COMPUTER AIDED DESIGN AND ANALYSIS OF CRANKSHAFT FOR DIESEL ENGINE

N. TRACY JONAFARK & Y. V. MOHAN REDDY
Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India

ABSTRACT

Crankshaft is one of the critical components for the effective and precise working of the internal combustion engine. In this paper a dynamic simulation is conducted on a crankshaft from a single cylinder 4-stroke diesel engine. A three-dimension model of diesel engine crankshaft is modeled using UNIGRAPHICS software. Finite element analysis (FEA) is performed to obtain the variation of stress magnitude at critical locations of crankshaft. Simulation inputs are taken from the engine specification chart. The dynamic analysis is done using FEA Software ANSYS which resulted in the load spectrum applied to crank pin bearing. This load is applied to the FE model in ANSYS, and boundary conditions are applied according to the engine mounting conditions. The analysis was done for different engine speeds and as a result critical engine speed and critical region on the crankshaft were obtained. Stress variation over the engine cycle and the effect of torsional load in the analysis were investigated.

KEYWORDS: Crank Shaft in Ansys, Finite Element Analysis, Stress Analysis

INTRODUCTION

Crankshaft is one of the most important moving parts in internal combustion engine. Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston into a rotary motion. And as the engine runs, the 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. Crankshaft model is modeled by UNIGRAPHICS NX5 software and then imported to ANSYS software. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal, crankpin and crank cheeks. Researched a three-dimensional model of a diesel engine crankshaft was established by using UNIGRAPHICS NX5 software. Using ANSYS analysis tool, it shows that the high stress region mainly concentrates in the knuckles of the crank arm & the main journal and the crank arm & connecting rod journal, which is the area most easily broken. Described the stress concentration in static analysis of the crankshaft model. This paper deals with the dynamic analysis of the whole crankshaft. Investigated first dynamic load analysis of the crankshaft. Results from the FE model are then presented which includes identification of the critically stressed location, variation of stresses over an entire cycle, and a discussion of the effects of engine speed as well as torsion load on stresses.

A detailed procedure of obtaining stresses in the fillet area of a crankshaft was introduced by Henry et al. [1], in which FEM and BEM (Boundary Element Method) were used. Obtained stresses were verified by experimental results on a 1.9 liter turbocharged diesel engine with Ricardo type combustion chamber configuration. The crankshaft durability assessment tool used in this study was developed by RENAULT. The software used took into account torsional vibrations and internal centrifugal loads. Fatigue life predictions were made using the multiaxial Dang Van criterion. The procedure developed is such it that could be used for conceptual design and geometry optimization of crankshaft. Jian Meng et al. [4]
analyzed crankshaft model and crank throw were created by Pro/ENGINEER software and then imported to ANSYS software. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal, crankpin and crank cheeks. Gu Yingkui et al. [7] researched a three-dimensional model of a diesel engine crankshaft was established by using PRO/E software. Using ANSYS analysis tool, it shows that the high stress region mainly concentrates in the knuckles of the crank arm & the main journal and the crank arm & connecting Guagliano et al. [9] conducted a study on a marine diesel engine crankshaft, in which two different FE models were investigated. Due to memory limitations in meshing a three dimensional model was difficult and costly. Therefore, they used a bi-dimensional model to obtain the stress concentration factor which resulted in an accuracy of less than 6.9 percent error for a centered load and 8.6 percent error for an eccentric load. This numerical model was satisfactory since it was very fast and had good agreement with experimental results. Nallicheri et al. (10) performed on material alternatives for the automotive crankshaft based on manufacturing economics. They considered steel forging, nodular cast iron, micro-alloy forging, and austempered ductile iron casting as manufacturing options to evaluate the cost effectiveness of using these alternatives for crankshafts.

Function of Crankshafts in IC Engines

The crankshaft, connecting rod, and piston constitute a four bar slider-crank mechanism, which converts the sliding motion of the piston (slider in the mechanism) to a rotary motion. Since the rotation output is more practical and applicable for input to other devices, the concept design of an engine is that the output would be rotation. In addition, the linear displacement of an engine is not smooth, as the displacement is caused by the combustion of gas in the combustion chamber. Therefore, the displacement has sudden shocks and using this input for another device may cause damage to it. The concept of using crankshaft is to change these sudden displacements to a smooth rotary output, which is the input to many devices such as generators, pumps, and compressors. It should also be mentioned that the use of a flywheel helps in smoothing the shocks. Figure 1 shows the P-V diagram during an engine cycle for a four stroke cycle engine, where Vd is the volume swept by the piston and Vbdc is the volume of the cylinder when the piston is at the bottom dead centre (BDC).

![Figure 1: Typical Crankshafts with Main Journals that Support the Crankshaft in the Engine Block](image1)

![Figure 2: Side View of the Engine Block at the Time of Combustion](image2)
Figure 3: P-V Diagram at Constant Delivery Ratio. Curve 5 is for 900 rev/min, Curve 6 for 1200 rev/min, Curve 7 for 1500 rev/min, and Curve 8 for 1800 rev/min

Operating Conditions and Failure of Crankshafts

Crankshaft is one of the largest components in the internal combustion engine that has a complex geometry consisting of cylinders as bearings and plates as the crank webs. Geometry section changes in the crankshaft cause stress concentration at fillet areas where bearings are connected to the crank webs. In addition, this component experiences both torsional and bending load during its service life. Therefore, fillet areas are locations that experience the most critical stresses during the service life of the crankshaft. As a result, these locations are main sections of fatigue failure of the component. The size of a crankshaft depends on the number of cylinders and horsepower output of the engine. The size of the crankshaft could range from 3.2 kg for a single cylinder engine with the output power of 12 hp, to 300 tons for a fourteen cylinder diesel engine with the output power of 108,920 hp. In an internal combustion engine, two load sources apply force on the crankshaft. The load applied by combustion in the combustion chamber to the piston is transmitted to the crankpin bearing by a four bar slider-crank mechanism. The other load source is due to dynamic nature of the mechanism. Since the engine operates at high speeds, the centrifugal forces are present at different rotating components such as connecting rods. These load sources apply both torsional and bending load on the crankshaft. classifies the cause of journal bearing failure or damage to three possible sources; “(a) operating sources such as oil absence on carter, defective lubrication of journals, high operating oil temperature, improper use of the engine (over-revving); (b) mechanical sources such as misalignments of the crankshaft on 18 the assembling, improper journal bearings (wrong size), no control on the clearance size between journals and bearings, crankshaft vibration; (c) repairing sources such as misalignments of the journals (due to improper grinding), misalignments of the crankshaft (due to improper alignment of the crankshaft), high stress concentrations (due to improper grinding at the radius on both sides of the journals), high surface roughness (due to improper grinding, origination of wearing), improper welding or nitruration, straightening operation, defective grinding.”. Another common failure in the crankshafts is mechanical crack nucleation at the fillet radius of journal bearings. Different criteria are used in identifying the crack in the fillet area the relationship of different failure modes such as surface cracks, stiffness change, and two-piece failures on different crankshafts.

The Most Common Causes for Crankshaft Failures are below

- Loss of effective lubrication. This can be due to contaminated lube oil, failed lube oil pumps, poor quality or incorrect specification lube oil.
- Over speeding of engines, or long term operation in a critical or forbidden rev range.
- Faulty crankshaft damper or detuner, designed to remove excessive vibration from the crankshaft. Failure of proper operation can lead to excessive crankshaft vibration and fatigue.
• Engine power imbalance leading to fatigue failure, cyclic loading. This can be caused by poor maintenance or monitoring of engine power, or even poor quality fuel.

• Hydraulic locking of cylinders, flooding of cylinders with cooling water.

• Bearing misalignment, which can be detected early with proper crankshaft deflection measurement.

• Design faults, a common problem as more licenses’ are passed out to new shipyards. Incorrect or blatant ignorance of material compositions or poor manufacture of crankshaft can lead to early failure.

• Overloading of engine.

• For propulsion machinery, grounding, and/or fouling of the propeller. It is essential that crankshafts are Manufactured using the correct materials. They are machined to a very high standard to avoid stress raisers leading to high areas of stress and potential points of failure.

UNIGRAPHICS NX5

NX is one of the world’s most advanced and tightly integrated CAD/CAM/CAE product development solutions. Spanning the entire range of product development, NX delivers immense value to enterprises of all sizes. It simplifies complex product designs, thus speeding up the process of introducing products to the market. The NX software integrates knowledge-based principles, industrial design, geometric modeling, advanced analysis, graphic simulation, and concurrent engineering. The software has powerful hybrid modeling capabilities by integrating constraint-based feature modeling and explicit geometric modeling. In addition to modeling standard geometry parts, it allows the user to design complex free-form shapes such as airfoils and manifolds. It also merges solid and surface modeling techniques into one powerful tool set.

BRIEF HISTORY OF CAD/CAM DEVELOPMENT

The roots of current CAD/CAM technologies go back to the beginning of civilization when engineers in ancient Egypt recognized graphics communication. Orthographic projection practiced today was invented around the 1800’s. The real development of CAD/CAM systems started in the 1950s. CAD/CAM went through four major phases of development in the last century. The 1950’s was known as the era of interactive computer graphics. MIT’s Servo Mechanisms Laboratory demonstrated the concept of numerical control (NC) on a three-axis milling machine. Development in this era was slowed down by the shortcomings of computers at the time. During the late 1950’s the development of Automatically Programmed Tools (APT) began and General Motors explored the potential of interactive graphics.

DESIGN CALCULATION FOR CRANKSHAFT

The configuration of the diesel engine for this crankshaft is tabulated in Table 1

<table>
<thead>
<tr>
<th>Table 1: Specifications of Atul Shakti Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
</tr>
<tr>
<td>Number of Cylinders</td>
</tr>
<tr>
<td>Bore x Stroke</td>
</tr>
<tr>
<td>Compression Ratio</td>
</tr>
<tr>
<td>Maximum Power</td>
</tr>
<tr>
<td>Maximum Torque</td>
</tr>
<tr>
<td>Maximum gas pressure</td>
</tr>
</tbody>
</table>
STRUCTURAL ANALYSIS

Units: /units, si, mm, kg, sec, k
Preference: Structural
Preprocessor: Element Type → Solid 20node 95 → ok

MATERIAL PROPERTIES OF FORGED STEEL

Youngs modulus = 221000MPa
Poission's ratio = 0.3
Density = 7833Kg/m3 = 0.00007833
Pressure → on areas = 0.3313N/mm2.

STRUCTURAL ANALYSIS OF FORGED STEEL
DYNAMIC ANALYSIS OF FORGED STEEL

Material Properties

Young’s Modulus = 221000Mpa

Poisson’s Ratio = 0.3

Density = 0.000007833 Kg/m³

10 Seconds
RESULTS AND CONCLUSIONS

- In this paper, the crankshaft model was created by UNIGRAPHICS NX5 software. Then, the model created by UNIGRAPHICS was imported to ANSYS software.

Table 2: Structural Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Displacement (mm)</th>
<th>Stress (N/m²)</th>
<th>Total Strain Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAST IRON</td>
<td>0.006241</td>
<td>14.506</td>
<td>0.112E-03</td>
</tr>
<tr>
<td>FORGED STEEL</td>
<td>0.005026</td>
<td>14.506</td>
<td>0.657E-04</td>
</tr>
</tbody>
</table>

Table 3: Dynamic Analysis of Forged Steel

<table>
<thead>
<tr>
<th>Time</th>
<th>Displacement (mm)</th>
<th>Stress (N/m²)</th>
<th>Total Strain Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 sec</td>
<td>0.005009</td>
<td>13.627</td>
<td>0.617E-04</td>
</tr>
<tr>
<td>20 sec</td>
<td>0.010015</td>
<td>27.255</td>
<td>0.213E-03</td>
</tr>
<tr>
<td>30 sec</td>
<td>0.015026</td>
<td>40.872</td>
<td>0.185E-03</td>
</tr>
</tbody>
</table>

RESULTS OF ANALYSIS

- The maximum deformation appears at the center of crankpin neck surface.
- The maximum stress appears at the fillets between the crankshaft journal and crank cheeks and near the central point Journal.
- The edge of main journal is high stress area.
- Analysis Results. So we can Say that Dynamic FEA is a good tool to reduce Costly experimental work.

CONCLUSIONS

Analysis results from testing the crankshaft under static load containing the stresses and deflection are listed in the Table. Since the forged iron crankshaft is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the cast iron crankshaft by forged crankshaft. We also reduce forged crankshaft the cost by the mass production.

Diesel engines are excellent propulsion engines from the viewpoint of fuel economy and the crankshafts, being important parts of the diesel engines, are required to have higher performances and qualities. We will continue to respond the needs for crankshafts from the engine manufacturers by continuing further research and development.
REFERENCES


5. MENG Jian., LIU Yong-qi., LIU Rui-xiang., and ZHENG Bin., 2011, “Intension Analysis of 3-D Finite Element Analysis on 380 diesel crankshaft,” International Conference on Computational and Information Sciences


