Static Stress Analysis and Optimization of a Diesel Engine Crankshaft using FEA

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ABSTRACT

Crankshaft is one of the most critically loaded component in the engine as it experiences cyclic loads in the form of bending and torsion during its working condition. Its failure will cause serious damage to the engine. So, its reliability verification must be performed. This topic was chosen because of increasing interest in the higher payloads, higher efficiency and lower weight crankshafts.

The static stress analysis is conducted on a crankshaft of a single-cylinder 4 stroke diesel engine using finite element method. ANSYS WB14 is used for the analysis using 4 different materials to find the distribution of maximum deformation, maximum shear stress and von-mises stress on the crankshaft. The results would provide a valuable foundation for the optimization of mass and material selection.

Keywords: Crankshaft, FEM, Stress, Fillet, Optimization etc.

I. INTRODUCTION

In recent years, there are many kinds or development of vehicle engine especially car and motorcycle engine. Each automotive company tried to develop their own engine to compete for new technology or invention in market. Internal combustion engine is one type of automotive engine in which fuel that run the mechanism is burned internally or burned inside the engine cylinder. There are two types in internal combustion engine which is reciprocating and rotary engine. The type of engine that usually used is two stroke and four stroke engine. In internal combustion engine, piston is one of the important part defined as cylindrical component that moves up and down in the cylinder bore by force produce during the combustion process.

Crankshaft is a large component in an engine having complex geometry that converts linear reciprocating displacement of the piston to a rotary motion of the crank with a four link mechanism. Since the crankshaft experiences a large number of load cycles during its service life, its fatigue performance and durability has to be considered in the design process. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with minimum weight, proper fatigue strength, higher fatigue life and satisfying other functional requirements.

Since crankshaft is subjected to several forces which vary in magnitude and direction (multiaxial). Connecting rod transmitting gas pressure from cylinder to crankpin, the stresses acting in the crankshaft vary with respect to time [5]. Most of time, crankshaft fails due to fatigue at fillet areas due to bending load. Fillet rolling can increase fatigue life [6]. Engine mechanism and geometry has large impact on fillet which experiences a large stress cycle during its working life. Small crack initiates at this fillet location due to the stress concentration which will propagate subsequently and failure of crankshaft takes place[1]. Most of the crankshafts that failed in fatigue were due to bending. Hence, fatigue Design and Development has always an important issue in the crankshaft production industry to manufacture less expensive crankshaft with high fatigue strength [2].

Fig.1 Nomenclature of crankshaft
Crankshaft consists of the shaft parts which revolve in the main bearings, the crankpin to which the big end of the connected rod is connected, the crank arms or webs (also called cheeks) which connect the crankpin and the shaft parts. The crankshaft main journal rotate in a set of supporting bearings (main bearings) causing the offset road journals to rotate in circular path around the main journal centers, the diameter of that path is the engine stroke. Crankshaft must be strong enough to take the downward force of the power stroke without excessive bending. So, the reliability and life of the internal combustion engine depend on the strength of the crankshaft mainly. As the engine runs, power impulses hit the crankshaft in one place and then another. The torsional vibration appears when a power impulse hits a crankpin toward the front of the engine and the power stroke ends. If not controlled, it can break the crankshaft.

Reasons for the failure of crankshaft

i. Incorrect geometry leads to stress concentration.
ii. Crankpin material & its chemical composition
iii. Pressure acting on piston
iv. overloading on the engine

Table 1 Materials used in the analysis with properties

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Parameter</th>
<th>Forged steel</th>
<th>Cast iron</th>
<th>Carbon steel</th>
<th>Gray Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ρ (kg/m³)</td>
<td>7200</td>
<td>7200</td>
<td>7800</td>
<td>7100</td>
</tr>
<tr>
<td>2</td>
<td>E (Gpa)</td>
<td>206.7</td>
<td>176</td>
<td>192</td>
<td>97</td>
</tr>
<tr>
<td>3</td>
<td>Γ</td>
<td>0.3</td>
<td>0.275</td>
<td>0.33</td>
<td>0.26</td>
</tr>
<tr>
<td>4</td>
<td>σy (MPa)</td>
<td>625</td>
<td>621</td>
<td>530</td>
<td>98</td>
</tr>
<tr>
<td>5</td>
<td>σu (MPa)</td>
<td>850</td>
<td>827</td>
<td>625</td>
<td>152</td>
</tr>
</tbody>
</table>

Stresses on crankshaft

Crankshaft experiences various stresses due to gas pressure generated inside the cylinder by the combustion of air and fuel mixture. The following two types of stresses are induced in the crankshaft.

1. Bending stress
2. Shear stress due to torsional moment on the shaft.

The crankshaft is subjected to various forces but generally needs to be analyzed in two positions. Firstly, failure may occur at the position of maximum bending; this may be at the centre of the crank or at either end. In such a condition the failure is due to bending and the pressure in the cylinder is maximal. Second, the crank may fail due to twisting, so the connecting rod needs to be checked for shear at the position of maximal twisting. The pressure at this position is the maximal pressure, but only a fraction of maximal pressure.

![Fig.2 Various forces acting on a slider-crank mechanism](image)

II. OBJECTIVE OF THE PROJECT

To analyze the stresses acting on the crankpin due to gas force. Analyze the maximum deformation, maximum stress point and dangerous areas of failure. Optimize the design to reduce the weight of the component so that inertia effect can be minimized.

III. METHODOLOGY

i. Measuring the dimensions of crankshaft
ii. Modeling the part in CATIA V5 software
iii. Importing the solid model into ANSYS module
iv. Applying load and boundary conditions
v. Comparing the ANSYS results
vi. Optimization

IV. LITERATURE REVIEW

C M. Balamurugan et al [1]. He has been studied the Computer aided Modelling and Optimization of crankshaft and compared the fatigue performance of two competing materials of crankshaft namely forged steel and ductile cast iron. The 3D models of crankshaft were created by solid edge software and then imported to ANSYS software. The optimization process included geometry changes compatible with the current engine, fillet rolling and results in increased fatigue strength and reduced the cost and mass of the crankshaft.

Abhishek Choubey and Jamin Brahmbhatt [2]. They analyzed the 3D model of the crankshaft of diesel which were created by SOLID WORKS Software and imported to ANSYS software. In the crankshaft maximum deformation was appeared at the centre of crankpin neck surface.
Von-mises stress appears at the fillets between the crankshaft journals and crank webs and near the central point journal. The edge of main journal is the critical area as it is high stress concentrated area.

R. J. Deshbhratar and Y.R Suple [3]. They were analyzed the 4- cylinder crankshaft modeled in Pro/E Software and imported into ANSYS software. Maximum deformation appears at the centre of crankshaft surface. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks, and near the central point. The edge of main journal is the high stress concentrated area. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks.

Ling et al. [4]. They conducted the fatigue life prediction of the model and residue life assessment based on statistics of historical working state (SHWS) at crankshaft using fatigue damage accumulation (FDA) theory. Dynamic response of typical operation performance is analyzed with software ANSYS. And high stress zone was found. Then, via rain flow cycle counting to obtain stress time history, together with SHOP, fatigue load spectra of key parts are compiled. Finally, FDA model is built up with nominal stress method and residue life based on SHWS is predicted the crankshafts of diesel engine. It was found that main shaft journal of crankshaft near the power output side and connected rod journal have relatively high stress, and FDA of the same time is relatively larger.

### Applied load and boundary conditions

A normal pressure of 11 MPa with factor of safety 1.5 is applied on the component when the crank is at the position of maximum bending moment or is at the dead centre. Load data were taken from the experiment conducted on the Kirlosker TV1 engine in our college energy conversion laboratory.

The two main journal areas are fixed in the analysis according to the real condition of the part in the engine. This constitute a fixed boundary condition in our static analysis. Boundary conditions applied here represents the actual running condition of the engine using engine performance data i.e. the pressure v/s crank angle curve.

### Table 2 Allowable bending and shear stress on Crankshaft [7]

<table>
<thead>
<tr>
<th>Material</th>
<th>Endurance in MPa</th>
<th>Allowable stress in MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bending</td>
<td>Shear</td>
</tr>
<tr>
<td>Chrome nickel</td>
<td>525</td>
<td>290</td>
</tr>
<tr>
<td>Carbon and cast steel</td>
<td>225</td>
<td>124</td>
</tr>
<tr>
<td>Alloy cast iron</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

### V. RESULT AND DISCUSSION

By the ANSYS WB14 analysis software got the results like von-mises stress, maximum shear stress and total deformation on crankshaft by applying load of 11 MPa at the centre of crankpin when crankshaft is at dead centre. The results obtained on 4 different material types of crankshaft are compared for stresses, deformation and mass. The material which has low density, induces low stress and deformation on a crankshaft has been selected as a suitable material in the analysis.
Modification to the present model

Results obtained from the present crankshaft are compared one another and shows that there is a chance for reducing the mass. Fillet of 5 mm radius has been applied on the less critical sections as shown in fig. mass of about 65 grams has been reduced. So, optimization in mass of the component has been achieved.
VI. CONCLUSION

Finally, by comparing all the determinants like von-mises stress, shear stress, deformation and mass on all type material crankshaft, Gray cast iron crankshaft is best suitable from the study. Since, all the determinants are within safe limit and mass of the Gray cast iron crankshaft is about 9.0277 kg which is lesser amongst different material crankshafts. For the present modal, fillet of 5 mm radius has been applied and 64 grams of material is reduced. Even though, all the determinants are within the allowable limit. By considering the inertia effect of crankshaft in the engine, Gray cast iron crankshaft will impose less inertia effect.

REFERENCES


