International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 1, January 2013

Research Paper

FINITE ELEMENT AND MBD ANALYSIS OF PISTON TO PREDICT THE ENGINE NOISE

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The engine vibration is considered as the major source of engine noise which deteriorates the engine performance and increases the pollution. The noise from the engine comprises of mechanical and combustion noise. Combustion noise is primarily due to rapid pressure fluctuations in the combustion chamber. The mechanical noise is due to mechanical impact forces during both motions of piston viz. primary and secondary motions.In this study the effect of the piston secondary motion is taken for the analysis considering combustion pressure contributing to the dynamics of the piston. The Kirloskar Diesel Engine is considered for the present study. The geometrical modeling of the engine is done using CATIA V-5 modeling tool. The finite element meshing is done using Hypermesh 9.0 meshing tool. This work analysis is carried out in ANSYS 10 commercial finite element analysis software. To understand the complex behavior of the piston in motion relative to the other engine parts, viz., connecting rod, crankshaft, a Multi Body Dynamic (MBD) analysis is carried out. This analysis showed the occurrence of piston tilt near TDC and BDC. The stress and displacement results are viewed and analyzed using Hyperview. The analysis results can effectively be used to optimize piston geometry and hence lateral forces are minimized to obtain minimum tilt of the piston. The minimization of the piston tilt eventually leads to the reduction of engine noise.

Keywords: Piston, Vibration, Finite element analysis, piston secondary motion, Hypermesh, Multibody dynamics

INTRODUCTION

The present work is study the engine parts viz piston considered as the main source or vibration and noise. The emphasis on the engine vibration and noise given rise to wide scope for the methods of predicting and controlling the engine noise and vibration. The noise and vibration in the IC engine is emphasis the combustion and mechanical movement of engine part. The Combustion noise is primarily due to rapid pressure fluctuations in the combustion chamber. The

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Mechanical noise is produced by the primary and secondary motion of the engine part. Primary motion of engine part is due to combustion pressure in the combustion chamber which makes piston to move from TDC to BDC but this motion is linear in nature, Secondary motion of engine part is due to impact load of the combustion, and it is transverse motion of engine part while piston moving from TDC to BDC vice versa.

The most common two internal combustion engines are petrol and diesel engines. Presently the IC diesel engines are replacing the more expensive petrol engines. The diesel engine are mostly being used as commercial engines due to high break power and high fuel economy, but it produces bad noise. The piston slap which is the result of piston side thrust on the cylinder liner as it moves TDC to BDC (Vinay and Kurbet, 2008).

The objectives of the present work is, to develop 3-Dimentional Finite Element (FE) model of piston for the piston motion considering regions; piston, piston before TDC, at TDC and after TDC, and to study stress distribution and deformation of piston in different regions.

An overview is given based on a literature survey of general theory for IC engine. The system is modeled using CATIA5 software to create needed geometry and finite element software to implement physics and carry out simulations. The problem is described in a single finite element model. 3-D models of the system are analyzed. The next would be a force analysis of the piston slap followed by the simulation aspects of the Finite element Method. Using commercial software ANSYS 10 and then meshing with software Hypermesh-9.

The Objectives of the paper is

- To develop 3-Dimentional Finite Element Model of piston liner assembly for piston motion considering regions:
  - Piston at TDC.
  - Piston after TDC.
  - Piston before TDC.
- To study stress distribution and deformation in liner assembly in region of objective 1.
- To study the mechanical impact loading on the piston for deformation of slap in the region of objective 1.
- To develop 3-Dimentional Finite Element Multi body dynamics Model of complete IC engine of real Kirlosker engine and applying Real boundary condition and working gas pressure curve of Kirlosker engine taken at 1500 rpm on piston head and observe the output.
- To study stress distribution and piston-slap of MBD analysis of Kirlosker engine.

INTERNAL COMBUSTION ENGINES

Engine Parts

The essential parts of automobile engine are as follows: cylinder block, cylinder head, crank case, piston, piston rings, piston pin, connecting rod, crank shaft, fly wheel, valves and mechanism.

Piston

Piston is considered to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into useful mechanical power. The purpose of the piston is to provide a means of conveying the expansion of the gasses to the crankshaft, via the connecting rod, without loss of gas from above or oil from below. Piston is essentially cylindrical plug that moves up and down in the cylinder. It is equipped with piston rings to provide a good seal between the cylindrical wall and piston. Although the piston appears to be a simple part, it actually quite complex from the design point of view. The efficiency and economy of the engine primarily depends on the working of piston. it must operate in the cylinder with minimum of friction and should be able to with stand the high explosive force developed in the cylinder and also the very high temperature ranging from 2000 °C to over 2800 °C during operation. The piston should be as strong as possible, however its weight should be minimized as for as possible in order to reduce the inertia due to its reciprocating mass (Nagaraj *et al.*, 2005).

Functions of Piston

- To receive the thrust force generated by explosion of the gas in the cylinder and transmits it to the connecting rod.
- To reciprocate in the cylinder as a gas tight plug causing suction, compression, expansion and exhaust stroke.
- To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to the obliquity of the rod.

The top of the piston is called head ring grooves are located at the top circumference portion of the piston. Portion below the ring grooves is called skirt. The portion of the piston that separates the grooves iscalled the lands. Some pistons have a groove in the top land called a heat dam which reduces heat transferred to the rings. The piston bosses are those reinforced section of the piston designed to hold the piston pin.

Piston Materials

The material used for pistons is mainly aluminium alloy. Aluminium pistons can be either cast or forged. Cast iron is also used for pistons. In early years cast iron was almost universal material for pistons because it posses excellent wearing qualities, coefficient of expansion and general suitability in manufacture. But due to the reduction of weight in reciprocating parts, the use of aluminium for piston was essential. To obtain equal strength a greater thickness of metal is necessary. But some of the advantage of the light metal is lost. Aluminium is inferior to cast iron in strength and wearing qualities, and its greater coefficient of expansion necessitates greater clearance in the cylinder to avoid the risk of seizure. the heat conductivity of aluminium is about thrice that of cast iron and this combined with the greater thickness necessary for strength, enables and aluminium alloy piston to run at much lower temperature than a cast iron one (200 °C to 250 °C as compared with 400 °C to 450 °C) as a result carbonized oil doesn’t form on the underside of the piston, and the crank case therefore keeps cleaner. This cool running property of aluminium is now recognized as being quite as valuable as its lightness. Indeed; pistons are sometimes made thicker than necessary for strength in order to give improved cooling.

DESCRIPTION OF I.C. ENGINE MODELS FOR FINITE ELEMENT STUDY

The Table 1 shows engine details:

Table 1: Description of IC Engine

S. No.	Description	Specification
1.	Engine	Kirlosker Engine
2.	Bore	80 mm
3.	Stroke	110 mm
4.	Engine rpm taken for study	1500 rpm
5.	Compression ratio	16.5:1
6.	Maximum torque	66 Nm
7.	Test condition/Type	Water cooled direct injection diesel single cylinder engine
8.	Max pressure at study rpm	54 bars

GEOMETRIC MODELING

Important steps in Geometric modeling are:

- Creating part (solid) modeling of each part;
- Assembling;
- Converting solid model into IGES format.

Drawing and dimension used in this study were retrieved from kirlosker engine by CMM coordinate measuring machine (Toshiyaki *et al.*, 2007) (Figures 1 and 2).

Figure 1: 2D Drawing of Piston

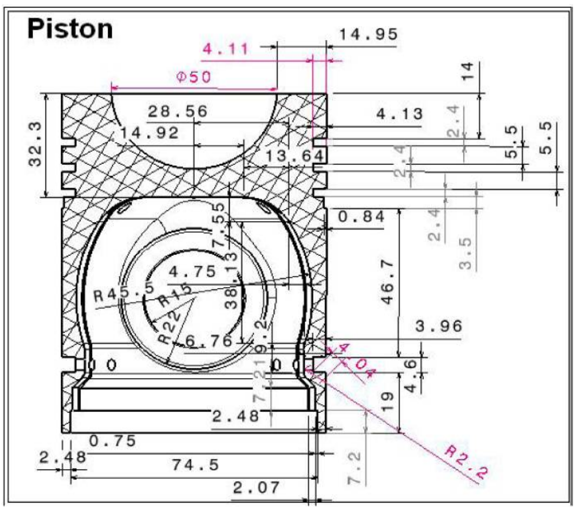
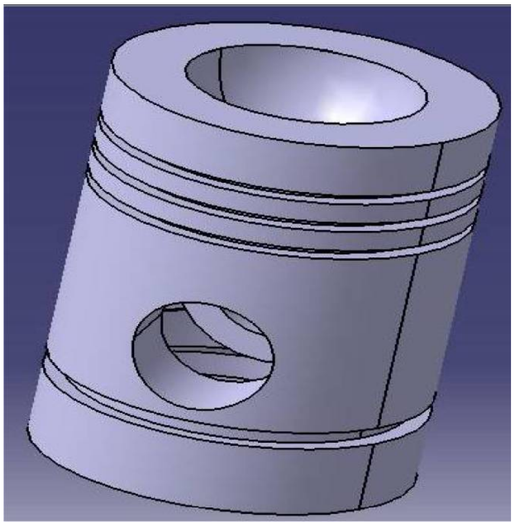


Figure 2: Piston Solid Model



Finite Element Modeling

Finite element modeling and analysis is one of the most popular mechanical Engg applications offered by existing cad /cam systems. This is attributed to the fact that the FEM is perhaps the most popular numerical technique for solving Engg problems. The method is general enough to handle any complex shape or geometry, any material properties, any boundary conditions, and any loading conditions .the generality of the FEM fits the analysis requirements of the complex Engg systems and designs, where closed form solutions of governing equilibrium equations are usually not available. In addition it is an efficient design tool by which designers can perform parametric design studies by considering various design cases, analyzing them and choosing the optimum design (Kurbet and Krishnakumar, 2004).

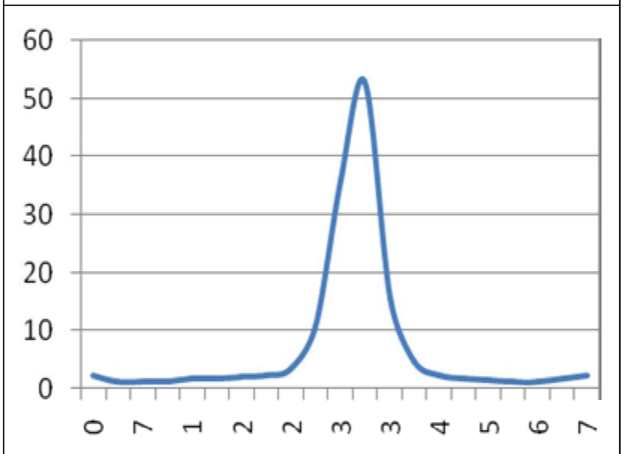
The finite element model of the piston is developed using ANSYS 11 modeling tool (Figure 4). The meshing the model was done with axisymmetric PLANE 42 elements. The material models is created using the Kirloskar engine data and are shown in the Table 2.

Table 2: Material Properties of the Kirloskar Diesel Engine

S. No.	Part Name	Material Name	Density	Young's Modulus		Poison Ratio
			In Kg/ m^3	In GPA	In N/mm^2	
1	Piston	Al alloy	2630	72.4	72400	0.31

For defining boundary conditions, the pressure curve of the Kirloskar engine at running speed of 1500 rpm is considered. The variation of the pressure with a different crank angle is shown in the Figure 3. The bottom skirt of the piston is constrained in all degrees of freedom. It is solved for different pressure values corresponding to the crank angle.

Figure 3: The Variation of the Pressure with Different Crank Angles



GENERATION OF FINITE ELEMENT MESH FOR MBD ANALYSIS

The required geometric information for the mesh generation is collected by importing the IGES file of the model in Hypermesh-9. The finite element mesh is generated for each of the assembly components by using standard command in the three dimensional form by using hexahedral elements, Tetrahedral and Pentamesh. All the meshed components are tested for the quality of the mesh. After proving the quality of the mesh, the components are assembled to represent the IC engine system. The quality setting in Hypermesh-9 preprocessor for quality check of the mesh was shown in Figure 5:

Each components were meshed independently and were shown in Figures 6 and 7:

Figure 4: Model Generated in ANSYS

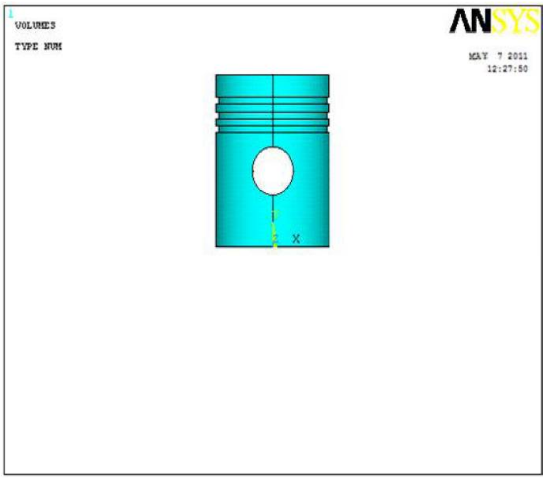
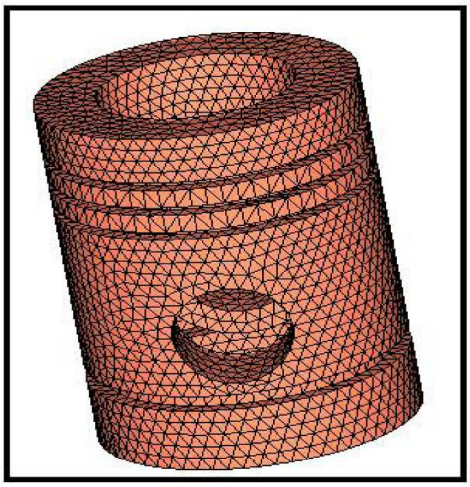


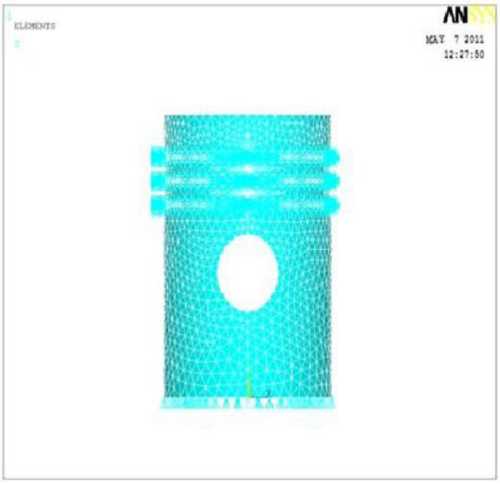
Figure 5: Meshed Model of Piston



Piston

Piston is critical to mesh with hexahedral hence it is meshed with tetrahedral mesh.

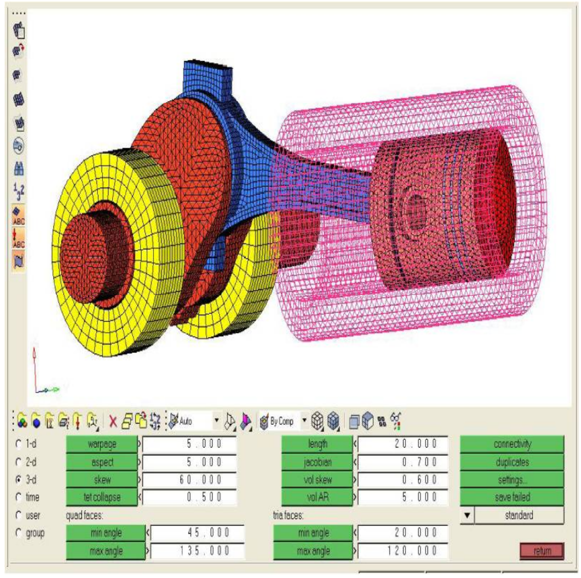
Figure 6: Boundary Conditions Applied in ANSYS



MULTI BODY DYNAMIC SIMULATION OF PISTON MOTION

The MBD analysis is carried out to understand the complex behavior of the engine parts during operating conditions. The pressure curve of the Kirloskar engine as considered for the structural analysis is considered for this analysis. The combustion pressure on the piston causes the piston to reciprocate between TDC and BDC. This in turn carried to the connecting rod and then to the crankshaft. Hence the engine components experience the gas force exerted on the piston. Here it is obvious to study the stress regions and displacements in different engine parts to predict the behavior of the parts. This will reveal the lateral motion of the piston for different crank angle positions and is used to predict the piston slap or tilt (Kurbet and Malagi, 2009).

Figure 7: Assembled Meshed Model in Hypermesh with Quality Check



RESULTS AND DISCUSSION

The analysis is carried out for different cases considered. The result data have been tabulated to plot the respective graph. The stress and displacement graphs have been considered to study the effect of gas pressure on the piston at different crank angle position.

The displacement curves are plotted to study the piston slap (displacement in x-direction). From the finite element analysis, the various stress and displacement values have been found out corresponding to the gas pressure taken from the actual engine readings and are tabulated in the Table 3. The 3600 crank angle corresponds to the TDC of the piston position in the cylinder. From Figure 3, the pressure v/s crank angle graph, it is evident that the maximum pressure of 56 bar is observed near TDC. Hence the structural analysis of the piston is taken from TDC to BDC travel during power stroke, i.e., after combustion of fuel in the chamber.

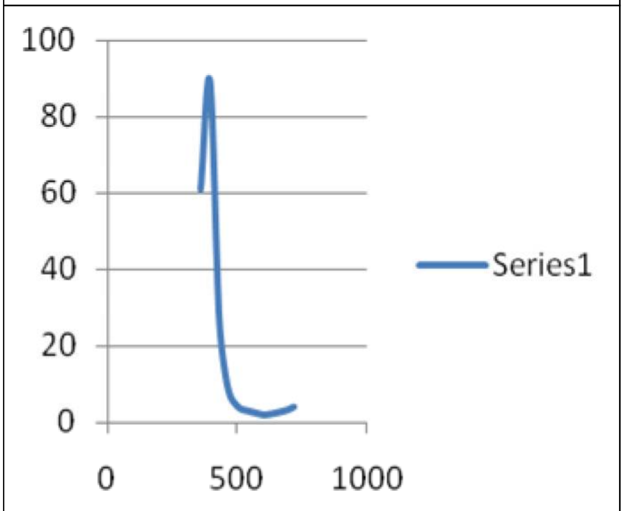
The stress developed in the piston for different crank angle position and the lateral displacements of the piston in x-axis are tabulated in the Table 3 shown in below (Malagi and Kurbet, 2009).

Table 3: The Gas Pressure, Von Mises Stress and x-Displacement of Piston

Crank Angle	Gas Pressure in N/mm^2	Von Mises Stress in N/mm^2	x-Displacement in mm
360	3.600	60.835	0.277
396	5.280	89.227	0.406
432	1.560	26.361	1.200
468	0.480	08.109	0.369
504	0.240	04.055	0.185
540	0.180	03.039	0.138
576	0.144	02.431	0.111
612	0.120	02.027	0.923
684	0.180	03.042	0.189
720	0.240	04.055	0.185

From the Figure 8, it was observed that the stress in the piston ismaximum near the 90 N/mm^2 pressure regions and causes the piston to deform more at this region. Hence

Figure 8: Variation of Von Mises Stress for Different Crank Angles



the gap between piston and cylinder reduces compared to the other region (Figure 9). This phenomenon causes the piston to tilt about the gudgeon pin axis and causes the piston to slap (Cho *et al.*, 2005).

The graph of x-displacement v/s crank angle shown in the Figure 10 which clearly indicates the change in the gap between cylinder and piston travel from TDC to BDC. This behavior of the piston tilt repeats for regular interval of the crank angle between 00 to 7200 of the complete cycle.

Figure 9: VonMises Stress

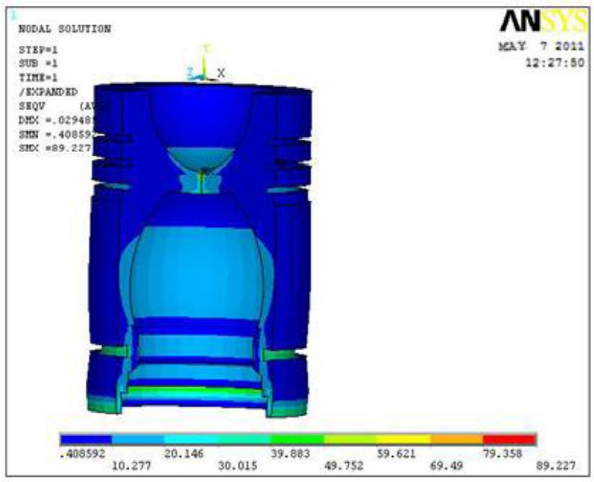


Figure 10: Variation of Piston-Cylinder Gap for Differentcrank Angles

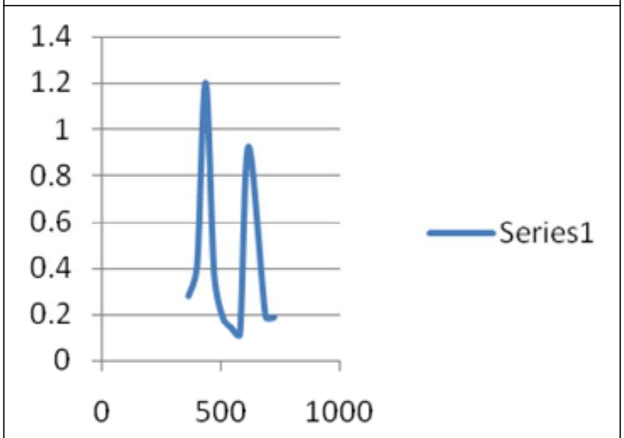


Figure 11: Displacement

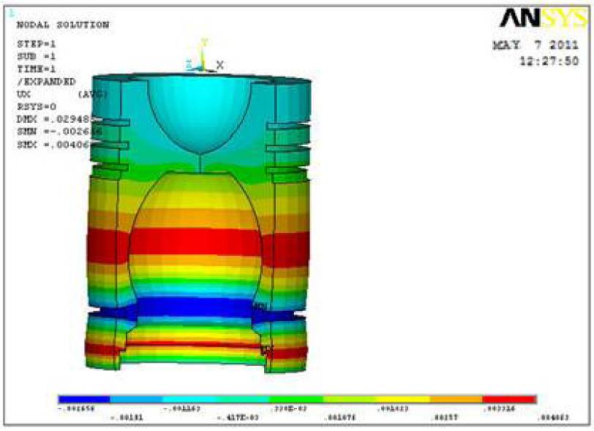


Figure 12: Deformation Zone in Piston at TDC

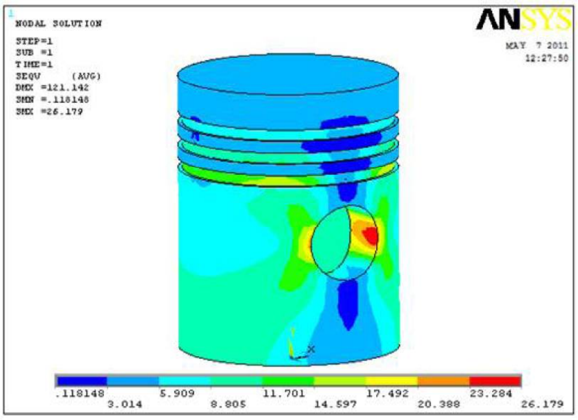


Figure 13: Distribution of Stresses in Piston-Cylinder Assembly at TDC

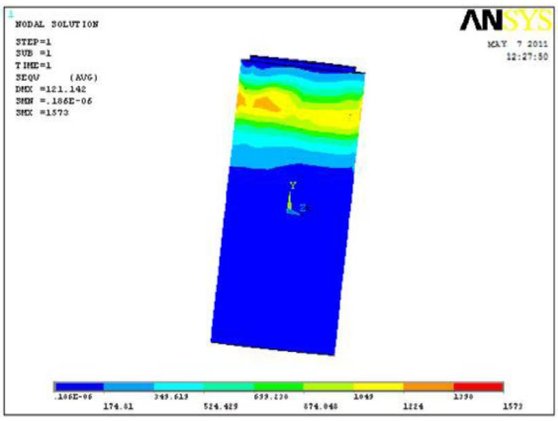


Figure 14: Piston Deformation Along X-Axis

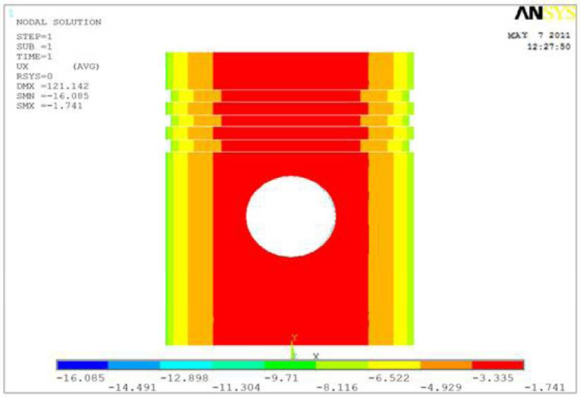
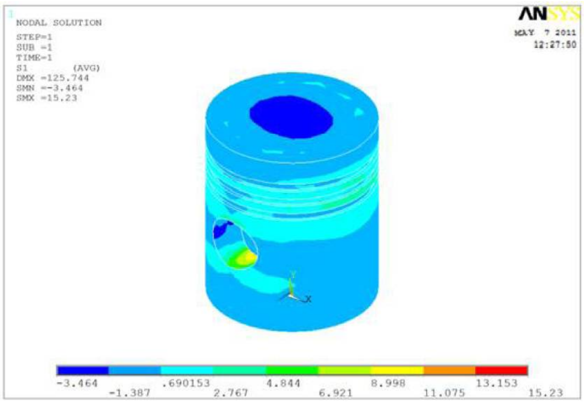


Figure 15: Piston Deformation Along Y-Axis



MBD ANALYSIS

The results obtained from the Multibody Dynamic analysis (MBD) are discussed as follows.

The stress distribution in the engine components is shown in the Figure 13. It was observed from the MBD analysis that the combined effect of the various forces acting on the engine components viz, connecting rod, crankshaft, piston, is inducing stress in each component. The maximum stress level in the piston is observed as 3.584×10^2 N/mm^2. The maximum displacement observed as 1.710 mm.

Figure 16: Von Mises Stress Distribution of MBD Analysis of Engine (Radioss Analysis)

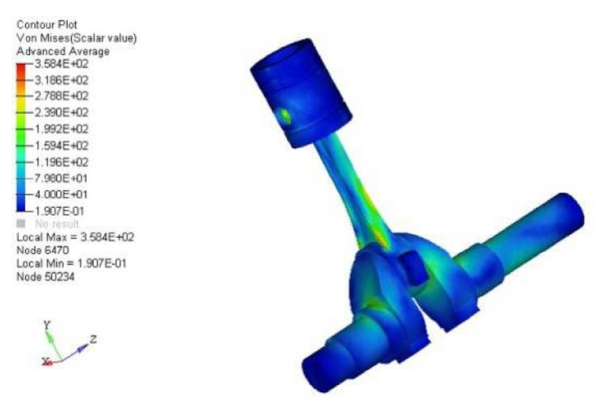


Figure 17: Displacement of MBD Analysis of Engine (Radioss Analysis)

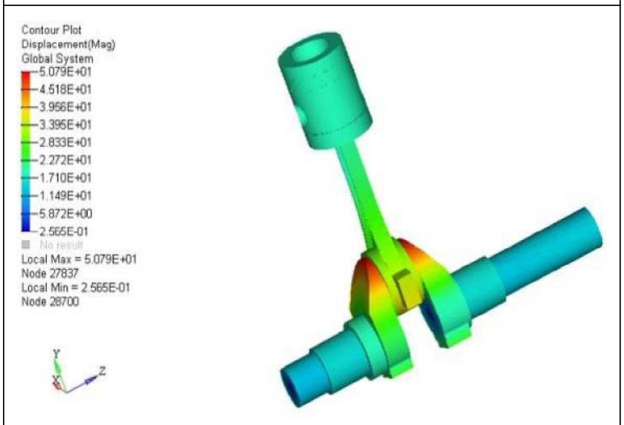


Table 4 shows the difference between the MBD analysis and structural analysis for stress and displacement.

Table 4: Comparision Between MBD ANS Structural Analysis

	MBD Analysis	Structural Analysis
Displacement along X-axes in mm	1.741	1.710
Stress in N/mm^2	159	157

CONCLUSION

The structural analysis of the piston for the various pressure on the piston for different position of the piston in the cylinder moving between TDC to BDC have been studied and the following conclusions are made.

- The piston experiences maximum stress in the region where the combustion of the fuel takes place, i.e., at the piston head and skirt.
- This high stress region in the piston deforms more than the other region of thepiston.
- The maximum x-displacement of the piston for structural analysis resembles the maximum displacement of the piston in MBD analysis. Hence the piston experiences maximum displacement in this region.
- The deformation in the piston causes it to displace more in this region and this cycle repeats even for the reduction in combustion pressure.
- The MBD analysis confirms the relative motion between the parts and reveals that the engine noise is associated with the stress developed in the engine parts.

FUTURE SCOPE

MBD Analysis is proposed, to incorporate the forces in motion for prediction of piston tilt and optimization of the geometry of the piston to reduce engine noise and vibration (NVH).

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