Survey on Coupled-Field and Fatigue Analysis on Connecting Rod Bearing using Finite Element Method

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Abstract—Perform a finite element analysis is to model the behavior of fatigue cracks in bi material specimen with an interface perpendicular to the crack plane and also perform a coupled thermo mechanical analysis on biomaterial specimen. In I.C engines, the power must be transferred from the piston-connecting rod assembly to the crankshaft via the plain bearings at the big end of the connecting rod. These bearings are made by bi materials generally steel and aluminium alloys. These bearing are subjected by mechanical load and thermal load due to lubricant oil. The engine bearing material may fail due to more deformation. The engine bearing may also suffer fatigue failure due to cyclic loads. Results show the deformation and fatigue strength of bearing material which helps to improve the design and innovation of new bearing materials.

Keywords- Coupled-Field Analysis, Fatigue crack growth, In homogeneous material, Finite element modelling

1. INTRODUCTION

Bearing is a device supporting a mechanical element and providing its movement relatively to another element with minimum power loss. Plain automotive journal bearings form an important part of the internal combustion engine and may suffer a complex combination of various types of failures under normal engine operating conditions. Competition between automobile manufacturers in achieving the best engine performance during the past few decades has resulted in sophisticated designs of automobile engines, which are lightweight, compact and have high output power. The high specific output power must be transferred from the piston-connecting rod assembly to the crankshaft via the plain bearings at the big end of the connecting rod.

In I.C Engines, there are several kinds of bearings available such as main crankshaft bearing, Small end bushes, Cam shaft bearings and connecting rod big end bearings, which transmit cycling loads applied to the piston. Connecting rod bearings are mounted in the big end of the connecting rod. A bearing consists of two parts which are commonly interchangeable. The connecting rod is subjected to the combined Mechanical loads, and it is transferred to crank pin through the engine bearing. The combined mechanical loads are the combination of inertia load and gas load. The inertia load is that force which develops as a result of the weight of the piston, rod, and crosshead assembly including piston rings, nuts, crosshead pin, and balance weights and the gas load is the force which develops inside the cylinder during combustion. So, in that case, the engine bearing plays a vital role in Internal Combustion engines. These bearings are also subjected by Thermal loads due to the temperature of lubricating oil. Because of these combined Mechanical and Thermal loads, the engine bearing material may fail due to more deformation. The engine bearing may also suffer Fatigue failure due to repeated / cyclic loads.

2. MATERIALS AND METHOD

2.1 Rod load calculation

In I.C engines, the connecting rod is subjected to the combined Mechanical loads, and it is transferred to crank pin through the engine bearing. The combined mechanical loads are the combination of inertia load and gas load. What are the loads acting on the connecting rod those all the loads acting on the connecting rod bearing also. So it is necessary to find out the rod load. This paper explained us how to calculate the rod loads. The inertia load is that force which develops as a result of the weight (mass) of the piston, rod, and crosshead assembly (including piston rings, nuts, crosshead pin, and balance weights) being in reciprocating motion. The gas load is the load or force which is produced inside the cylinder during combustion. The gas load on each end of the piston is determined by finding the pressure inside each end of the cylinder at various points in the stroke. The net load applied to the crosshead pin bushing is found by the algebraic summation of the inertial load and the total gas load [1].

To describe the rod load effects we must not only consider the magnitude of the rod load for design integrity, but we must also observe its direction of application. The direction of the rod load has a paramount effect on the lubrication of the crosshead pin bushing. When the load is being applied to one side of the bushing, some finite amount of clearance develops on the opposite side. This clearance is filled with oil thereby lubricating and cooling that side of the bushing, In order to lubricate the other side of the bushing, o clearance must develop there also. A reversal in the direction of application of the load must occur for this to happen, And it is also evident hot the magnitude and duration of this reversal must be such that a complete filling of this clearance space with oil can be effected, This is necessary to achieve adequate lubrication and cooling.

2.2. Modeling fatigue crack growth in a bimaterial specimen

Most technical materials have a heterogeneous micro and nano structure. In many advanced materials and components, inhomogeneous structures are intentionally produced in order to gain certain mechanical, tribological, or functional properties. Performed a two-dimensional finite element analysis to find the behavior of fatigue cracks in bimaterial specimens made of diffusion bonded ARMCO-iron and SAE 4340 steel with an interface perpendicular to the crack plane the numerical analyses are based on experiments conducted by Pippan et al and found the crack growth rate for given values of applied stress intensity range ΔK_{app} and applied load ratio Rapp, the near-tip J-integral J_{tip} was calculated at the maximum and minimum load. To allow for crack Reciprocating compressors operating with non-reversing loads are highly subject to bushing damage. Many post instances hove shown that a bushing can fail within a very few minutes while operating under non-reversing loads, While this design configuration reflects some performance improvements in non-reversing or marginal reversing load applications, it does not provide a suitable non-reversing load design that could be used for non-reversing condition.

The net rod load con be controlled by altering the constituents which comprise the rod load - namely the inertial load and the gas load, we certainly must evaluate how changes in each effect the rod load. Increasing the rotating speed of the compressor will increase the inertial load and the amount of the reversal Adding weight to the crosshead and piston assembly will also increase the inertial load and. the size of the rod load reversal. The effect of the total-gas load on the net rod load is quite different from the inertial effect. Increasing the total gas load may either increase or decrease the rod load reversal. The size of the cylinder bore will affect the reversal in either way. Smaller bores in double acting cylinders tend to decrease the reversal, but decreasing the bare in single acting configurations tends to increase the reversal. Summary of this discussion was to provide a thorough understanding of rod loads and their effects. While gas loads and external rod loads can be used as a general guide, they alone do not completely define the actual rod load. Closure, the effective near-tip stress intensity range $\Delta K_{eff,tip}$ was evaluated from the near-tip stress intensity range ΔK_{tip} and the near-tip load ratio R_{tip}. Calibration curves for homogeneous ARMCO-iron and SAE 4340 steel are used to calculated the crack growth rate da/dN from the values of $\Delta K_{eff,tip}$. The distance between interface and crack tip L is varied to simulate the behavior of a growing crack. By using the following relations we can calculate the crack growth.

$$da / dN = C \, \Delta K^{m}$$

where C is the intercept and m is the slope of the crack.

The specimen is symmetric with respect to the crack plane, only the upper half of the specimen is modeled; Fig.1 No real crack extension during cyclic loading is modeled. Instead we assume a specimen with a stationary crack of length *a* subjected first to thermal loading and second to mechanical loading to the minimum and maximum load, *F*min and *F*max, There is a jump of the material properties at the interface. The parameter **e** denotes the unit vector in the direction of crack growth, **n** the unit normal vector to the interface, and **n** is the outer unit normal to the contours **Γ**r , **Γ**int , and **Γ**far where the J-integral values are evaluated. Calibration curves for homogeneous ARMCO-iron and SAE 4340 steelwere used to calculate the crack growth rate da/dN from the values of _Keff,tip.

The distance between interface and crack tip L was varied to simulate the behavior of a growing crack. The computed curves da/dN versus L curves are in good agreement with the experimental curves measured by Pippan et al. The computational results showthat the both the thermal residual stresses and the yield stress gradient effect have a strong influence on the effective, near-tip stress intensity range _*K*eff,tip, the near-tip load ratio *R*tip, and the crack growth rate *da*/*dN*.

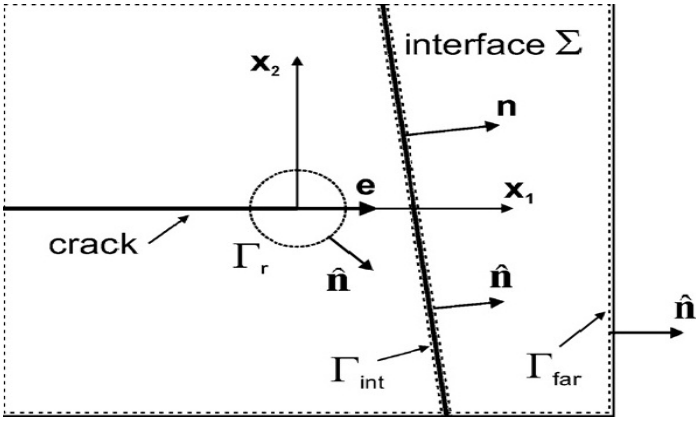

Fig: 1. Bi-material body containing a crack and a sharp interface

2.3. Fatigue analysis of connecting rod

Connecting rods are widely used in variety of car engines. The function of connecting rod is to transmit the thrust of the piston to the crankshaft, and as the result the reciprocating motion of the piston is translated into rotational motion of the crankshaft. It consists of a pin-end, a shank section, and a crank end. Pin-end and crank-end pin holes are machined to permit accurate fitting of bearings. A connecting rod must be capable of transmitting axial tension, axial compression, and bending stresses caused by the thrust and pull on the piston and by centrifugal force.

The connecting rod of the tractors is mostly made of cast iron through the forging or powder metallurgy. When the repetitive stresses occur in connecting rod it leads to fatigue phenomenon which can cause so dangerous ruptures and damages. For the reason that the connecting rod failure is usually due to the fatigue phenomenon, consequently in this research a U650 tractor connecting rod behavior, from the fatigue point of view, is investigated through the ANSIS software.

Fatigue phenomenon is a complicated subject which seems to be not known a lot. The best theory for the explanation of fatigue phenomenon proposal is the strain-life theory which is used for the fatigue strength estimation. But for the application of this theory there must be some assumptions made for the ideal state, so it results in some uncertainties. Rupture due to the fatigue is usually occurred in discontinuities or where we have the stress concentration. When in these places the existing stress, exceeds the allowable one it gives rise to the So, It was needed to seek for the component behavior during the cyclic deformations. The following equation to represents the relationship between fatigue life and the total strain.

$$(\Delta\epsilon/2) = \sigma_F/E\ (2N)^b + \epsilon_F\ (2N)^c$$

Where $\Delta\varepsilon$ is the total stress, N is the fatigue longevity, E is the Young's modulus, b and c are the exponents of fatigue strength and fatigue elasticity, and finally σ_F and ϵ_F are the coefficient of fatigue strength and elasticity respectively. The model of U650 connecting rod was created then the next stage is meshing. The 10 node pyramid elements were used. The reason for choosing this element was to make the geometrical parts of a complicated mechanical component so enable us to gain more authentic results based on the high techniques of fatigue life calculation.

After meshing the critical points were determined. After determination of these critical points, they were elected as the points for fatigue investigation. Filling the fatigue parameter blanks, the S-N data collected from the fatigue test of the specific alloy into the software should import. 1.25 was taken as the stress concentration factor which was a representative of a difference between the real model and the operating condition with the sample under the test in fatigue test.

Through the fatigue analysis of the connecting rod, two loadings were taken into account. By the finite element analysis method and the assistance of ANSIS software, it is able to analyze the different car components from varied aspects such as fatigue and consequently save the time and the cost. The way that defined loadings was effective on the results achieved. So, they should fit as much as possible the real conditions.

3. RESULTS AND DISCUSSIONS

The definite-element analysis software, a three-dimensional definite-element analysis has been carried out to the gasoline engine piston. Considering the thermal boundary condition, the stress and the deformation distribution conditions of the piston under the coupling effect of the thermal load and explosion pressure have been calculated, thus providing reference for design improvement. The finite element analysis to the piston is to establish the reasonable and accurate finite element model first, thus carrying out analysis by marking cell grids to obtain the accurate results finally. According to the structural symmetry of the piston, in order to be convenient for calculation and decrease workload, cut the established piston model to maintain 1/4 and then import the model to the finite element software for the finite element analysis to the piston according to the fine interface between the modeling software and the finite element analysis software. During the importing process, some details have been omitted, such as the chamfer and the snap ring of the piston pin etc. The geometrical model for the piston is as shown in Figure2.

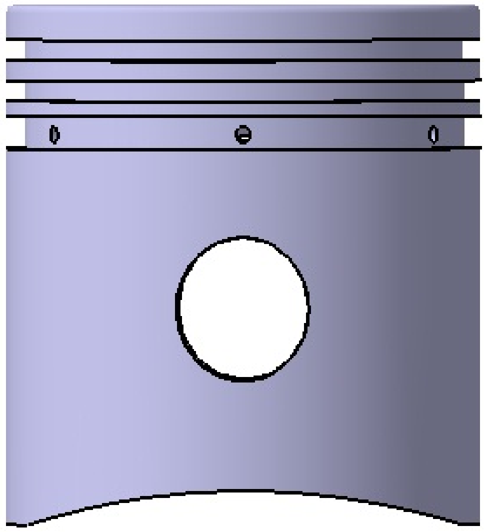

Fig.2. Geometrical model of the piston

The heat of the gas and the piston top mostly come from heat convection of the gas and the piston top, the heat transfer within the piston abides by Fourier Law and no heat can occur within the piston itself, so the thermal analysis to the piston is a stable thermal analysis to the problem without any internal heat source. Fourier Law is the basis for the heat conduction theory, and the vector expression for the Fourier Law is:

$$q = -k \text{ X } gradT$$

Where, q—heat flux, which is a the vector in $w/\ m2$; k—the heat conduction coefficient of the material treated as the constant, in $w/(m\times\ K)$; $gradT$ — the temperature gradient, also a vector, in $°C\ /m$. Where, the negative sign means that the direction of q is always opposite to that of $gradT$.

The mechanical load to the piston during the working process includes: the working medium pressure within the cylinder, the piston inertia force, the bearing reaction force of the interior surface of the pin boss hole and the lateral pressure of the skirt. while operation, the piston will be affected not only by the high-pressure gas pressure, the inertia force caused by high-speed reciprocating motions, the lateral pressure, friction forces and effects of other mechanical loads, but also by the effect of the thermal load caused by high-temperature gases. Although the thermal load and mechanical load are two kinds of different loads acting on the piston, they will both affect the reliability and endurance of the operation of the piston. Deformation occurs to the piston under the effect of the thermal load and the piston deformation will affect the transfer of heat, the thermal stress and the mechanical stress, so it is necessary to integrate the dual function of the thermal stress and the mechanical stress of the piston to carry out coupling analysis and solve so as to better reflect the stress field distribution and deformation condition of the piston in the operation condition. The result shows that the stress and deformation are both within the allowable range, so the piston is safe. The deformation and the stress of the piston are mainly determined by the temperature, so it is necessary to decrease the piston temperature through structure improvement, e.g. by using the combined piston with small heat conduction coefficient and large heat conduction coefficient of the skirt and inner cylinder. And thermo mechanical analysis by finite element method is very useful to calculate the stress and deformation of bearing due to coupling loads [5].

The various kinds of loads acting on connecting rod, those are inertia load and gas load were identified. It will be help us to do the fatigue analysis. The fatigue strength of bi- material specimen was analyzed by the j- integral method in finite element method. It is revealing the various methods available for analyzing the crack growth of inhomogeneous materials. The important of stress concentration factor and the selection of elements for meshing also clearly explained.

VI.CONCULSION

This study was very useful us to know how to find out the fatigue strength of the bi material bearings. We can clearly understand the ways to the ways to control the rod load. From that can evaluate the life span of the bearing material and can design a new bearing materials with the high tribological properties.

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