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Design Assessment and Finite Element Analysis of Crankshaft

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ABSTRACT

Crank shaft is a part of the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism. 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 largely. As the engine starts, 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 crank shaft.

This project mainly focuses on the design assessment, optimization and failure analysis of a forged steel crank shaft development for the single cylinder four stroke diesel engine cycles. The analysis was done for the single cylinder four stroke diesel engine and as a result, critical region on the crankshafts were obtained. Stress variation over the engine cycle and the effect of torsional load in the analysis were investigated. And also the effects of impact load in the analysis were investigated.

Keywords - *Crankshaft, Crankpin, Torsional Vibration, Impact Load.*

1. INTRODUCTION

Crankshaft is a part of an engine that is used to convert reciprocating motion into rotary motion, in order to convert this it uses crank throws and additional bearing surfaces to which each cylinder is attached. We know that it takes a huge number of loads during the working of an engine, the performance of the fatigue and components durability must be taken care during the design consideration. The crankshaft consists of main journals, crank pins, crank webs, counter weights and oil holes.

It can be forged using a steel bar, nowadays manufacturers majorly using forged crankshaft because of its lesser weight and due to its inherent damping. By means of forged crankshafts, vanadium micro-alloyed steels are generally used as these steels can be air cooled after reaching high strengths without additional heat treatment, with exception to the surface hardening of the bearing surfaces. Currently iron crankshafts are used frequently because the carbon steels needs additional heat treatment process but in the case of carbon steels, it can be found in cheaper production engines, where the application of load acting will be less.

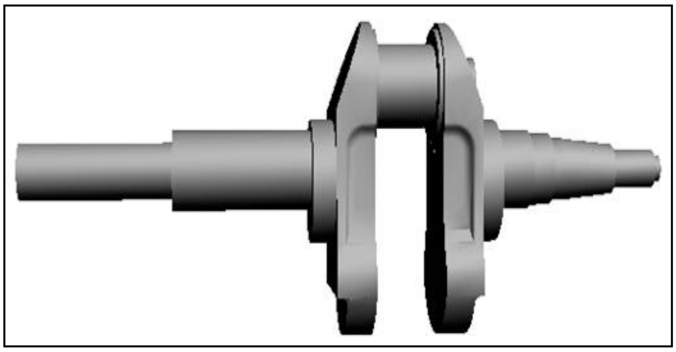
Fig 1: Crankshaft.

In favor of some engines it is necessary to provide counter weights for the reciprocating mass of each piston and connecting rod to improve engine balance. These are typically cast as part of the crankshaft but, rarely, are bolt-on pieces. Whereas counter weights add a considerable amount of weight to the crankshaft, it provides a smoother running engine and allows higher RPM levels to be reached.

2. GEOMETRY AND FE MODELING

This chapter discusses the geometric creation and computer aided modeling of the crankshaft. The crankshaft cad model is made by using NX-CAD (unigraphics) software. By using a device called as clipper and with the help of coordinate measuring machine, the crankshaft dimensions were measured. Crank web slope has been made according to the scale of the geometry.

2.1 Geometry Details



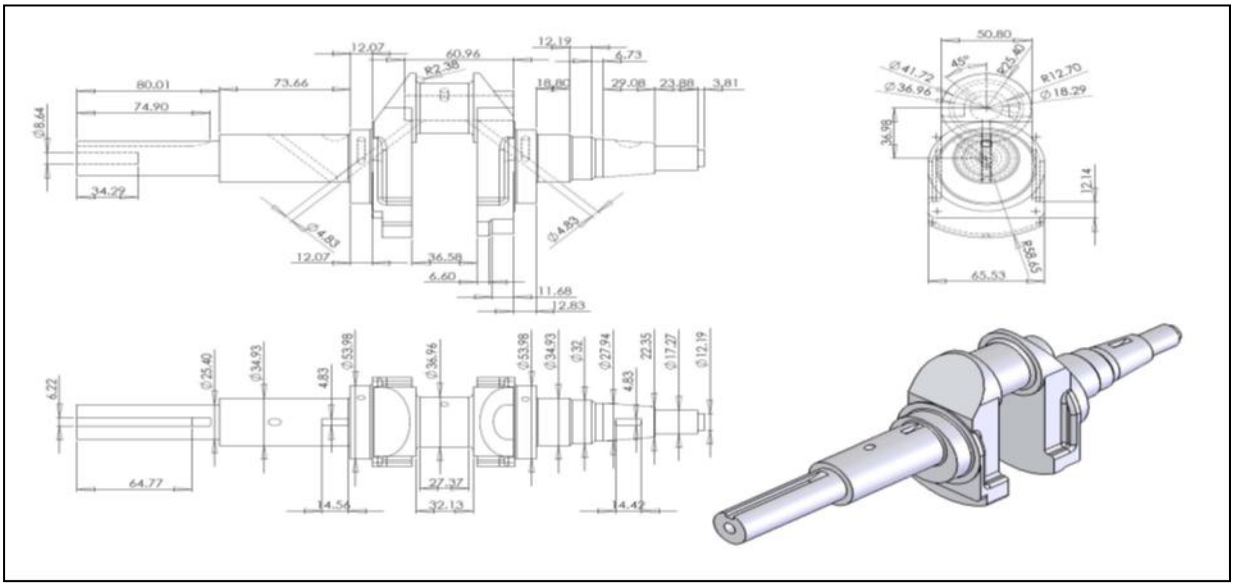


Fig 2: Dimensions of Crankshaft and 3D Model.

Configuration of the engine to which the crankshaft belongs:

- Crankshaft radius 37 mm.
- Piston diameter 89 mm.
- Mass of the connecting rod 0.283 kg.
- Mass of the piston assembly 0.417 kg.
- Connecting rod length 120.78 mm.
- Izz of connecting rod about the center of gravity 0.663×10-3 kg-m^2.
- Distance of C.G. of connecting rod from crank end center 28.6 mm.
- Maximum gas pressure 35 Bar.

2.2 Material Properties for Forged Steel

The main factor for making use of steels is due to the large range of mechanical properties which can be obtained by heat treatment.

Material Property	Unit	Forged Steel
Modulus of Elasticity	GPa Ksi	221 32,053
Poisson's Ratio	-	0.30
Mass Density	kg/m^3 lb/in^3	7833 0.283

2.3 FE Modeling

Meshing is known as dividing structure into elements or converting geometric modeling into mathematical models. By using the proper values, the mesh has been created for the crankshaft model. For meshing the complex geometry and for getting the high accuracy, quadratic element has been chosen. By varying the element size the mesh has been done.

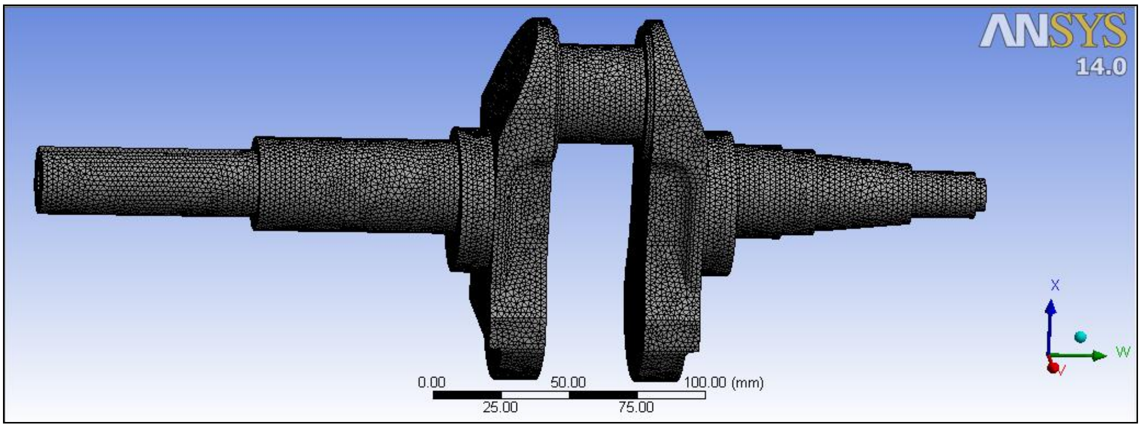


Fig 3: Mesh Geometry.

The element type which is used for the model is quadratic tetrahedron because its accuracy will be more and it reduces the rigidity of the material. Suitable results were obtained for the forged steel crankshaft i.e. 491800 elements and 93087 nodes. The meshed crankshaft model is as shown in the above figure.

2.4 Mesh Statics

Nodes	93087
Elements	498100
Element Type	Tetrahedron
Element size	2.5 mm

Table 1: Mesh Statics.

2.5 Loading and Boundary Conditions

The boundary condition we used for the model is by constraining the model with a main bearing journal from one side and near the key slot end on the other side. Near the bearing surface there is a compress fit to the model due to this it does not permit to have any motion of the crankshaft other than rotation about its main axis. In view of the fact that only half portion of the bearing surfaces facing the load direction and it constraint the motion of the crankshaft, this constraint is defined as a fixed semicircular surface as wide as ball bearing width. In this study a load of 400 N is applied on the top of the crankpin surface. The moment is applied on the same surface in the z direction. The distribution of load is same for all the design iterations. Boundary conditions are applied for the model as per the project needs and it is as shown in the below figure.

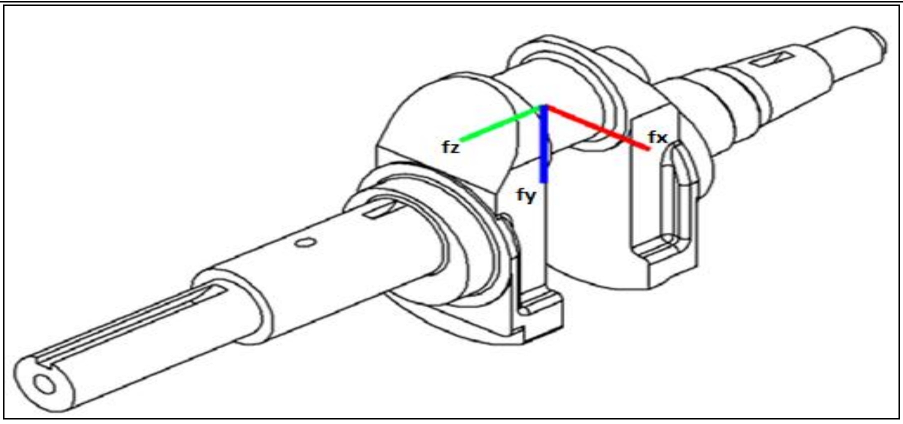


Fig 4: Boundary Condition for the Crankshaft Model.

3. RESULTS AND DISCUSSIONS

3.1 Modal Analysis - Over view

The modal analysis is mainly performed for obtaining the natural frequency of the system, in fact, any system. With the help FE analysis the mode shapes and the modal behavior of the object can be seen. It is primarily used to check whether the model is getting failed because of resonance. In order to check the resonance, natural frequency has been determined. After obtaining the natural frequency, it is compared with the excitation frequency. If the obtained natural frequency and excitation frequency are same, then the component will see the resonance. As a result the body tends to vibrate and the crankshaft may get damaged.

The lowest frequency modes are the preferred modes because at that mode the object tends to vibrate less and makes the material lay on the safer side.

Base line Mode shapes (for R=0.1 mm)

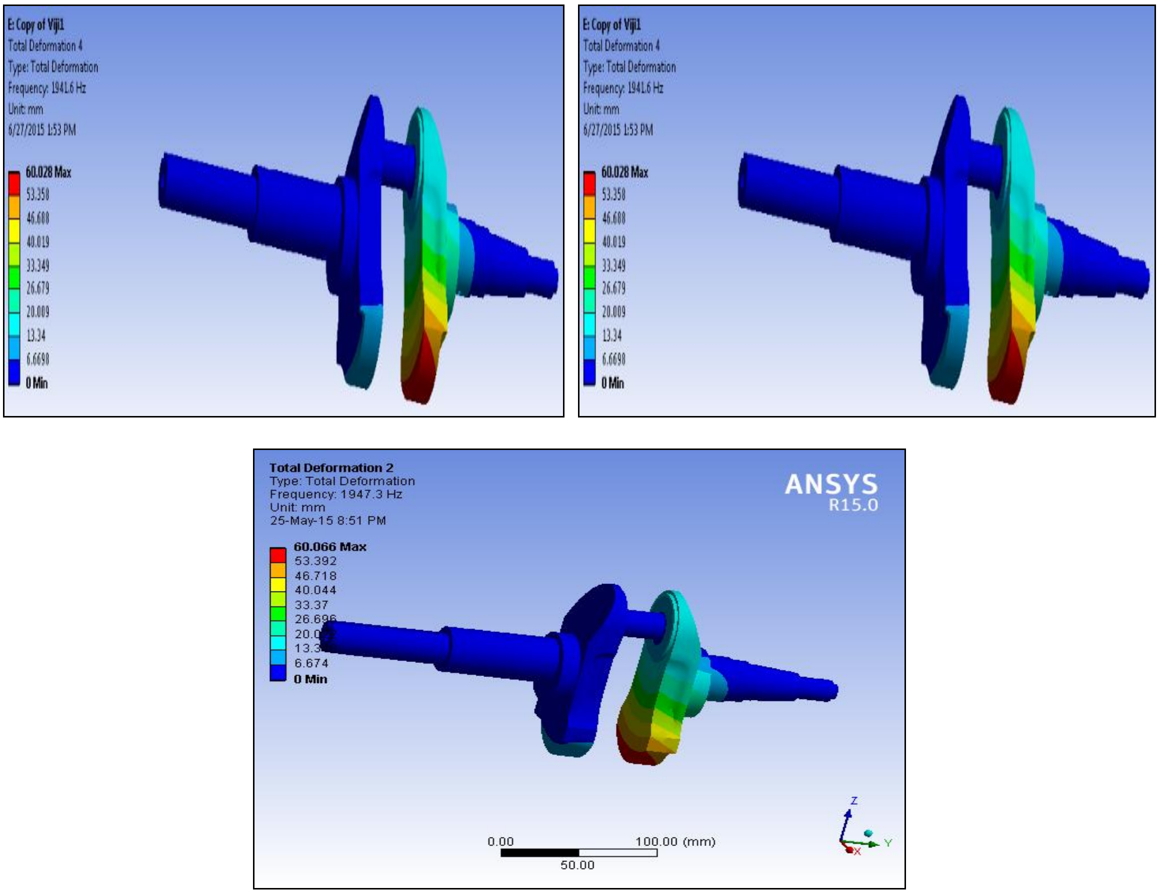


Fig 5: Modal Analysis plots for first 3 Modes.

Mode shapes	Base line design	Modified design 1	Modified design 2
1	1236	1237.3	1239
2	1731.4	1729.7	1732.8
3	1923.4	1925.9	1927.1
4	1944.5	1941.6	1947.3

Table 2: Natural Frequencies (HZ) of Mode Shapes.

3.2 Dynamic Load Analysis

In this analysis there will be complex loading due to the motion of the piston. The main aim of this analysis is to determine the direction and magnitude of the crankshaft. In this analysis a piston load of 400 N is applied on the crankpin surface. The difference between modal and dynamic analysis is the stress values. In modal analysis we get the overestimate results, where as in dynamic analysis we get the realistic stresses. In modal analysis there is no application of loads, where as in dynamic analysis the loading plays an important role.

Baseline design (for R=0.1 mm)

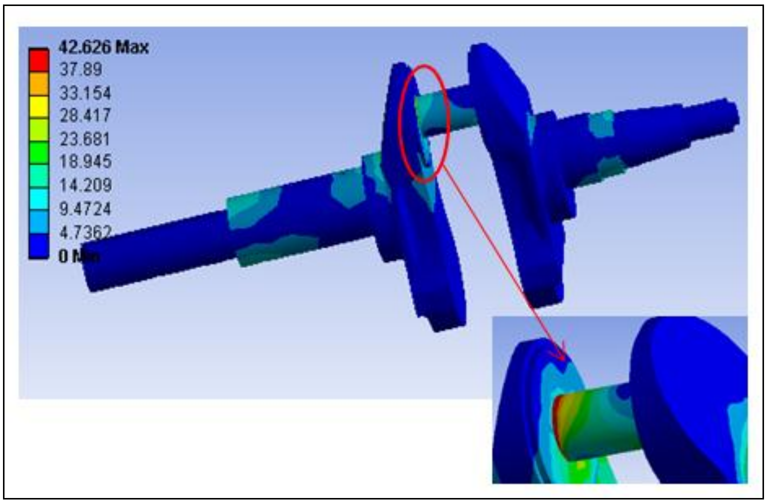


Fig 6: Maximum von-Mises Stress Plot Obtained from Harmonic Analysis for Baseline Design.

Sl No	Design	Stress
1	Base line design	41.626 MPa
2	Modified design 1	34.36 MPa
3	Modified design 2	31.335 MPa

Table 3: von-Mises Stress Comparison Table for all the iterations.

The downward force of the piston must be taken care as it is coming with the huge force during power stroke, if it is not controlled it can damage the crankshaft. As we know that life of engine depends on strength of the crankshaft. From the above analysis, we came to know that crankpin fillet region is getting affected due to cyclic loading. In order to overcome this failure, we have made few design optimizations by changing the crankpin fillet radius from .1 to 0.5mm and 1mm. The FE analysis was carried out for this crankpin fillet radius, by changing this design parameters, the stress has been moved away from the failure region and stress has been reduced which is as shown in the above table. From this analysis the failure of crankpin has been eliminated and the component is safe.

3.3 Effect of Torsional Load

In the internal combustion engine of the crankshaft, the torsional vibration is concentrated more because it could damage crankshaft itself. Especially, when the excitation frequency matches the natural frequency. As this project mainly focuses on the failure analysis of crankshaft, due to this torsional load analysis has been done. By applying a load in the Z direction, the analysis was performed. From this analysis it came to know that for this particular engine, the torsional load has no effect on the critical location.

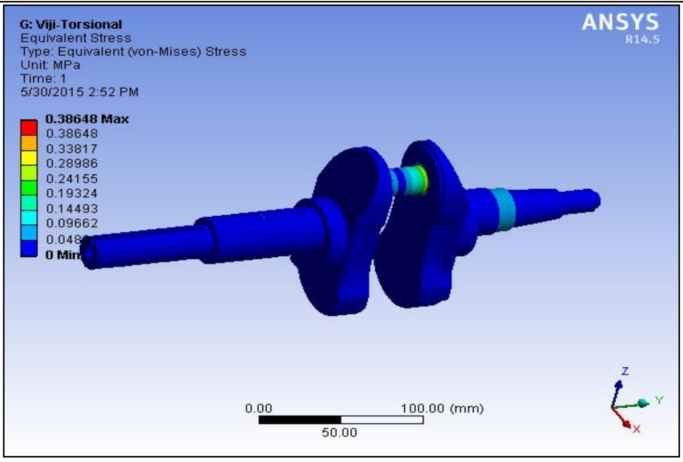


Fig 7: Effect of Torsional Load

3.4 Impact Analysis (Transient Analysis)

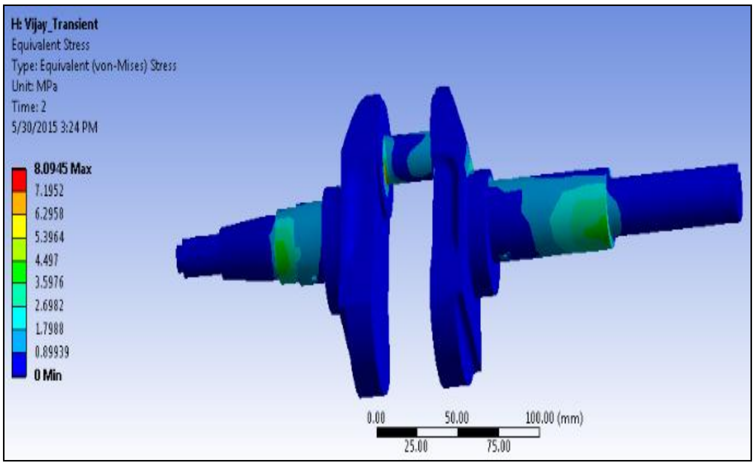


Fig 8: Effect of Impact Load.

Impact analysis was done on the forged steel crank shaft for the single cylinder four stroke diesel engine cycles. As we know that it must be strong because life and reliability of the engine depends on the strength of the crankshaft largely. As a result the impact analysis was done on the component; the analysis was done for the sudden raise in the load that is by applying 5G load the failure analysis was done to check the damage of the component but there was no effect on the range of von-Mises stress at the critical location. Hence the design is safe.

4. CONCLUSION

Failure analysis of single cylinder four stroke diesel engine crankshafts was carried out and the following conclusions are made from this work.

- Finite Element Analysis results revealed that the first crankpin fillet is the most vulnerable point to fracture.
- The results suggest re-evaluation of the design and manufacturing.
- Considering the piston load in the dynamic loading conditions has affected the von-Mises stress at the critical location and hence there was a need of change in design and hence optimization of the fillet rolling process has been made by changing the fillet radius and the stress region or failure point has been moved to other component, where there is no effect of load.
- The effect of torsion on the stress region is also relatively small at the critical locations.
- Impact load analysis is made for 5g load conditions; it has no effect on von-Mises Stress at vulnerable point.
- By doing this assessment, failure of crankshaft has been eliminated and the component is safe.

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