Study on Influence of Temperature on I C Engine Vibration-A Finite Element Approach

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Abstract- In an IC engine during the power stroke, after combustion of fuel, the thermal energy is converted in to mechanical energy by exerting combustion pressure on the piston. The primary motion of the piston is transferred to the crank. In addition to this primary motion, there exists a lateral motion (secondary motion) of the piston which is the main cause for the piston tilt and hence the piston slap. This piston slap is considered to be one of the chief sources of vibration which produces the engine noise. Therefore the lateral motion of the piston in x-direction is studied, in relation with the variation of combustion pressure on piston. The combustion temperature and the pressure are correlated for the dynamic analysis of the piston motion. The Kirloskar 4 stroke diesel engine is considered for the present study. The corresponding data of the engine performance parameters are logged and are used for the analysis. Multi Body Dynamic (MBD) analysis is carried out for dynamic analysis. The effects of variation of temperature and pressure on the lateral motion of the piston are found to play the role.

I. INTRODUCTION

An engine is a device which transforms one form of energy into another form and most of the engines convert thermal energy into mechanical work. 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, this motion is desired in IC engine for transfer of motion from one part to another but this is not producing much vibration in engine as compare to secondary motion. 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. Transverse motion produced is not desired in IC engines because it produces piston slap and twisting movement in the engine. The diesel engine are generates a lot of noise because of high impact of load due to combustion of diesel, as it produces secondary motion which causes piston slap and twisting in the engine parts.

The objectives of the present work is, to develop 3-dimentional Finite Element (FE) model of piston for the piston motion considering piston regions; piston before TDC, at TDC and after TDC, and to study stress distribution and deformation of piston in different regions. The multi-body dynamic (MBD) analysis of the engine considering all the components is carried out. The temperature data is obtained from the experiments conducted for the maximum pressure of 56 Bars. Then to find out the effect of pressure and temperature on the strength of the piston and other engine components in terms of the stress induced, and to find out the maximum displacement of the piston to predict the piston lateral motion which causes the piston slap/tilt, which is the major source of engine vibration and hence noise. An overview is given based on a literature survey of general theory for IC engine. The system is modeled using CATIA V5 software to create needed geometry of the engine. The 3D models of the system are analyzed. The simulation aspects of the finite element method using commercial software ANSYS and meshing with software Hypermesh-9.

II. TEMPERATURE CONSIDERATIONS

An engine is a device which transforms one form of energy into another form and most of the engines convert thermal energy into mechanical work. Heat Engine is a device which transforms the chemical energy of a fuel into thermal energy. IC engines transform about 25 to 35 per cent of the chemical energy in the fuel into mechanical energy. About 35 per cent of the heat generated is lost to the cooling medium, remainder being dissipated through exhaust and lubricating oil. During the process of combustion, the cylinder gas temperature often reaches quite a high value. A considerable amount of heat is transferred to the walls of the combustion chamber. Excessive cylinder wall temperatures will therefore cause the rise in the operating temperature of piston head. This in turn will affect the strength of the piston seriously.

A. Variation of Gas Temperature

Temperature inside the engine cylinder is almost the lowest at the end of the suction stroke. During combustion there is a rapid rise in temperature to a peak value which again drops during the expansion. This variation of gas temperature is shown in "Fig. 1"

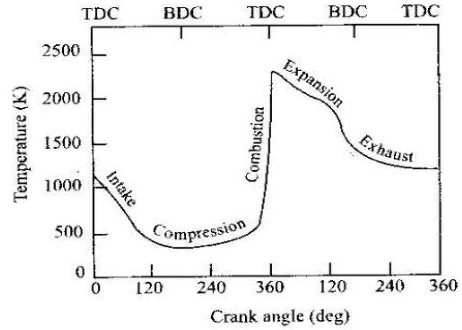

Fig. 1. Temperature Variation

B. Piston Temperature Distribution

The piston crown is exposed to very high combustion temperatures. "Fig. 2" shows the typical values of temperature at different parts of a cast iron piston. It may be noted that the maximum temperature occurs at the centre of the crown and decreases with increasing distance from the centre. The temperature is the lowest at the bottom of the skirt. Poor design may result in the thermal overloading of the piston at the centre of the crown.

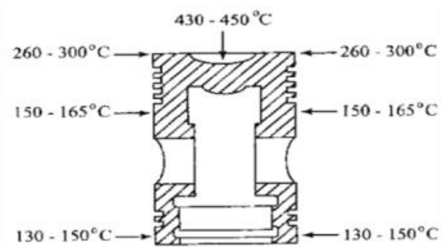

Fig. 2. Piston Temperature Distribution

C. Cylinder Temperature Distribution

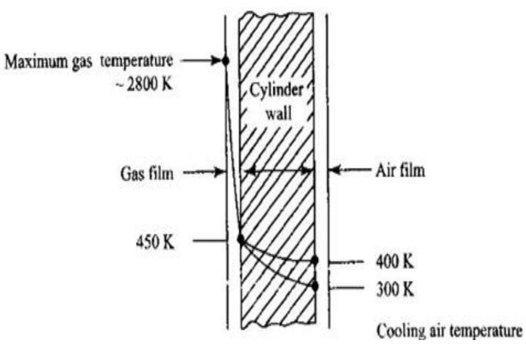

Fig. 3. Cylinder Wall Temperature Distribution of a Properly Cooled Cylinder

Whenever a moving gas comes into contact with a wall, there exists a relatively stagnant gas layer which acts as a thermal insulator. The resistance of this layer to heat flow is quite high. Heat transfer from the cylinder gases takes place through the gas layer and through the cylinder walls to the cooling medium. A large temperature drop is produced in the stagnant layer adjacent to the walls. The peak cylinder gas temperature may be 2800 K while the while the temperature of the cylinder inner wall surface may be only 450K due to cooling.

"Fig. 4" shows how the temperature of various automobile components increases with time after a cold engine is started. In cold weather, the startup time to reach steady-state conditions can be as high as 20-30 minutes. Some parts of the automobile reach steady state much sooner than this, but some do not. Fairly normal operating conditions may be experienced within a few minutes, but it can take as long as an hour to reach optimum fuel consumption rates.

Engines are built to operate best at steady-state conditions, and full power and optimum fuel economy may not be realized until this is reached. It would be poor practice to take off with an airplane, when full power is needed, before the engine is fully warmed up. This is not as critical with an automobile. Driving before total engine warm-up causes some loss of power and fuel economy, but if there is engine failure, the distance to fall is much less than in an airplane.

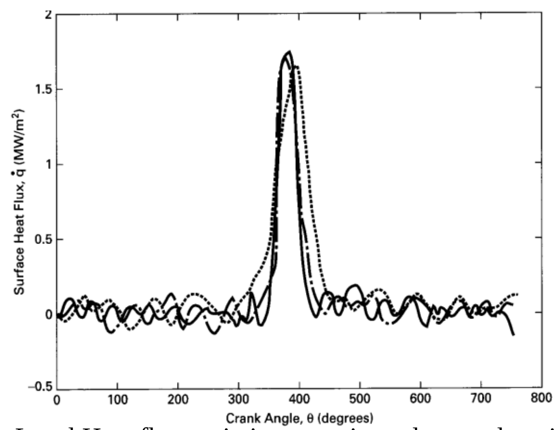

Fig. 4. Local Heat flux variation experienced at one location in a single cylinder of a typical engine for three consecutive engine cycles.

III. DESCRIPTION OF I.C. ENGINE

The specifications of the engine (Kirloskar made) and the material properties are given the Table I and II repectively. The photographs of the engine test rig and computerized data acquisition system are shown in the "Fig. 6" and "Fig. 7" respectively.

TABLE I
ENGINE DETAILS

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

TABLE II
MATERIAL PROPERTIES OF THE KIRLOSKAR DIESEL ENGINE PISTON

Density Kg/m^3	Young's Modulus N/mm^2	Poissons Ratio
2630	72400	0.31

Fig. 6. Single Cylinder I.C. Engine

Fig. 7. Computerized Engine set up for clearance/ gap Measurement for study of Engine Dynamics

IV. RESULTS AND DISCUSSIONS

The MBD analysis is carried out for stress results. The stress and displacement graphs have been considered to study the effect of gas pressure on the piston at different crank angle position. The experiments are conducted for the given pressure of the engine. The variation of the temperature for different crank angles is noted. These data are shown in the Table III.

TABLE III
CRANK ANGLE WITH DIFFERENT PRESSURE AND HEAT RELEASE

Sl. No	Crank Angle ^{0}	Pressure (Bar)	Heat Release (K)
1	10	0	0
2	294	0	0
3	296	0.1	60
4	300	0.6	330
5	320	5.6	1769
6	340	19.3	3002
7	350	27.4	3107
8	366	54.7	5688
9	368	54.7	5915
10	372	47.9	5724
11	374	47.4	6019
12	376	40.2	5451
13	392	20.5	4934
14	410	8.4	3577
15	426	3.2	2015
16	434	1.6	1181
17	436	1.3	996
18	438	1.1	873
19	440	0.8	657
20	442	0.6	509
21	444	0.3	263
22	446	0.1	90
23	450	0	0
24	700	0	0

The variation of temperature in terms of heat release and the pressure inside the cylinder for different crank rotation is plotted and are shown in "Fig. 8" and "Fig. 9" respectively.

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 III.

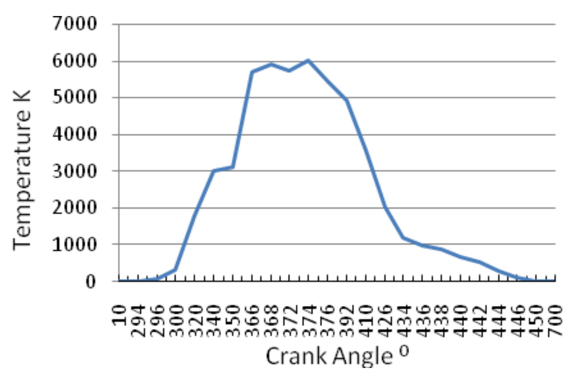

Fig. 8. Temperature V/s Crank Angle

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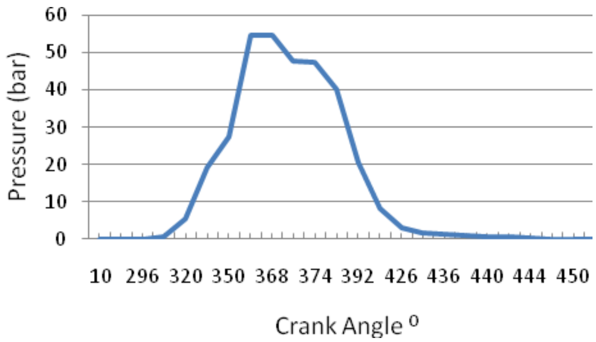


Fig. 9. Pressure V/s Crank Angle

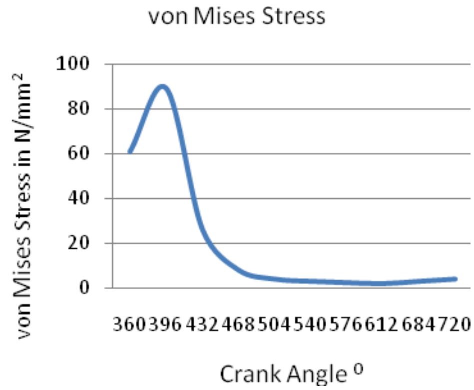
The 360^0 crank angle corresponds to the TDC of the piston position in the cylinder. From "Fig. 9", the pressure v/s crank angle graph, it is evident that the maximum pressure of 56 bars is observed near TDC. Hence the structural analysis of the piston is taken from TDC to BDC travel during power stroke 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 IV.

TABLE IV
THE GAS PRESSURE, VON MISES STRESS AND X-DISPLACEMENT OF PISTON

Crank Angle	Gas Pressure in N/mm2	von Mises Stress in N/mm2	x-displacement (gap) 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

The temperature variation for the different crank angles show that at TDC, during combustion stroke the temperature of the mixture raises rapidly and hence the pressure on the piston also increases simultaneously. Hence the piston experiences maximum load at this region. So the engine components experience maximum stress at this region shown in "Fig. 10"



Crank

Fig. 10. Variation of von Mises stress for different crank angles

It is also observed that the stress in the piston is maximum (90 N/mm^2) near the high pressure region and causes the piston to deform more at this region. Hence the gap between piston and cylinder reduces compared to the other region. This phenomenon causes the piston to tilt about the gudgeoning pin axis and causes the piston to slap.

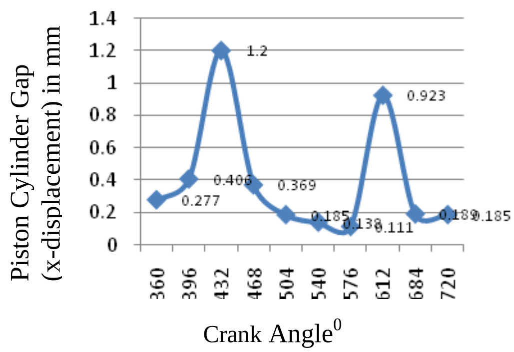


Fig.11. Variation of piston-cylinder gap for different crank angles

The graph of x-displacement v/s crank angle shown in the "Fig.11" which clearly indicates the change in the gap between cylinder and piston travel from TDC to BDC. This behaviour of the piston tilt repeats for regular interval of the crank angle in between 0^0 to 720^0 of the complete cycle. During initial stage of compression stroke gap between cylinder and piston is considerably more as shown. For next cycle the during compression stroke the gap between cylinder and piston will be reduced because of force developed during power stroke of previous cycle i.e. inertia force will be developed so secondary motion of piston will decrease. Between 425^0 to 450^0 crank angle the cylinder gap is greater and is up to 1.2mm and again it is reduced to 0.923mm in between 580^0 to 680^0.

V. CONCLUSIONS

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 and the temperature of the engine is maximum, i.e. at the piston head and skirt. This high stress region in the piston deforms more than the other region of the piston. This deformation is proportional with rapid temperature raise.

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. Between 425^0 to 450^0 crank angle the cylinder gap is greater and is up to 1.2mm and again it is reduced to 0.923mm in between 580^0 to 680^0.

The deformation in the piston causes it to displace more in this region and this cycle repeats even for the reduction in combustion pressure and temperature. The MBD analysis confirms the relative motion between the parts and reveals that the engine noise is associated with the maximum stress developed in the engine parts.

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