Transient Load Analysis and stress analysis of Six Cylinder Crankshaft

Ashish Kalantri[1], Dr. Vivek Yakkundi[2]
[1]PG Student, Department of Mechanical Engineering, LTCOE, Navi Mumbai.
[2]Guide, Principal, LTCOE, Navi Mumbai.

Abstract

A fish bone diagram (see fig. 1.2) is developed to study the root cause analysis of crankshaft failure. The objective of this study is to find stress magnitude at critical locations by using finite element analysis. In this study a dynamic simulation is conducted on forged steel crankshaft of six cylinder four stroke diesel engine. The dynamic force analysis is carried out analytically. The load is then applied to the FE model in ANSYS and boundary conditions are applied. Considering torsional load in the overall dynamic loading conditions has no effect on von Mises stress at the critically stressed location. The effect of torsion on the stress range is also relatively small at other locations undergoing torsional load. Therefore, the crankshaft analysis could be simplified to applying only bending load. The principal plane stresses obtained by using finite element analysis are compared with normal stresses obtained by theortical calculation. Also vonmises stress is calculated theoretically and compared with finite element analysis (ANSYS) results.

I. INTRODUCTION

Crankshaft is an important engine component which is subjected to fluctuating or cyclic loads often resulting in failures. Crankshaft is an important engine component which is subjected to fluctuating or cyclic loads often resulting in failures. Three methods which are used to predict fatigue life include stress life (S-N curve), strain life (E-N) and linear elastic fracture mechanic (LEFM). This method can be helpful to test fatigue life but only disadvantage is that plasticity effect is not considered and provides poor accuracy for low cycle fatigue.Hence study is restricted to the stress analysis only.

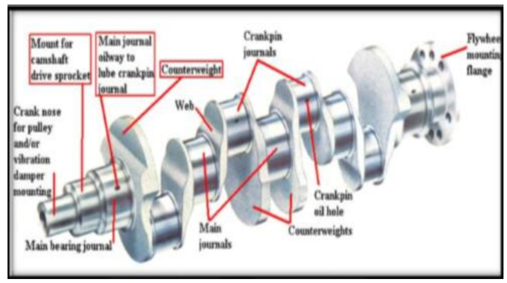

Figure 1.1: Crankshaft with main journals that support the crankshaft in the engine block. Crankpin journal are offset from the crankshaft centreline

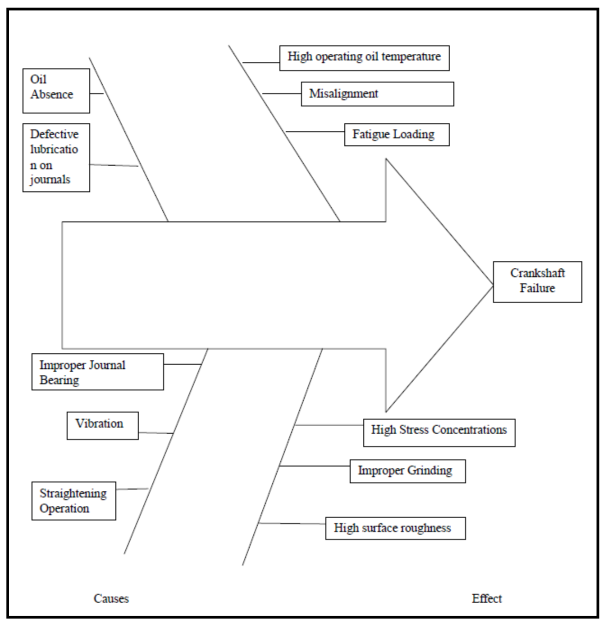

Figure 1.2: Fishbone diagram

II. DYNAMIC LOAD ANALYSIS OF THE CRANKSHAFT

The Crankshaft experiences a complex loading due to the motion of the connecting rod, which transforms two sources of loading to the crankshaft due to gas forces and inertia forces of moving parts. The main objective of this study is to obtain accurate magnitude of loading on crankshaft that consists of bending and torsion. The significance of torsion during a cycle and its maximum value compared to the total magnitude of loading need to be investigated to see if it is essential to consider torsion during loading or not. In addition, there is a need for obtaining the forces acting on the crankshaft which are time dependent during a cycle to carry out the FE analysis over the entire engine cycle to obtain stresses on the crankshaft.

The main objective of this chapter is to determine the magnitude and direction of the loads that act on the bearing between connecting rod and crankshaft, which is then used in the FE analysis over an entire cycle. An analytical approach on the basis of a single degree of freedom slider cranks mechanism.

To find forces acting on the crankshaft, it is necessary to find the forces acting on piston. These forces are time dependent and vary with crank angle. Generally it can be obtained by doing experiments and the results are in terms of graph. Therefore finding the forces at particular crank angle is difficult. Hence Get Data graph digitizer software is used for determining the values of forces acting on piston. The identified values are used in analytical calculations to determine forces acting on the crankshaft. A program is developed in MATLAB software to obtain the force distribution for performing analytical calculations.

A. *Determinations of gas forces*

Get Data software is used for determining the gas forces acting on the crankshaft? It converts the graphical data into digital format. Hence, it is possible to obtain the values at any point on the curve. Any arbitrary point can be selected on the graph. Corresponding values of parameter along X and Y axis are obtained. Results from this software can be saved in excel format. Thus it is very easy to use this data as per the functional requirement.

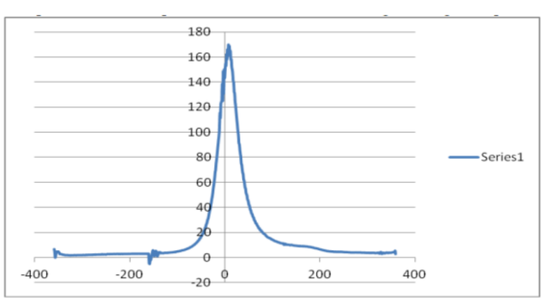

Figure 2.1: Pressure v/s crank angle (P - θ) diagram

The main objective is to determine the magnitude and direction of the loads that act on the bearing between connecting rod and crankshaft, which is then used in the FE analysis over an entire cycle. An analytical approach is used on the basis of a single degree of freedom slider cranks mechanism.

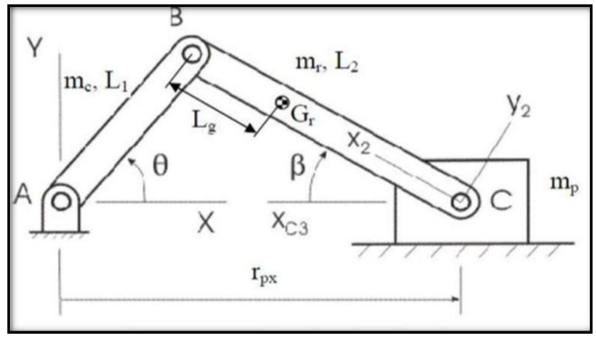

Figure2.2: Slider Crank Mechanism

Figure 2.2 shows the slider crank mechanism (Reciprocating engine). Where $r_{px}$is the distance between the crank centre and the piston centre and it varies with respect to crank angle θ and it is given by the equation below.

r_{px}= $L_1\cos(\theta) + L_2\cos(\beta)$

To find forces acting on the crankshaft, it is necessary to find the forces acting on piston. These forces are time dependent and vary with crank angle. Generally it can be obtained by doing experiments and the results are in terms of graph. On Y-axis pressure in bar is plotted and on X-axis crank angle in degree is plotted.

B. *Analytical approach used for determining the forces on crankshaft*

The identified values are used in analytical calculations to determine forces acting on the crankshaft. A program is developed in MATLAB software to obtain the force distribution for performing analytical calculations.

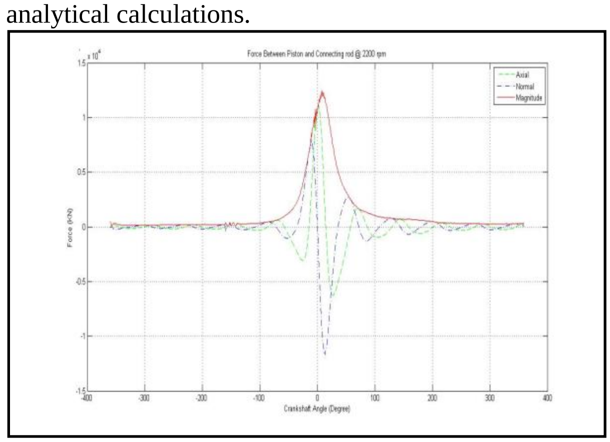

Figure 2.3: The bending and torsional load distribution is obtained by performing analytical calculations using MATLAB software

Therefore finding the bending and torsional load at particular crank angle is difficult. Hence Get Data graph digitizer software is used for determining the values of bending and torsional forces acting on piston.Hence a transient analysis (time dependent) using dynamic loading need to be performed to understand the maximum von mises stress faced by the crankshaft with respect to time in one cycle of the engine.

III. STRESS ANALYSIS OF CRANKSHAFT USING FINITE ELEMENT METHOD

There are two different approaches for applying the loads on the crankshaft to obtain the stresses at different time. One method is to run the FE model many times during the engine cycle or at selected times over 720° by applying the magnitude of the load with its direction in a way that the loading could define the stress-time history of the component.

A. Finite element modeling

Finite element modeling of any solid component consists of geometry generation, applying material properties, meshing the component, defining the boundary constraints, and applying the proper load type. These steps will lead to the stresses and displacements in the component. In this study, similar analysis procedure is performed for forged steel crankshafts.

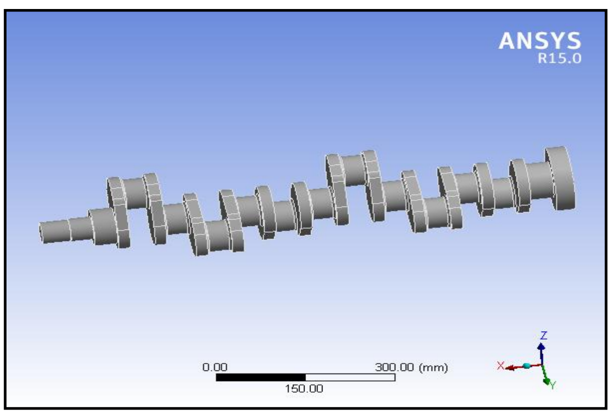

Figure 3.1: Solid Model of Forged Steel crankshaft

1) Mesh generation

FE analysis is performed on crankshaft for the dynamic load analysis. In this section, meshing for dynamic FEA is presented for the forged steel crankshafts. The Hex Dominant method is used for FEA mesh.

Quadratic elements are used to mesh the crankshaft finite element geometry. Quadratic elements are used for meshing the generated geometry to the ANSYS WORKBENCH software. Using linear quadratic elements results in a rigid model with less accuracy, whereas using quadratic elements increases the accuracy and lessens rigidity of the geometry. In order to mesh the geometry with this element type, the mapped meshing feature of ANSYS WORKBENCH software is used. In this feature, the global mesh size can be defined, while for locations free local meshing is used to increase the number of for critical locations free local meshing is used to increase the number of elements for accurate stress at location with high stress gradients. convergance of stresses at different locations is considered is considered as the criterion for mesh size and number of elements selection

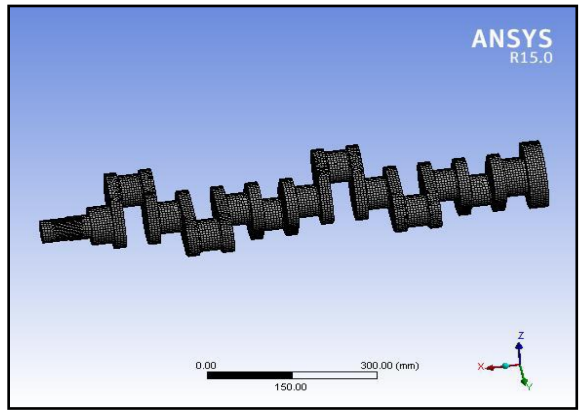

Figure 3.2: Meshed geometry of the forged steel crankshaft with 111983 elements.

2) Loading and boundary conditions

It is seen from the crankshaft design that it is constrained i.e. supported by 7 ball bearings in the engine. These bearing areas are constrained by using cylindrical support given in ANSYS constrain menu. Cylindrical support is only applied on cylindrical surfaces. It restricts all DOF (Degree of freedom) except rotational about cylinder axis.So now the crankshaft can only rotate about the cylindrical axis with all the other degree of freedom arrested. The forces are applied on cylinders by applying load given in ANSYS constrain menu. Prior to this initial conditions are set with degrees converted into time in 8 steps.

B. Finite element analysis results and discussion

In the present work, there are two approaches for applying the loads on the crankshaft. One of the approaches used for FE analysis is to run the model over 720° at different angle. In the ANSYS software time is considered to be independent function as default. Therefore crank angle is converted into time and the loads are applied at these time. In this way, dynamic finite analysis is performed for forged steel crankshaft and results are obtained and explained below.

C. Principal plane stress and Normal stress

The Mohr's circle diagram principle is used to calculate normal theoretical stress.
Following equations are used [13]:

$$\sigma_1 = ((\sigma_x + \sigma_y)/2) + (((\sigma_x - \sigma_y)/2)^2) + (\tau_{xy})^2)^{1/2} \quad \ldots\ldots(1)$$

$$\sigma_2 = ((\sigma_x + \sigma_y)/2) - (((\sigma_x - \sigma_y)/2)^2) + (\tau_{xy})^2)^{1/2} \quad \ldots\ldots(2)$$

The values of σ_1, σ_2 and τ_{xy} are obtained from ANSYS software and simplifying equations 1 and equation 2 for all the 8 steps, theoretical normal stresses σ_x and σ_y in MPa is obtained and results are compared as follows:

Table 3.1 Principal plane stress and normal stress values for forged steel crankshaft at 2200 rpm

	FEA Stress			Theoretical stress	
	Principal Plane stress in Mpa			Normal stress in MPa	
CRANK ANGLE	TIMINGS	σ_2	σ_1	σ_x	σ_y
90	0.00681	85.263	243.56	242.8	86.023
180	0.01362	137.2	519.99	519.375	137.81
270	0.02043	84.552	320.3	319.685	85.161
360	0.02724	5230.3	15361	15360.3	5231
450	0.03405	989.1	4002	4001.383	989.717
540	0.04086	351.14	1106.8	1106.18	351.76
630	0.04767	2105.4	8144.2	8143.59	2106
720	0.05448	78.232	261.54	260.876	78.9

σ_1 and σ_2 are Principal plane stresses in MPa and τ_{xy} is shear stress in MPa.
Also vonmises stress is calculated theoretically and compared with finite element analysis (ANSYS) results.

Table 3.2 Von Mises stress for forged steel crankshaft at 2200 rpm

	FEA Principal Stress in MPa		Von Mises stress in MPa	
	Principal Stress		Theoretically calculated stress	FEA Stress
TIMINGS	σ_2	σ_1	σ_{vth}	σ_v
0.00681	85.263	243.56	214.0668038	218.22
0.01362	137.2	519.99	466.7663357	430.91
0.02043	84.552	320.3	287.5050001	265.49
0.02724	5230.3	15361	13526.77792	14435
0.03405	989.1	4002	3610.532455	3410.5
0.04086	351.14	1106.8	979.6243094	860.28
0.04767	2105.4	8144.2	7322.151605	6736.4
0.05448	78.232	261.54	232.5136988	224.45

IV. CONCLUSION AND FUTURE SCOPE

Present project work is for six cylinder diesel engine with four stroke cycle. The principal plane stresses obtained by using finite element analysis are compared with normal stresses obtained by theoretical calculation. Also vonmises stress is calculated theoretically and compared with finite element analysis (ANSYS) results.
Crankshaft is an important component of engine, failure even makes the engine useless and requires costly procurement and replacement. An extensive research in the past clearly indicates that the problem has not yet been overcome completely and designers are facing lot of problems specially related with multi-axial loading (Bending and Torsion), stress concentration and stress gradient and effect of variable amplitude loading. The Finite element method is the most popular approach and found commonly used for analyzing fracture mechanics problems. The method can be applied to linear and non-linear problems.

Present project work is for six cylinder diesel engine with four stroke cycle. Work can be extended to multi-cylinder engine for example railway engines (32 cylinders) with minor modifications.

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