Pitting Action Due to Bubble Formation in the Cooling Fluid of a Piston Liner

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ABSTRACT

During the reciprocation motion of the piston in the cylinder, the piston exerts small amount of forces on the piston skirt due to the taper in the piston design. These forces tend to develop deflections on the cylinder liner. Because of these deflections there is every possibility of disturbance in the coolant around the cylinder liner. Because of this reason bubbles are formed and destroyed in the coolant. These bubbles are also formed due to excessive harmonic vibrations of the engine and also by loosely fitted liners. The continuous formation and destruction of bubbles in the cylinder liner coolant releases energy which will attack the cylinder liner and pitting action is caused. Because of this pitting action the life of the cylinder liner decreases.

In this project study of these forces and vibrations are done using CAD/CAE softwares. The main objective of this project is to study the presence of cavitation and find the possible ways of increasing the life of the engine components. Modal analysis followed by harmonic analysis is carried out in the frequency range of 0-100Hz.The thermal loads applied from the combustion chamber and fluid structure interaction is also considered for the analysis. The presence of cavitation is shown as negative pressure in the analysis. A model has been built out using Modeling software UNIGRAPHICS NX.Finite Element Analysis software Ansys is used to performharmonic analysis. The pressure distribution in the cylinder liner is plotted and discussed.

FINITE ELEMENT ANALYSIS

In this paper, A model to plot pressure distribution in the cylinder liner is carried out using CAD software, with the help of Finite Element Analysis, harmonic analysis and Fluid Structure Interaction Analysis is carried out. Some important results have been shown with the negative pressures which shows the presence of cavitation in the cylinder liner surface, stressing the importance of improving the piston and cylinder liner design. To show the presence of cavitation a coupled field analysis is done to transfer the temperature distribution on the liner structure. The analysis is then followed by harmonic analysis with fluid structure interaction (FSI) in the frequency range of 0-100Hz.

METHODOLOGY:

Create the 3D model of the cylinder liner in UNIGRAPHICS NX. Perform Modal analysis on the cylinder liner to calculate the natural frequencies in the frequency range of 0-100Hz.Perform thermal analysis on the cylinder liner to find the temperature distribution on the liner.The temperature distribution from the thermal analysis was applied as a body load on the cylinder liner structure.Harmonic analysis was carried on the cylinder liner with fluid structure interaction in the frequency range of 0-100Hz to check for the presence of cavitation.Plot displacements and pressure variations along the liner to find the cavitation in the fluid region(coolant)

3D Modeling

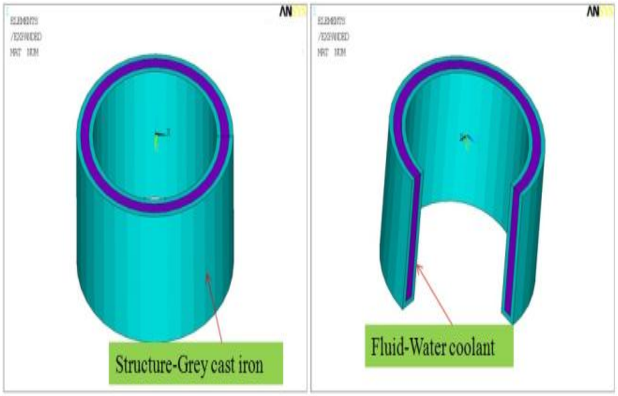

Fig.1.3D model of the cylinder liner used for analysis

THERMAL PROPERTIES OF THE STRUCTURE IN S.I UNITS

Specific heat = 547 J/kg-K

Thermal conductivity = 80 W/m·K

Boundary conditions for thermal analysis:

A temperature of 473k and convection with film coefficient of 16 and bulk temperature of 303k is applied on the lower end of the structure as shown in the following figure.

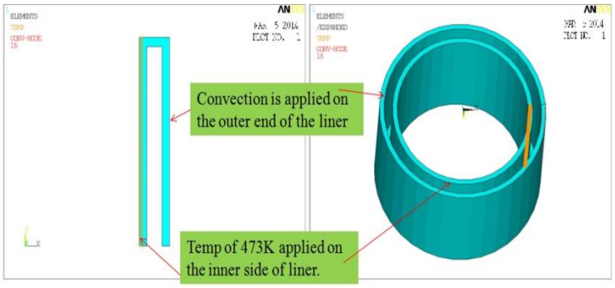

Fig.2. Boundary conditions applied on the cylinder liner for thermal analysis

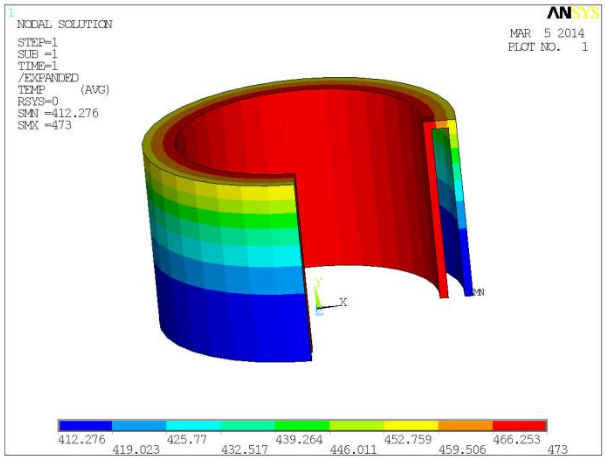

Fig.3.Temperature distribution on the cylinder liner along the thickness for thermal analysis

Results from thermal analysis: At the end of thermal analysis the temperature variation is observed to be between 412k and 473k as shown in the figure above.

Modal Analysis:

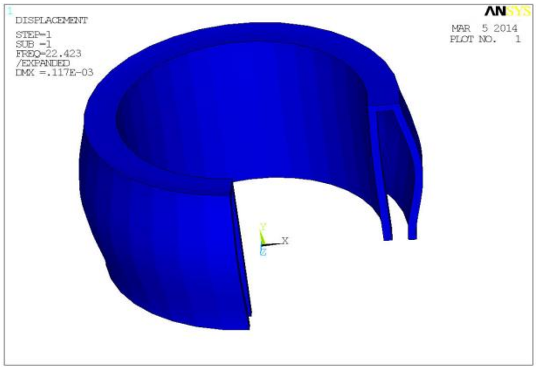

Fig.4 mode shape @ 22.4Hz

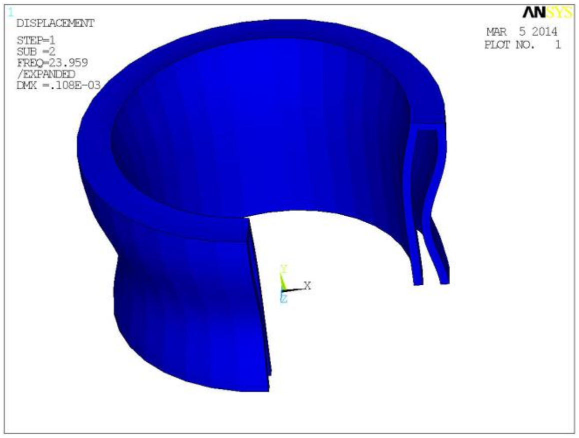

Fig.5mode shape @ 23.9Hz

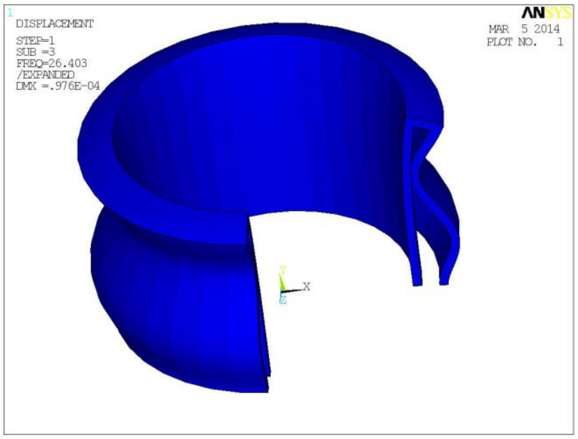

Fig.6 mode shape @ 26.4Hz

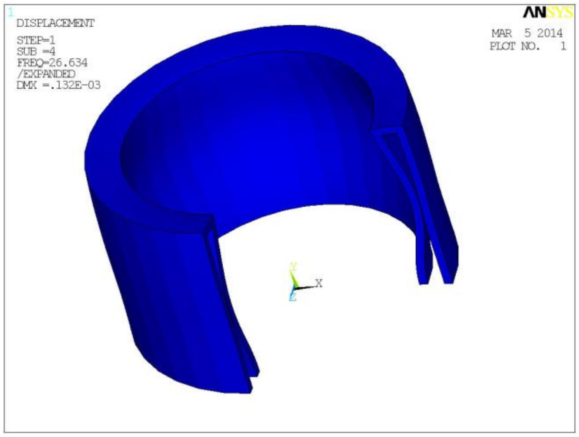

Fig.7mode shape @ 26.6Hz

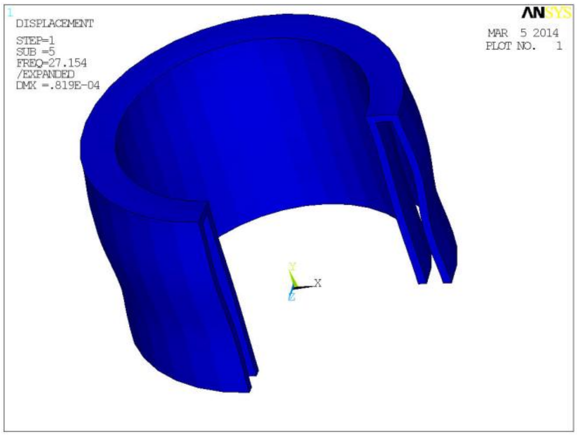

Fig.8 mode shape @ 27.1Hz

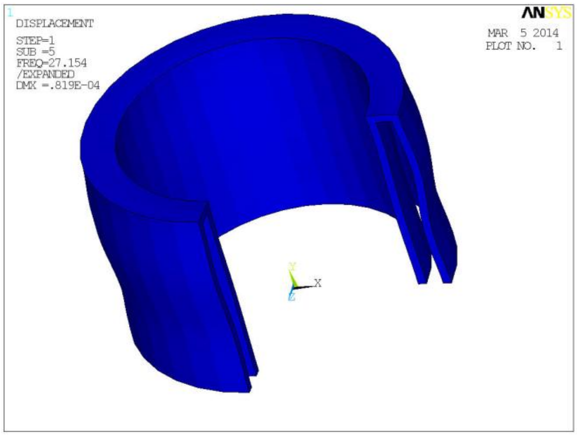

Fig.9mode shape @ 29.1Hz

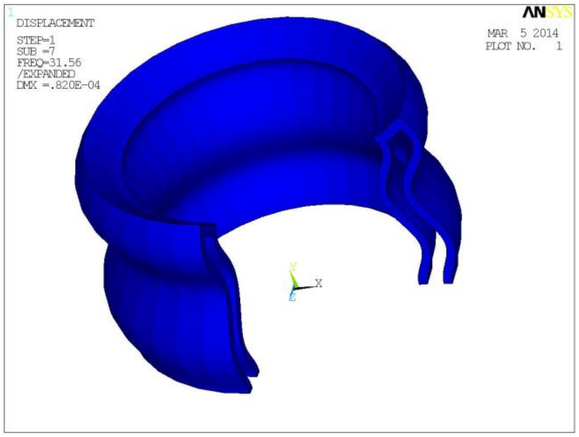

Fig.10 mode shape @ 31.5Hz

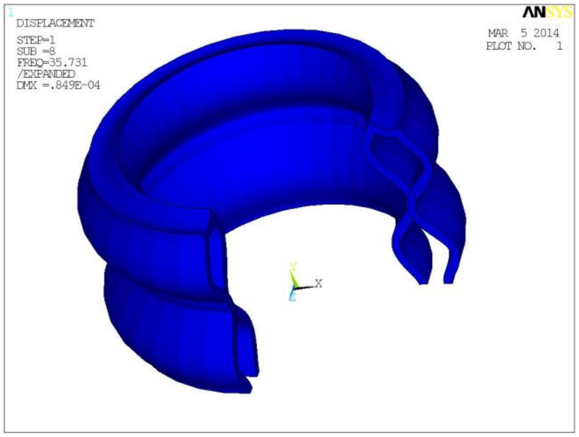

Fig.11 mode shape @ 35.7Hz

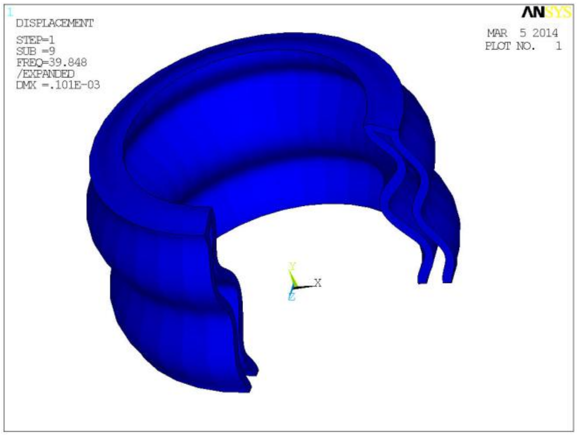

Fig.12 mode shape @ 39.8Hz

From the modal analysis it is observed that there exists 17 frequencies in the frequency range of 0-100Hz.However the maximum operating speed of the engine is 2000rpm.That means the maximum operating frequency is 2000/60=33.3Hz.So harmonic analysis has been carried out in the frequency range of 0-40Hz by applying the operating loads and efforts are made to show the presence of cavities. The presence of cavities is shown by the presence of negative pressure.

Before we move to Analysis using FLUID-STRUCTURE Interaction we replace the thermal element Quad4node 55 with structural element Quad4node 42 with the same dimensions and similar mesh. The material properties are also changed as per the structural requirements of the harmonic analysis.

Material properties of the structure and fluid used for harmonic analysis in S.I units.

Grey cast iron

Young's modulus = 2E11 N/m^2

Poisons ratio = 0.3

Density = 7850 kg/m^3

Fluid properties in S.I units

Water

Density of water = 1000 kg/m^3

Sonic velocity = 1555 m/s

Impedance = Density x Sonic Velocity = 1000 x 1555

Admittance = 1

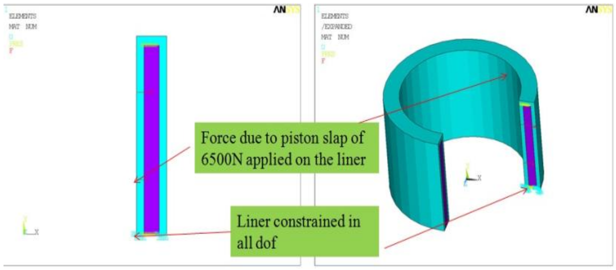

Fig.13 Boundary conditions and Loading applied on the liner with fluid inside

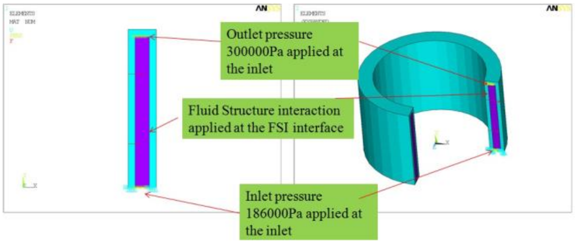

Fig.14 FSI and pressures applied on the fluid with liner

RESULTS AND DISCUSSIONS

Pressure variation along the length of Liner in the fluid is observed at following frequencies

TIME/FREQ
22.423
23.959
26.403
26.634
27.154
29.112
31.56
35.731

Table frequencies where the results are plotted

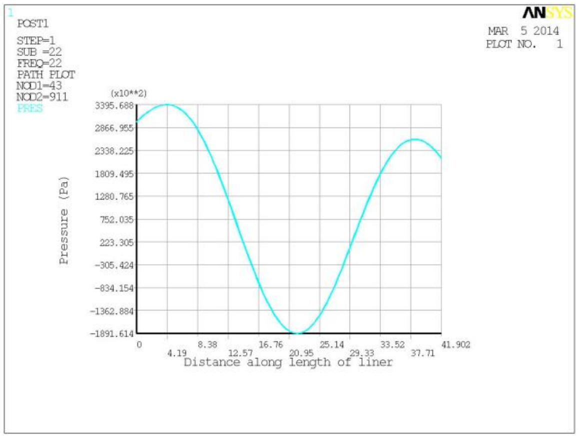

Fig.15 Graphical representation of pressure variation along the length of Liner in the fluid at 2 Hz

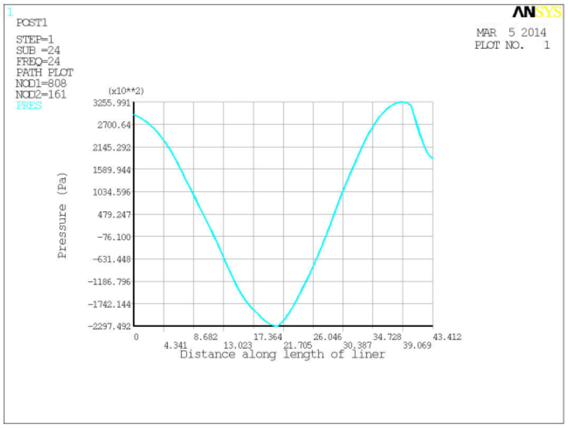

Fig.16 Graphical representation of pressure variation along the length of Liner in the fluid at 24 Hz

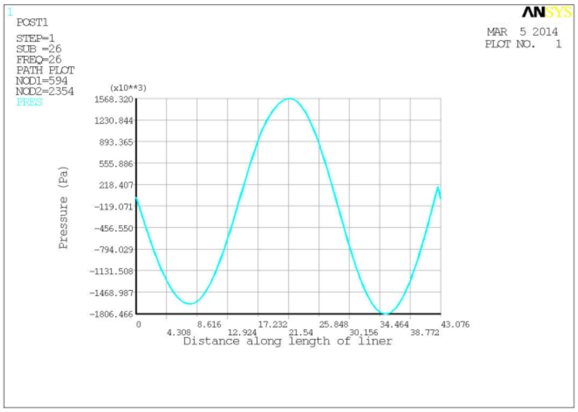

Fig. 17 Graphical representation of pressure variation along the length of Liner in the fluid at 26 Hz

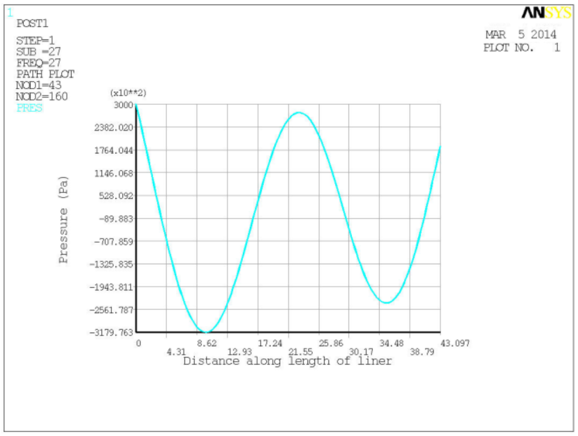

Fig.18 Graphical representation of pressure variation along the length of Liner in the fluid at 27 Hz

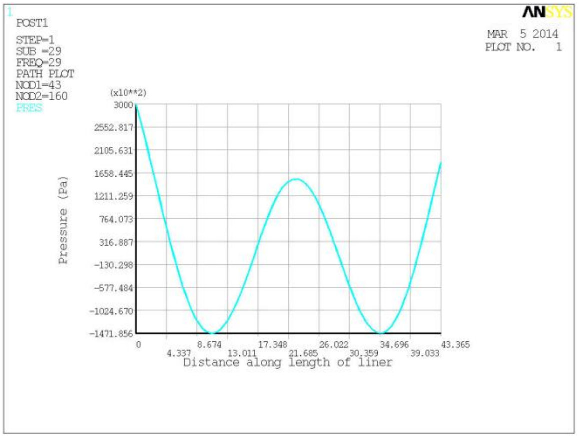

Fig.19 Graphical representation of pressure variation along the length of Liner in the fluid at 29 Hz

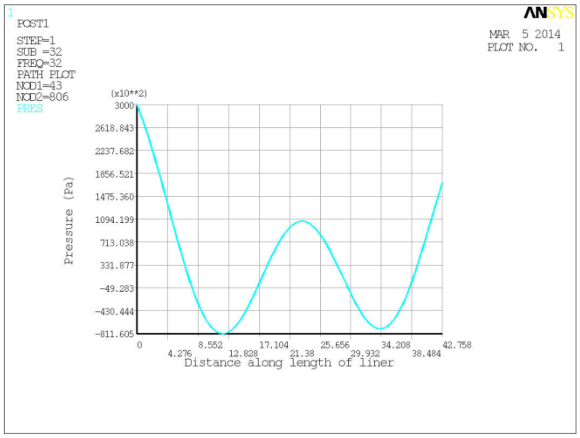

Fig.20 Graphical representation of pressure variation along the length of Liner in the fluid at 32Hz

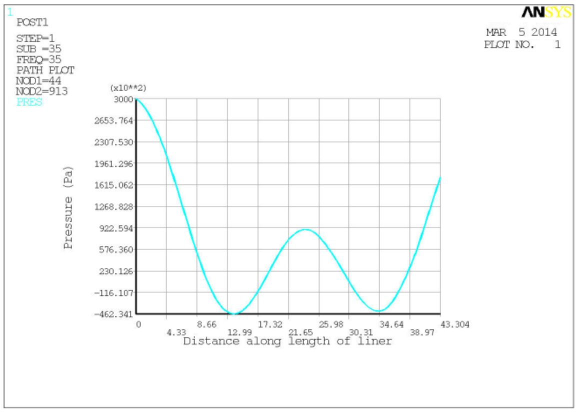

Fig.21 Graphical representation of pressure variation along the length of Liner in the fluid at 35 Hz

Conclusion

In this paper a steady state thermal analysis was done to find the temperature distribution across the liner. The temperature distribution is applied as a body loads in the harmonic analysis.

From the modal analysis it s observed that there exist 8 natural frequencies in the operating zone of 12-35Hz, I.e. 750-2000rpm.Harmonic analysis was done to check the presence of cavitation at the frequencies obtained from the modal analysis.

From the harmonic analysis it was observed that negative pressures exist, which is the indication of cavitation from the frequency of 22Hz, I, e 1320rpm.

From the above analysis it can be concluded that the liner does not have cavitation effect upto 1320rpm.Above 1320 rpm the liner experience the presence of cavitation.

The minimum pressure of -396828 Pa is observed on the fluid-structure interaction at a frequency of 24 Hz.

The minimum pressure of -206000 Pa is observed on the fluid-structure interaction at a frequency 26 Hz.

The minimum pressure of -352045 Pa is observed on the fluid-structure interaction at a frequency 27 Hz.

The minimum pressure of -178386 Pa is observed on the fluid-structure interaction at a frequency 29 Hz.

The minimum pressure of -111888 Pa is observed on the fluid-structure interaction at a frequency 32 Hz.

The minimum pressure of -62062 Pa is observed on the fluid-structure interaction at a frequency 35 Hz.

The pressure distribution of the models in the above analysis shows the presence of negative pressure which is an indication that cavitation can occur at those frequencies. The presence of cavitation in Diesel engines is real and cannot be over looked. This pitting action will also lead to economic and material damage to theend users. Efforts are made to analyze the sources and types of cavitation. It is concluded that the forces applied by piston and vibrationcaused due to the reciprocating motion is a source of cavitations.

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