DESIGN AND MODAL ANALYSIS OF AUTOMOTIVE CRANKSHAFT FOR MATERIAL OPTIMIZATION USING ANSYS WORKBENCH

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Abstract—Crankshaft is one of the most important parts in internal combustion engine, which converts the reciprocating displacement of the piston to a rotary motion. Finite element analysis (FEA) is performed to obtain the variation of stresses. The linear static and modal analysis will be conducted using FEA Software ANSYS. Linear Static and Modal Analysis will be conducted on the crankshaft with three different materials like Static Structural, Chilled Cast Iron, Titanium Alloy and Aluminum Alloy to obtain variation of stresses and deformations in the crankshaft. The Von-Mises Stresses induced in the crankshaft with Titanium Alloy and Aluminum Alloy is lesser than Structural Steel and Chilled Cast Iron. Natural frequencies has been plotted by performing Modal Analysis. In this project Aluminum Alloy 6061 has been suggested for crankshaft for better performance compared to other materials. The FE result validations has been done by theoretical calculations.

I. INTRODUCTION

A crankshaft is a mechanical segment equipped for play out a change among reciprocating movement and rotational development. In a reciprocating engine, it translates reciprocating development of the cylinder into rotational development; while in a reciprocating compressor, it changes over the rotational movement into reciprocating movement. So as to do the change between movements, the crankshaft has “crank throws” or “crankpins”, additional bearing surfaces whose hub is counterbalanced from that of the wrench, to which the "enormous closures" of the interfacing poles from each barrel append.

II. OBJECTIVES AND METHODOLOGY

Objectives:
- The primary objective of the current work is to study the stresses of Crankshaft with different materials like Structural Steel, Chilled Cast Iron, Titanium Alloy and Aluminum Alloy by FEA analysis.
- Design and material optimization of crankshaft for better performance of engine

Methodology:
1. 3d CAD model of the design will be created.
2. FE Model of the design will be created.
3. Analysis under Static and modal conditions will be done with different materials and the behavior of component will be estimated.
4. Based on the results obtained in analysis the design will be optimized in different stages.
5. Finalized design will be presented.
III. RESULTS & DISCUSSIONS

DESIGN CALCULATIONS FOR THE CRANK SHAFT:
Following table shows the engine configuration of the diesel engine for the crankshaft:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>395cc</td>
</tr>
<tr>
<td>No. Cylinders</td>
<td>1</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>18:1</td>
</tr>
<tr>
<td>Max Power</td>
<td>8.1 HP@3600RPM</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>16.7 N.m@2200RPM</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>35 Bar</td>
</tr>
<tr>
<td>Bore Dia</td>
<td>53.73mm</td>
</tr>
</tbody>
</table>

Table: Engine Specifications

Force from Piston, $P_{\text{max}} = 35 \text{ bar} = 3.5 \text{N/mm}^2$
Bore Diameter, $D = 53.73\text{mm}$
Diameter of Crank Pin = 32mm
$b_2 = 15\text{mm}$
\[ F_Q = P_{\text{max}} \times A = P_{\text{max}} \times \frac{\pi D^2}{4} = 3.5 \times \frac{\pi (53.73)^2}{4} \]

\[ F_Q = 7.93 \text{kN} \]

To find thrust force acting on connecting rod \( [F_C] \) & the angle of inclination \([\theta] \) of connecting rod with line of stroke is given by,

\[ \sin \theta = \frac{F_Q}{L} \rightarrow \frac{\sin 35^\circ}{4} \]

\[ \theta = 8.24^\circ \]

Therefore, thrust force in connecting rod, \( F_C = \frac{F_Q}{\cos \theta} \rightarrow F_C = \frac{7.93}{\cos 8.24^\circ} \)

\[ F_C = 8.01 \text{kN} \]

Thrust force can be split into Tangential component & Radial component

1. Tangential force on crankshaft, \( F_T = F_C \sin (\theta + \theta) \)
   \[ = 8.01 \sin (35^\circ + 8.24^\circ) \]
   \[ F_T = 5.48 \text{kN} \]

2. Radial force on crankshaft, \( F_R = F_C \cos (\theta + \theta) \)
   \[ = 8.01 \cos (35^\circ + 8.24^\circ) \]
   \[ F_R = 5.83 \text{kN} \]

Reaction at bearing 1 & 2 due to tangential force is given by,

\[ H_{T1} = H_{T2} = \frac{F_T}{2} = 2.74 \text{kN} \]

Similarly, reaction at bearing 1 & 2 due to Radial force,

\[ H_{R1} = H_{R2} = \frac{F_R}{2} = 2.91 \text{kN} \]

**DESIGN OF CRANK PIN**

Diameter of crank pin, \( d = 32 \text{mm} \)

We know the bending moment at the center of crankshaft,

\[ M_C = H_{R1} + b_2 \]

\[ = 2.91 \times 15 \]

\[ M_C = 43.65 \text{ KN.mm} \]

Twisting moment on Crank Pin, \( T_C = 61.94 \text{KNmm} \)

Equivalent twisting moment, \( T_e = \sqrt{(M_C^2 + T_C^2)} \rightarrow T_e = 75 \text{ KN.mm} \)

Therefore, Von Mises stress induced in Crank Pin, \( M_{ev} = \sqrt{\left[(K_b + M_C)^2 + \frac{3}{4}(K_t + T_C)^2\right]} \)

\[ M_{ev} = 70.46 \text{ KN.mm} \]

We know, \( M_{ev} = \frac{\pi}{32} d^3 \sigma_v \)

\[ \sigma_v = \frac{32 M_{ev}}{\pi d^3} \]

\[ \sigma_v = 21.90 \text{ N/mm}^2 \]

**IV. FEA RESULTS OF CRANK SHAFT**

In this project Static and Modal Analysis has been conducted for different materials as follows:

i. Structural Steel
ii. Chilled Cast Iron
iii. Titanium Alloy
iv. Aluminum alloy 6061

Geometry of Single Cylinder Crankshaft

![2D Drawing of Single Cylinder Crankshaft](image1)

**Fig: 2D Drawing of Single Cylinder Crankshaft**

3-D Model of Single Cylinder Crankshaft:

![3D Model of Single Cylinder Crankshaft](image2)

*Fig shows 3D model of single cylinder crankshaft generated by using CAD tool Software*

**FINITE ELEMENT MODEL OF SINGLE CYLINDER CRANKSHAFT:**
- Below fig shows the Finite Element Model of Single Cylinder Crankshaft which is generated by using CAE tool Ansys 15.0.
- Fine mesh has been generated to get better results
- Good quality Tetra Mesh is done.

![Finite Element Model Crankshaft](image3)

**Fig : Finite Element Model Crankshaft**
BOUNDARY CONDITIONS FOR LINEAR STATIC ANALYSIS:
In this project, Crankshaft of Single Cylinder Engine of Automotive is acting under maximum pressure of 3.5 MPa on Crank Pin End and both the bearing ends are fixed as shown in the figure.

LINEAR STATIC ANALYSIS OF SINGLE CYLINDER CRANKSHAFT WITH STRUCTURAL STEEL:
Linear Static analysis of crankshaft with chilled cast iron has been conducted. Below table shows the material properties of Structural Steel.

- **MATERIAL PROPERTIES OF STRUCTURAL STEEL:**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOUNGS MODULUS</td>
<td>2.1e^5 MPa</td>
</tr>
<tr>
<td>POISSONS RATIO</td>
<td>0.27</td>
</tr>
<tr>
<td>DENSITY</td>
<td>7.8e^-6 Kg/mm^3</td>
</tr>
<tr>
<td>ULTIMATE TENSILE YIELD STRESS</td>
<td>460 MPa</td>
</tr>
</tbody>
</table>

**Table : Material Properties of Structural Steel**

RESULTS OF VON MISES STRESS AND DEFORMATION OF CRANKSHAFT WITH STRUCTURAL STEEL:
- Below fig 6 shows the Von-Mises Stress plot of Structural Steel
- Maximum stress of 17.84 MPa has got at the time of Bearing Pressure
- The maximum stress is within the allowable stress, hence the design is safe
VON-MISES STRESS PLOT:

Fig : Von-Mises Stress Plot

DEFORMATION PLOT:

Fig : Deformation Plot
Fig : Zoom In View of Maximum Deformation

- Above fig shows the maximum deformation plot
- Maximum deformation of 0.0019 mm has got at the time of Bearing Pressure

SHEAR STRESS PLOT:

Fig: Shear Stress Plot.

- Above fig shows the shear stress plot.
- Maximum Shear Stress of 5.35 MPa is lesser than Allowable Shear Stress and the design is safe.
MODAL ANALYSIS OF SINGLE CYLINDER CRANKSHAFT WITH STRUCTURAL STEEL

Below are the Boundary Conditions used for the modal analysis:

- In case of Modal Analysis, no Loads or Forces will be applied.
- Component Natural Frequency is verified between 0 to 3600 RPM

Deformation plots for different Natural Frequencies:

<table>
<thead>
<tr>
<th>Total Deformation</th>
<th>Total Deformation 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Deformation Plot 1" /></td>
<td><img src="image2" alt="Deformation Plot 2" /></td>
</tr>
<tr>
<td><img src="image3" alt="Deformation Plot 3" /></td>
<td><img src="image4" alt="Deformation Plot 4" /></td>
</tr>
<tr>
<td><img src="image5" alt="Deformation Plot 5" /></td>
<td><img src="image6" alt="Deformation Plot 6" /></td>
</tr>
<tr>
<td><img src="image7" alt="Deformation Plot 7" /></td>
<td><img src="image8" alt="Deformation Plot 8" /></td>
</tr>
</tbody>
</table>
Table: Frequency Modes of Single Cylinder Crankshaft with Structural Steel

The following bar chart indicates the frequency at each calculated mode:

Summary:

- Above table shows the natural frequencies generated
- The maximum natural frequency in the crankshaft with Chilled Cast Iron is 10885 Hz
- It can be cleared that no one natural frequency is coincided with operating frequency, hence no resonance occurs
V. CONCLUSION

Linear Static Analysis and Modal Analysis has been performed by using FE Method for the different materials of Crankshaft. From the above FE Analysis of Crankshaft the following conclusions are made:

1. Von-Mises Stress and Maximum Deformations has been plotted for better performance of crankshaft
2. From the above analysis it can be observed that the Von-Mises Stress in the crankshaft with Structural Steel and Chilled Cast Iron are more compared to Titanium Alloy and Aluminum alloy 6061
3. Maximum deformation in the crankshaft with all the materials are negligible
4. Maximum Shear Stress in Titanium Alloy and Aluminum alloy 6061 is lesser compared Structural Steel and Chilled Cast Iron
5. From the modal analysis it can be observed that none of the natural frequencies are coincides with operating frequency and hence no resonance occur
6. Finally it can be concluded that from the above result the Titanium Alloy and Aluminum Alloy are suitable for the manufacturing of Crankshaft due to lesser stresses
7. Since Aluminum Alloy is cost effective and lighter weight, hence in the point of cost optimization Crankshaft with Aluminum Alloy is suitable and sustainable

REFERENCES

II. Ahmed Ibrahim, et.al. “Stress Analysis of Thin-Walled Pressure Vessels”, 3 February 2015.