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Fatigue Life assessment of crankshaft under Bending and Torsional Loading

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Abstract

Fatigue is a phenomenon which occurs due to repetitive loading on the component. Fatigue due to combined bending and torsion is most common reason for failure of IC engine crankshaft. The objective of this work is to evaluate fatigue life of an alloy steel crankshaft. Physical testing of crankshaft subjected to combined bending and torsion for evaluation of fatigue life is not a feasible solution because of very high cost of experimentation. Also, to sustain in competitive market, timely delivery of the component is very important. The crankshaft is modelled and stresses are analysed using finite element software. The fatigue life of crankshaft subjected to pure bending and pure torsion loading is obtained during actual testing. The possibility of using fatigue test data from pure bending and pure torsion loading is explored in present work to estimate the fatigue life due to combined loading. The results obtained from simulations are then correlated with experimental results of loading.

Keywords: Fatigue Life, Combined Loading, Sequential Loading, Bending, Torsion

1. Introduction

Fatigue is the most commonly encountered type of failure for metallic structures operating under cyclic loading. Fatigue failure often comes without warning and may cause significant damage as well as loss of life. Fatigue failure cannot be stopped from occurring but it is possible to avoid it by proper studies. Hence, Fatigue is the most important failure mode to be considered in a mechanical design. The goal of fatigue analysis in the design process is to perform fatigue and durability calculations much earlier, thereby reducing or removing the need for expensive redesign later on. Physical testing of the component involves considerable cost and time. Carrying out the physical testing always is not a good solution if the cost and time are the constraints. Finite element analysis can be considered as the alternative to the physical testing. Crankshaft is an important component of internal combustion engine with complex geometry. Crankshaft experiences a large number of load cycles during its service. Design and Development has always an important issue in crankshaft production industry to manufacture less expensive crankshaft with high fatigue strength. Most of the crankshafts that failed in fatigue were due to combined bending and torsional fatigue. Therefore, analysis of fatigue due to combined loading considering combined bending and torsional is done by many researchers.

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2. Finite Element Analysis

In static analysis the component is assumed to be in equilibrium condition and the effect of various loadings is calculated. A static analysis is the effect of inertia and damping is ignored and the effects of static loading conditions on a structure are calculated. In static analysis it is assumed that loading and response vary slowly with respect to time. Also it is assumed that displacement is very small. The static analysis results of displacements, stresses, strains and forces in structure for components give a clear idea about whether the structure or component will withstand the applied maximum force or not. The results of static analysis are then used as input for fatigue analysis. The objective of FEA is to investigate stresses, experienced by the crankshaft and find out the critical locations. The stresses obtained can then be used to predict the fatigue life and determine the expected failure regions. A single throw of alloy steel crankshaft is used for the finite element analysis. Linear elastic analysis was used since the crankshaft is designed for long life where stresses are mainly elastic. Bending and Torsional loading conditions were considered for the analysis. 3-D solid model was developed in Pro-E 2.0. The geometry created is then imported in HyperMesh for creating the finite element model. The ABAQUS profile in HyperMesh is selected for pre-processing. The boundary conditions are as per the test set up used for experimental testing. As per the customer requirement the crankshaft was subjected to torsion of 47.4 KN-m. The resonant bending fatigue test was carried out, so the bending load of 57 KN is applied on one plate to create the required bending moment. At exactly opposite side of bending load an accelerometer is fixed. At that point all degrees of the freedom are locked.

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2.2 Material of crankshaft

Crankshaft of alloy steel has material properties and parameters as listed in Table 1.

Table: 1 Crankshaft material properties

Modulus of Elasticity/ Poisson's ratio	210 GPa/ 0.3
Yield Strength	480 MPa
Ultimate Tensile Strength	760 MPa
Density	7850 Kg/m3
Surface roughness	2μm

2.3 Static Analysis Results

Figure 3 shows the view of the fillets showing the areas under compression with blue color and those under tension with red color due to applied bending moment. The maximum stress obtained at the fillet is 753 MPa which is well below the yield strength of the material for pure bending. For individual moment loading, areas near the fillets as well as the area near to oil holes are mostly affected. From figure 4, it is seen that maximum stress is 741 Mpa. Combined (Bending + Torsion) loading shows that the stresses developed are the cumulative effect of stresses of individual loadings. From figure 5, it is seen that maximum stress is 639 MPa which is less than that for individual bending or individual moment loading.

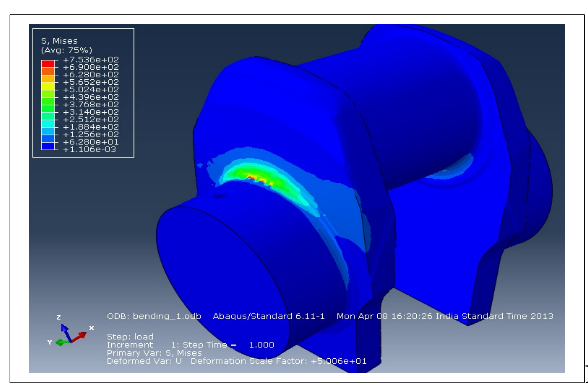

Figure 1 : Von-Mises stresses result due to Bending

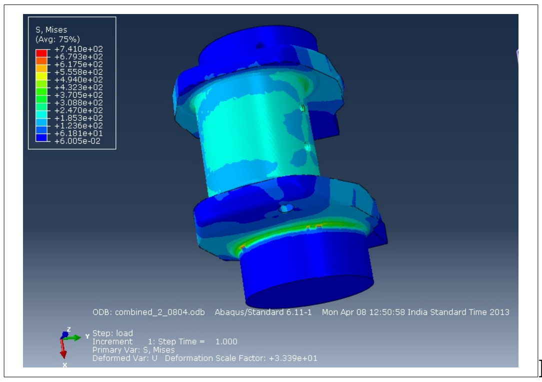

Figure 2: Von-Mises stresses result due to Torsion

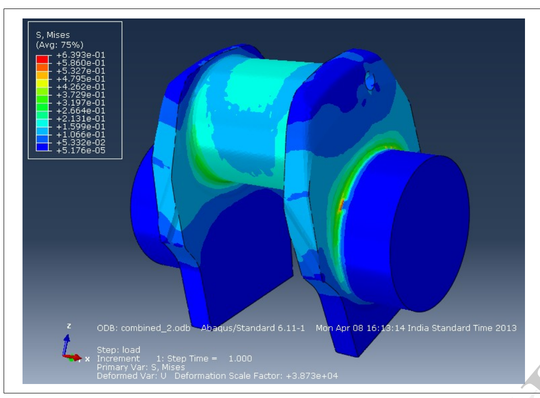

Figure 3: Von-Mises stresses result due to Combined (Bending + Torsion) loading

3. Fatigue Life Assessment by FEA

The main objective of estimating the fatigue life of crankshaft is to investigate the behaviour of crankshaft under complex loading conditions. Due to the repeated bending and twisting, crankshaft fails, as cracks form in fillet area. Fatigue analysis of crankshaft is done in MSC Fatigue. .

The results obtained from the static analysis are used as input to the fatigue analysis. Fatigue results are tabulated as below.

Table 2 : Fatigue life results

	Fatigue life cycles by software (Nos.)	Fatigue life cycles by actual testing (Nos.)
Individual Bending	3170000	5000000
Individual Torsion	1620000	2000000
(Bending + Torsion) loading	463000	

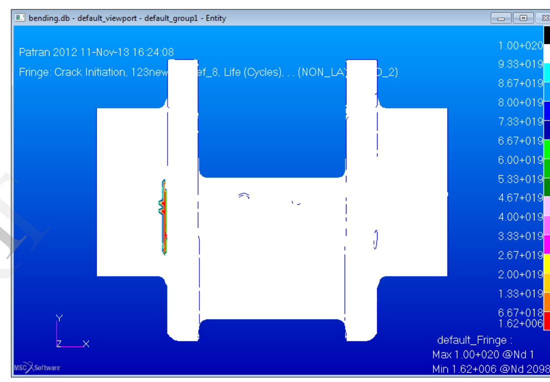

Figure: 4 Fatigue results under pure Bending

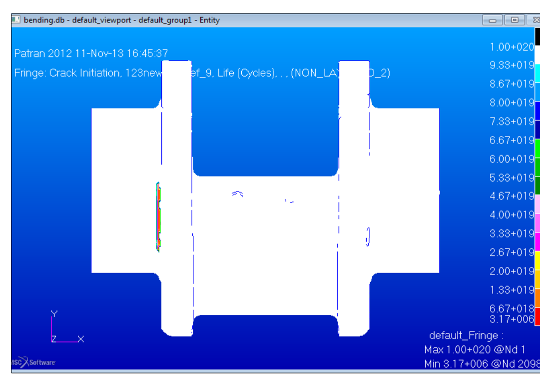

Figure: 5 Fatigue results under pure Torsion

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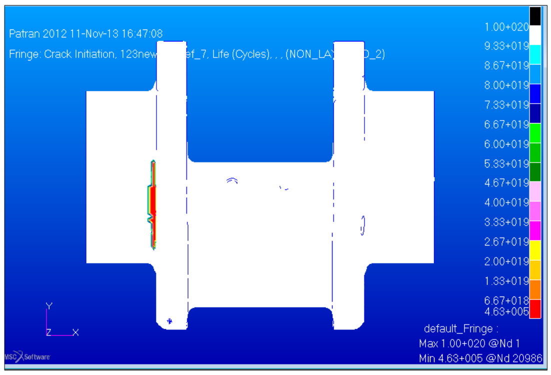

Figure: 6 Fatigue results under combined Bending and Torsion

4. Experimental Investigation of Fatigue Life of Crankshaft

4.1 Resonant Bending Test Set-up

The experimental fatigue testing in bending is based on the tuning fork method. The experimental results would then be compared with FEA results so that the FEA results can be validated. In the tuning fork method the single throw of crankshaft is assembled with two plates that become tines of the tuning fork, the total assembly of tines, crankshaft, stringing rod and stringing rod holder is hanged by ropes as shown in Figure 7. A crankshaft section is attached to two heavy steel tines and the system acts as a large tuning fork.

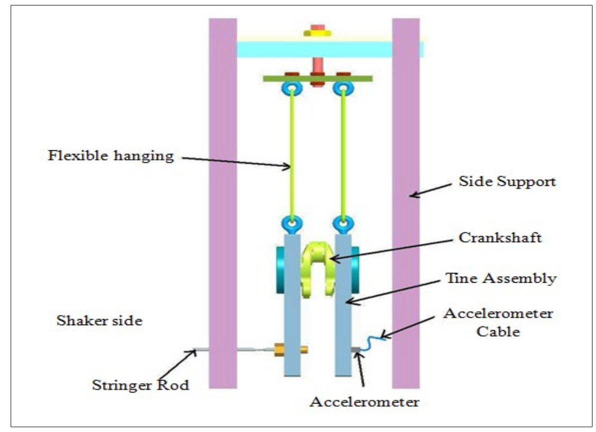

Figure: 7 Fatigue life test set-up for crankshaft.

5. Results and Discussions

The results obtained by FEA and experiments are described and the comparison between the two is discussed in this chapter. The critical locations in the crankshaft section are pin fillets, oil holes and journal fillets. The strain gauges were therefore mounted at these critical locations. These locations are labeled as 'a' and 'b' shown in Figure 8.

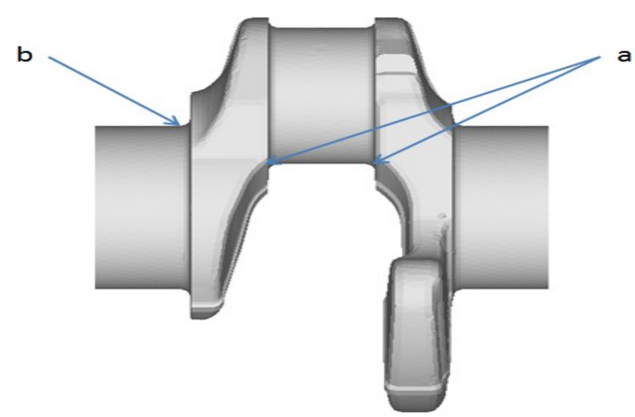

Figure: 8 Strain gauge mounting locations on crankshaft.

6. Conclusions

Fatigue life analysis of forged steel crankshaft was done using finite element methods and experimental

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methods. FE model of crankshaft is created using Hypermesh, FE analysis is done in ABAQUS 6.11and fatigue life was calculated with the help of MSC Fatigue software. Conclusions of presented study are listed as below:

1. There are two major loads in an engine the inertia load due to weight of the different components of engine and gas pressure after explosion of the fuel. These two loads are responsible for creating the bending and torsional moments in the crankshaft.
2. The static stress analysis is required to find out the maximum stresses and critical locations in the crankshaft.
3. Due to complex geometry finite element analysis is necessary to obtain the stresses in the crankshaft.
4. From the static analysis it is observed that the maximum stress is obtained at the pin fillet area which is found to be 753 MPa (Bending), 741 (Moment) and 639 (Bending + Moment).
5. During crankshaft fatigue tests, circumferential cracks developed in the crankpin And journal pin fillet area which is identified as the critical location from FEA.

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