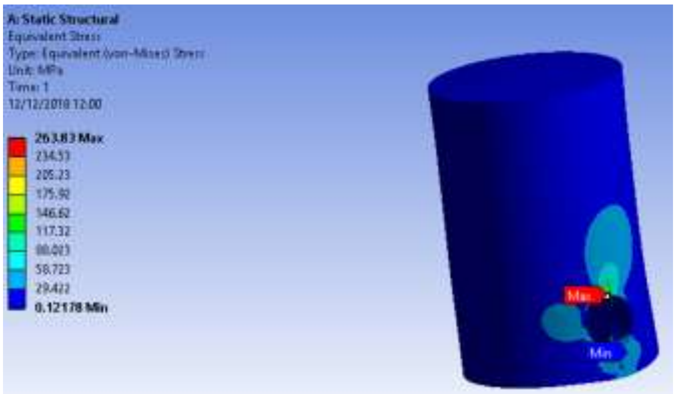

Fig. 4.4 – Stress analysis of piston

5. DESIGN & ANALYSIS OF OPTIMIZED SHELL

Mechanical Efficiency, η = B.P / I.P

B.P = 163 W

I.P = 163 / 0.8 = 203.75 W

I.P = P × A × L × N / 2

203.75 = P × 0.112 × 0.015 × 1500/ 2 × 60

P = 203.75 × 2 × 60 / 0.112 × 0.015 × 1500

= 9.70 Mpa

Max pressure = 10 × P

= 10 × 9.70

= 97.02 Mpa

Assuming piston material as Aluminum Alloy Steel

Permissible Stress of aluminum alloys is Sut = 900 Mpa

Considering uniformly distributed load & FOS as 2

We have to calculate actual FOS for pressure vessel.

Allowable Stress (σall) = Syt / Fs

= 900/2

= 450 Mpa.

According to Grashoff's formula

Iteration 1:

Consider the thickness of the piston as 2 mm,
Thus, the calculations are as follow
Thickness of piston
$Tc = D \sqrt{(3 \times Pmax / 16 \times \sigma t)}$
$2 = 10 \sqrt{3 \times 97.02 / 16 \times \sigma t}$
$\sigma t = 450$ Mpa
thus, if we compare the actual stress with allowable stress then the above design is safe.
Weight of Piston
Density = Mass/ Volume
Volume of piston $= \prod \times h\ (r_1^2 - r_2^2) + \prod \times r_2 \times t$
$= \prod \times 0.015\ (0.005^2 - 0.004^2) + \prod \times 0.004 \times 0.002$
$= 2.55439E\text{-}05\ m^3$

Mass of piston $= V \times \rho$
$= 0.071523$ Kg

If we compare the weight reduction of above design with existing one then we are achieving weight reduction. It is up to 12 grams and 15 % weight reduced.

Same like above 3 such iterations are carried on. The following table shows the iterations:

Thick	D2	D1	Stress		Weight	Diff.
0.0025	0.0075	0.01	291.06	Safe	0.0838	0
0.002	0.008	0.01	450.78	Safe	0.0715	0.0123
0.0015	0.0085	0.01	808.5	Not Safe	0.0569	0.0269
0.001	0.009	0.01	1819.12	Not Safe	0.0401	0.0436

Table 5.1 - Iteration table for optimized piston

After studying the above system, we can have the optimum thickness as 2 mm which is having a stress of 450 Mpa in it and weight reduction of 12 grams.

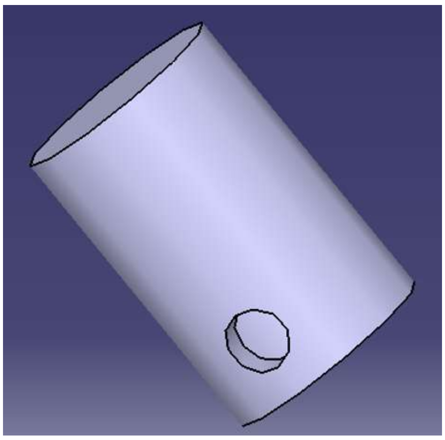

Fig. 5.1 – Geometric model of optimized piston

Fig. 5.2 – Meshing of optimized piston

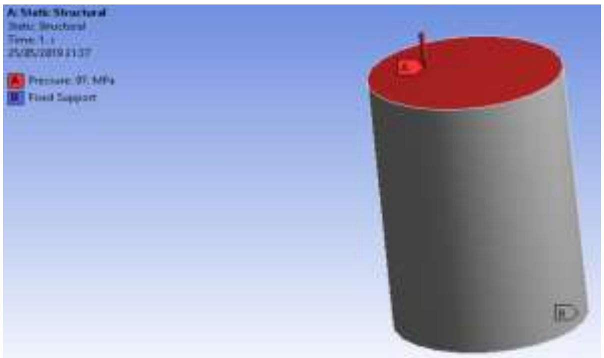

Fig. 5.3 – Boundary conditions for optimized piston

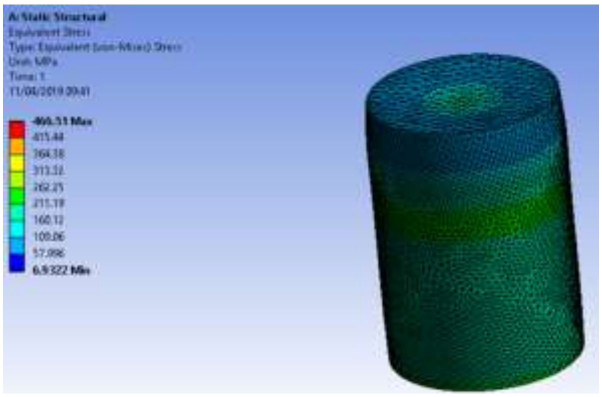

Fig. 5.4 – Stress analysis of optimized piston

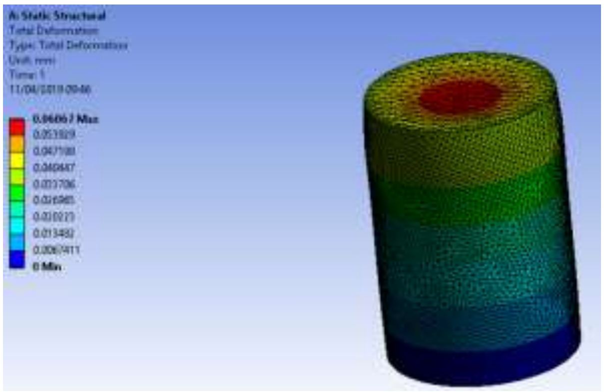

Fig. 5.5 – Deformation analysis of optimized piston

6. RESULT AND DISCUSSIONS

After studying the above system, we can have the optimum thickness as 2 mm which is having a stress of 450 Mpa in it and weight reduction of 12 grams. Total weight of piston is 83 grams, actually the system is small and hence the weight of piston is less. If we think according to the % of weight reduction then 14.67 % of weight reduction was achieved. This weight reduction is very less but it is important according to the total system optimization.

Thickness = 2 mm

Outer Diameter = 148 mm

Inner diameter = 144 mm

Total weight reduction of 12 grams was obtained. It means total optimization of 14.67 % is achieved.

Comparison of Stress on basis of Theoretical and analytical results.

Analysis of Piston was carried out with use of Ansys Software. Results of stress was calculated and Comparison of both design calculations and Ansys was tabulated below:

Dimensions	Design calculations Results	Ansys Results
Thickness = 2 mm Outer Diameter = 148 mm Inner diameter = 144 mm	**Stress 450 Mpa**	**Stress 466.5 Mpa**

Table 6.1 - Theoretical & analytical comparison of piston

7. CONCLUSION

Optimization was achieved on piston of compressor. Some of components of system like motor assembly and vents are kept as it is due to its proper design. Design calculations, analysis model, and optimized system are compared on stress basis. The weight reduction achieved on piston does not affect the load carrying capacity of system. **12 grams** weight reduction is achieved by optimize design than existing design. **14.67 % of material was saved** on optimized system than existing system which further save cost of system.

8. FUTURE SCOPE

- The use of composite materials can be done for more weight reduction. This weight reduction can also bring a lightest compressor.
- The scotch yoke mechanism is used to get rotary motion from the piston, this system can be optimised.
- Use of heat treatments can also increase the surface strength and thus again thickness can be reduced.
- Vibration analysis of whole system can be increase working capacity of system

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