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Fatigue Analysis of Air compressor piston

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Abstract-The piston is a key component of a engine which always keep on reciprocating under certain pressure force and transmitts its motion to crankshaft hence, it is inevitable to study its fatigue behaviour. In the present work, fatigue failure analysis of an air compressor piston of Aluminum Alloy has been done using Goodman crietria for alternating stresses. The piston model has been generated in Catia and then fatigue analysis has been done in Ansys Workbench. From the results, the critical points under cyclic loading has been pridicted. Further the results for alternating stresses in various parts alongwith fatigue life of the piston has been attained which shows piston can work upto 8.13 e6 no. of cycles without any sign of failure.

Keywords – Piston, Ansys, Fatigue, Safety Factor.

I. Introduction

The majority of component designs involve parts subjected to fluctuating or cyclic loads. Such loading induces fluctuating or cyclic stresses that often result in failure by fatigue. About 95% of all structural failures occur through a fatigue mechanism.

The damage done during the fatigue process is cumulative and generally unrecoverable, due to the following:

- It is nearly impossible to detect any progressive changes in material behavior during the fatigue process, so failures often occur without warning.
- Periods of rest, with the fatigue stress removed, do not lead to any measurable healing or recovery.

A piston is the most important component of reciprocating engines, reciprocating pumps, air/gas compressors and pneumatic cylinders, among other similar mechanisms or better to say it as heart of the engine because it transfers the reciprocating motion i.e. power to the crank obtained during power stroke. It is continuously subjected to reciprocating motion (alternating loads) under certain gas pressure hence it becomes obligatory to do its fatigue failure analysis.

Air compressors works[4] on the principle of Boyle’s law i.e. Pressure and Volume are inversely proportional to each other. The most common way to achieve this is with the help of a reciprocating piston. Each reciprocating piston compressor has a crankshaft, connecting rod, a piston, cylinder, and a valve head. Air compressors are usually powered by electricity or gas depending on the model. Most compressors also have a tank, which is there to store compressed air for the purpose of keeping the air pressure within a set range while powering various air tools.

Fatigue life analyses of construction elements performed with finite element method can reduce or even totally eliminate the costs resulting from repeated redesigning or withdrawing defective products. It is also possible to significantly reduce cost of tests, which are performed before prototype production.

M. R. Ayatollahi [1] have shown that to have an efficient and long lasting diesel engine, we have to know its High Cycle Fatigue (HCF) and Low Cycle Fatigue (LCF) life. The HCF is calculated by using ANSYS, and the stress concertation and notch effects are also noted. The LCF is calculated through series of different methods and then their results are compared to each other. W. Torbacki [2] have conducted a research to study the strength and fatigue limit of piston type hydraulic cylinders is computed by Finite Element Method (FEM) and Fatigue Life Prediction Method. It localizes the prone to damage zones and Wohler fatigue graph for variable values of pressure and stress concentration factor were made. Thomas O. Mbuya [3] ran an experiment in which a practical simulation is observed to monitor fatigue crack initiation and S-N fatigue behavior of hipped models of two pistons after overaging at 260 C for 100 hours. it was concluded that porposity can significantly affect fatigue performance if there is a difference in porposity of the unhipped and hipped models. Fatigue cracking was also formed mainly from the intermetallic particles. K.Kadambanathan [4] has studied fatigue life and critical locations at each node of piston ring under four loading conditions and also calculate the stresses using finite element model. Along with this, damages initiated at the crown, ring grooves, pin hole sand skirt are assessed. A compendium of case studies of fatigue-damaged pistons is presented. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work

II. Methodology

Fatigue is the failure of a component as a result of cyclic stress. The failure occurs in three phases: crack initiation, crack propagation, and catastrophic overload failure. The duration of each of these three phases depends on many factors including fundamental raw material characteristics, magnitude and orientation of applied stresses, processing history, etc. Fatigue failures often result from applied stress levels significantly below those necessary to cause static failure.Fatigue failures are typically characterized as either low-cycle (<1,000 cycles) or high-cycle (>1,000 cycles).

$$\sigma_{Mean} = \frac{\sigma_{\max} + \sigma_{min}}{2}$$

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{min}}{2}$$

$$\Delta\sigma = \sigma_{max} - \sigma_{min}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

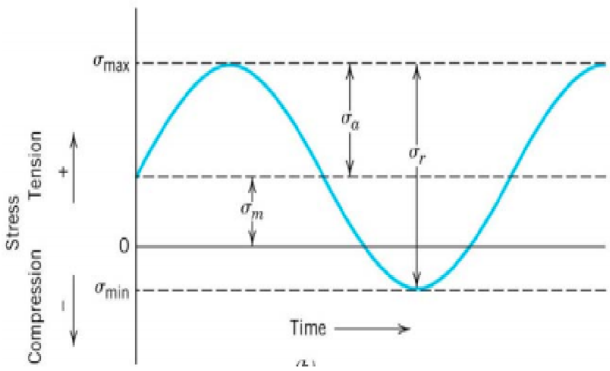

Fig. 1- Alternating Stress

Fatigue life represents the period or no. of cycles for which component works without failure. Two approaches are used for calculating fatigue life which are as following -

i) Stress-Life Approach

(a) Load amplitudes are predictable and consistent over the life of the part (b) Stress-based model - determine the fatigue strength and/or endurance limit (c) Keep the cyclic stress below the limit S

ii) Strain-Life Approach

(a) Gives a reasonably accurate picture of the crack-initiation stage (b) Accounts for cumulative damage due to variations in the cyclic load (c) Combinations of fatigue loading and high temperature are better handled by this method (d) LCF, finite-life problems where stresses are high enough to cause local yielding (e) Most complicated to use

Goodman Line is based on Ultimate strength (σ_u) and σ_n -

$$\sigma_a/\sigma_n + \sigma_m/\sigma_u = 1$$

Factors of Safety (FS):-

$$\frac{\sigma_a}{\sigma_n} + \frac{\sigma_m}{\sigma_u} = \frac{1}{FS}$$

III. Input Parameters

Material Properties

Aluminium Alloy having properties as shown in the below table has been used for the present work.

Sr. No.	Properties	Values
1	Density	2.77e-006 kg mm^-3
2	Coefficient of Thermal Expansion	2.3e-005 C^-1
3	Specific Heat	8.75e+005 mJ kg^-1 C^-1
4	Compressive Yield Strength	280 MPa
5	Tensile Yield Strength	280 MPa
6	Tensile Ultimate Strength	310 MPa

IV. Boundary Conditions

Applying boundary condition is the most significant part of preprocessing step in an Finite element problem. Gas pressure of 3.18 Mpa has been applied on the piston head and Cylindrical support has been given at the piston pin position as shown in the fig. - .

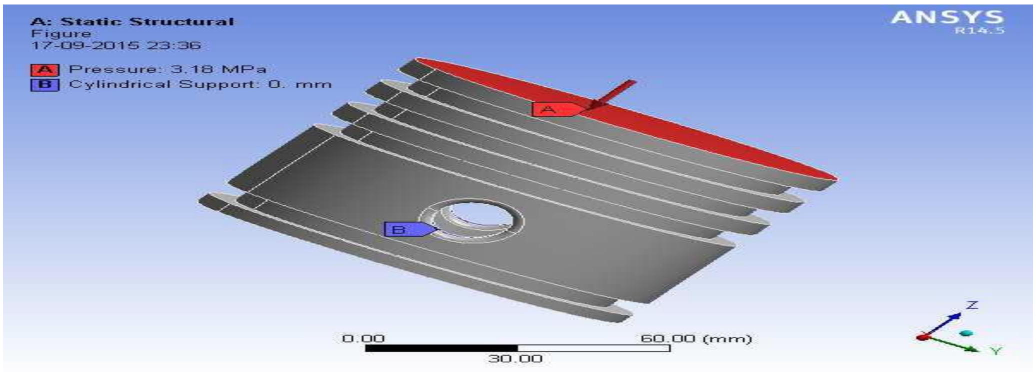

Fig. 2- Boundary Conditions

V. Results & Discussions

After conducting simulation important results have been observed which are shown in the following figs. The fig.3 - represents the fatigue life of the piston under prescribed boundary condition and fluctuating loads. From it can be predicted that the piston has minimum fatigue life of 8.1355 e6 i.e. It will work atleast for these no. of cycles without any failure.

The fig. 4- represents the factor of safety for the piston. From this result, the region which requires more safety factor can be predicted.

The fig. 5- represents the equivalent alternating stresses which get induced in the piston due to application of fluctuating loads.

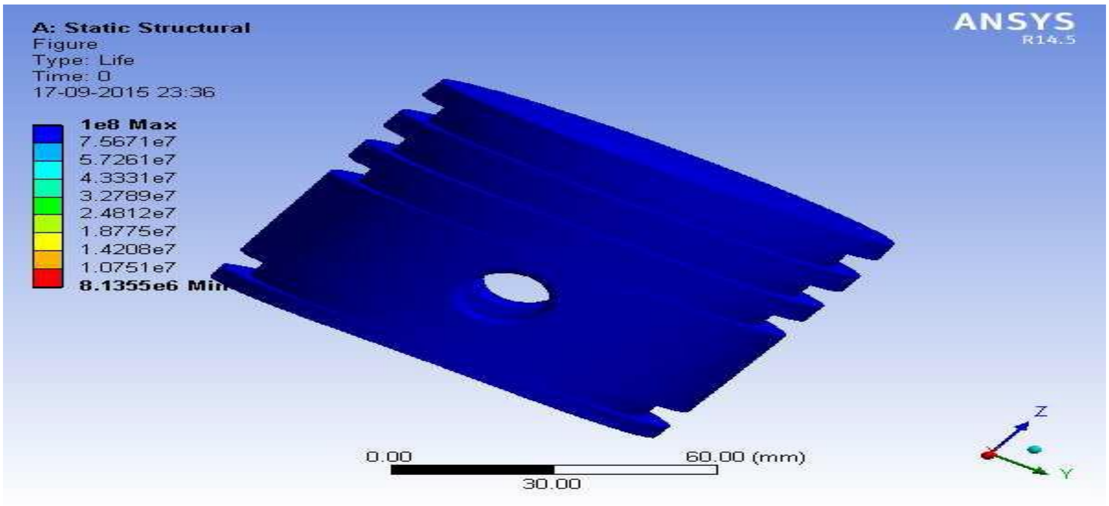

Fig.3 – Life of piston under applied boundary conditions

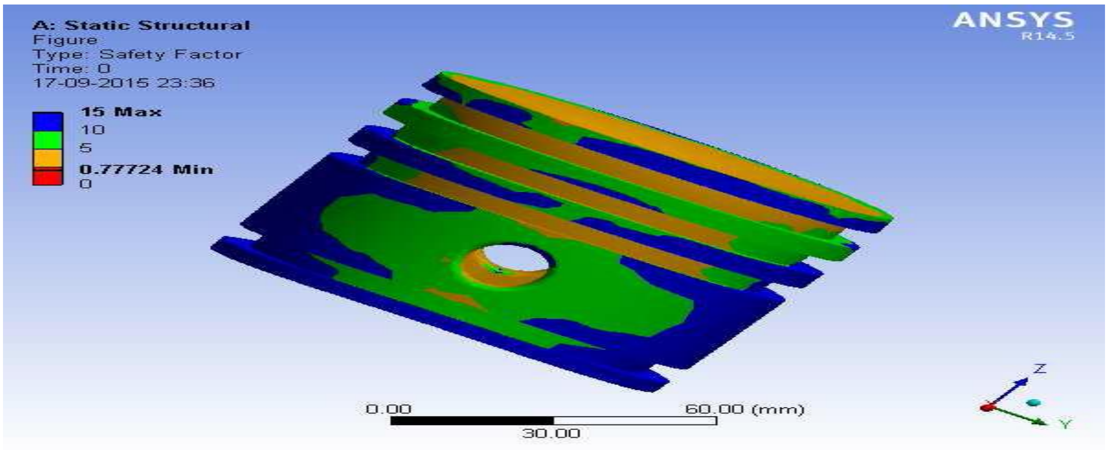

Fig.4 – Safety factor

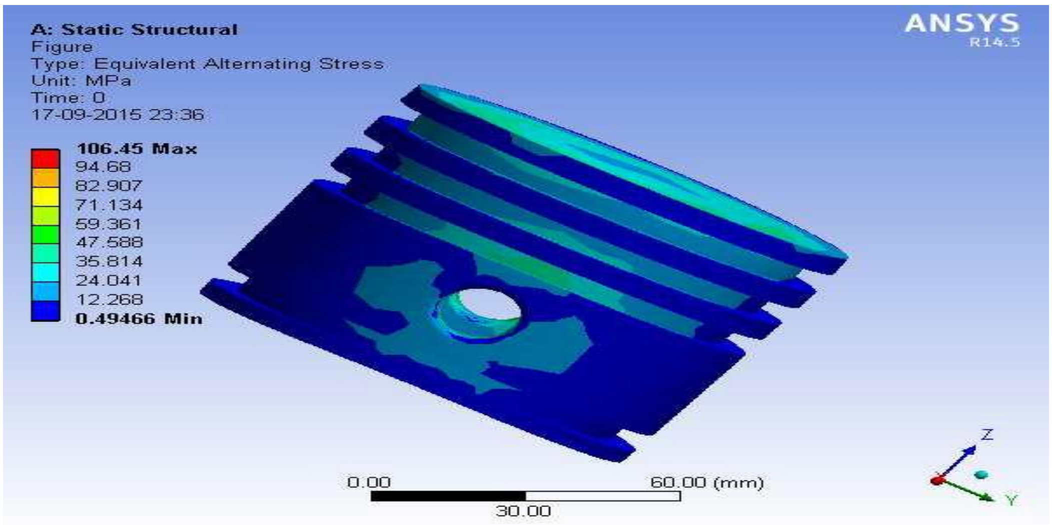

Fig.5 – Equivalent alternating stresses in the piston

VI. Conclusions

From the above work conducted in this paper it can be concluded that the air compressor piston of Aluminium Alloy will work satisfactorily for 8.1355 e6 no. of cycles without any failure under fluctuating loads (for Goodman crietria). There are some regions of piston where high safety factor has to be given for its safe and smooth functioning. Also the points of severe equivalent alternating stress can be easily observed.

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