Investigation and Optimization of two cylinder crankshaft by FE Analysis

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Abstract - ***Crankshaft is one of the major and critical components for the effective and precise working of the internal combustion engine. Study is done on the crankshaft and found that there are tremendous stress induced in crankshaft. However it is necessary to reduce the stress and increase the life of crankshaft. The stress and life are calculated first analytically and then also by Finite element analysis (FEA). A static simulation is conducted on a forged steel crankshaft used in two cylinder 2 - stroke engine. A three-dimension model of engine crankshaft is created using CATIA-V5 software. FEA is performed to obtain the variation of stress and also its magnitude at critical locations . Stress variation over the engine cycle and the effect of torsion and bending load in the analysis are investigated. Von-misses stress is calculated theoretically and FEA, and thus validated. The stress obtained by structural analysis of the forged steel crankshaft was found well below the allowable limit. The Fatigue analysis was performed to determine life, damage, and factor of safety of the crankshaft using a stress-life approach. The Dynamic vibrational analysis is used to determine the natural frequency at different modes of crankshaft.***

Key Words: *Structural Analysis, Natural frequency, Technical parameters, FEA*

1. INTRODUCTION

Crankshaft plays an important role in all Internal Combustion Engines. The reciprocating motion of piston is converted to rotary motion of crankshaft in reciprocating engine with four bar link mechanism. This motions are converted by means of “crank throw” or “crankpins”.

Crankshaft is attached to flywheel to reduce the fluctuating loads and damper is attached to both the ends to minimize the torsional vibration. Crankshaft is subjected to severe stress when loaded. It is attached to engine block by means of bearing on main journal, flywheel, and to the piston by means of connecting rod. About 75% of energy loss occur in engine by vibration, friction and noise in crankcase and piston area. Crankshaft is an important component to investigate and optimize to improve the performance of IC engine.

Rinkle garg and Sunil Baghl. [1] in there paper have discussed about crankshaft model which was created in Pro-E modelling software and later imported to ANSYS for simulation. It conclude that there is increase in strength which reduces the maximum stress, strain and deformation. The weight of crankshaft is decreased which minimizes inertia force on crankshaft, which leads to reduce the cost and improve the I.C engine efficiency.
C.M. Balamurugan et al [2] had done the modelling in SOLID EDGE and later imported to ANSYS for simulation. In their paper they have optimized the crankshaft and compared with two different material, ductile cast iron and forged steel which results in increase fatigue life.
Gu Yingkui, Zhou Zhibo. [3] crankshaft model of diesel engine was created in Pro-E and analyzed in ANSYS. In their paper they have studied high stress area which is the joint between the web and crankpin which is more likely to break.
Jamin Brahmbhatt and Abhishek choubey. [4] created a 3D model in SOLID WORKS and simulation was done in ANSYS. Dynamic analysis was done to calculate the stress in critical areas. The results showed that the edge of main journal was at maximum stress region and the center of crankpin shows the maximum deformation area.
R. J. Deshbhratar, and Y.R Suple. [5] have modelled crankshaft by Pro-E and analyzed by ANSYS software. The highest stress appears at the fillet area and near the center of crank pin. At maximum times crankshaft deforms due to bending under natural frequency as the maximum deformation is there on neck of the crankpin.
K. Thriveni and Dr.B.Jaya Chandraiah. [6] have studied static analysis of 1-cylinder 4-stroke IC engine. Modelling was done in CATIA and solution in ANSYS. They conclude that the maximum stress is seen in neck of crankpin and fillet area and maximum deformation is seen at the neck of crankpin.

Alex.K.D, Arjun.P, Hassan.K, Vyshak.P. [7] modelled the crankshaft by CATIA and dynamic analysis was done in ANSYS in which von-misses stress and principal shear stress was found. Crankshaft material was En-9 medium carbon steel in which static analysis gives approximate results and dynamic analysis gives accurate results. They noticed that in dynamic analysis torsional loads has no effect so only bending load is applied. They also noticed that maximum stress occurs in fillet area.

Mahesh L. Raotole, D. B. Sadaphale, J. R.Chaudhari. [8] have studied the life estimation of crankshaft using finite element modelling. They found the input values of the model using MATLAB and later used in ANSYS for simulation. They performed dynamic analysis at different engine speed and fillet radius and concluded that crankshaft fails in fillet region. That's why designer should always consider fatigue life as important parameter of design.

Ashwani Kumar Singh, Praveen Kumar Singh, et al. [9] the modelling of crankshaft was done in Pro-E and simulation in ANSYS. They used nickel chrome steel and structural steel for the material of crank shaft, and concluded that nickel chrome is more reliable than structural steel.

In a literature survey by Zoroufi and Fatemi. [10], they have discussed the fatigue performance and compared forged steel and cast iron crankshafts. In their study failure sources of crankshaft were discussed and also different methods of crack forming in fillet region. They also compared nodular cast iron, forged steel, austempered ductile iron, which concluded that fatigue properties of forged steel are better than cast iron. They also added the cost analysis and geometry optimization of crankshaft.

2. FINITE ELEMENT ANALYSIS

Finite element analysis of solid crankshaft is done by generation of a model, applying material properties, meshing, applying boundary and loading condition. Simulation is done by ANSYS 14.5 software.

2.1 GEOMETERY OF CRANKSHAFT

Forged steel crankshaft used in forging industry is as shown in Figure 1.

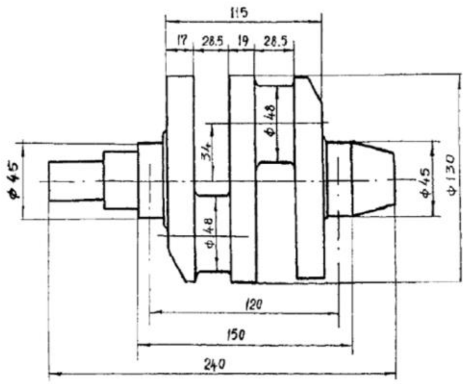

Fig -1: Existing 2D model showing the dimensions of crankshaft

In order to get the optimized geometry, different parameters like web thickness, fillet radius and material re varied. Figure 2 shows the optimized crankshaft on which the static structural, fatigue and modal analysis has been done.

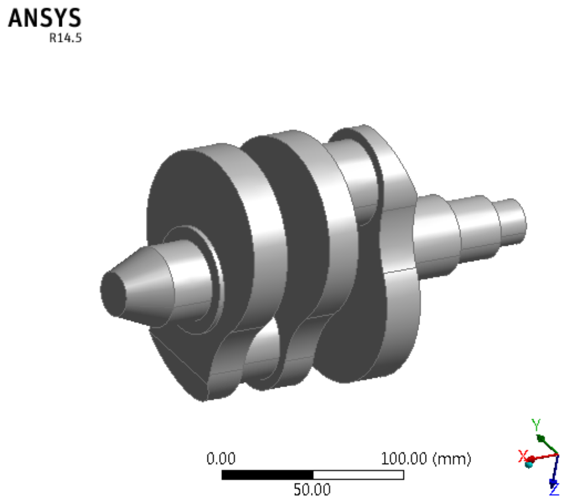

Fig -2: Optimized solid model of crankshaft

2.2 MATERIAL PROPERTIES

Material properties of forged steel considered for crankshaft is as shown shown in table no 1.

Table-1: Material properties of forged steel crankshaft

SR NO	PROPERTIES	VALUE
1	MODULUS OF ELASTICITY	$2.1X10^5$ N/mm^2
2	POISSONS RATIO	0.30
3	DENSITY	7850 Kg/ mm^3
4	YIELD STRENGTH	250 N/mm^2
5	TENSILE STRENGTH	460 N/mm^2
6	ELONGATION (MINIMUM %)	18%
7	HARDNESS	201-255

2.3 GENERATION OF MESH

An analysis with an initial mesh is performed first and then reanalysed by increasing no of elements. The two solutions are compared. If the results are close to each other, the initial mesh configuration is considered to be adequate. If there are substantial differences between the two, the analysis should continue with a more-refined mesh and a subsequent comparison until convergence is established. Tetrahedron mesh is preferred in this analysis, because the stiffness of the element is more as compared to other type of meshing. In present meshed component, the element size is 5mm, total number of elements is 71053 and total number of nodes are 105026. Figure 3 shows meshed model of crankshaft.

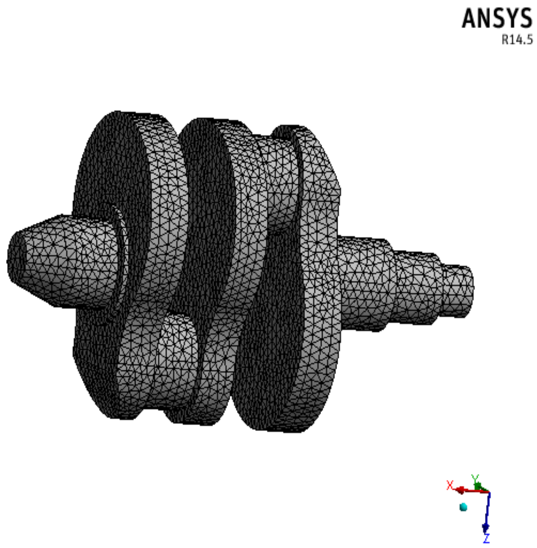

Fig -3: Discretization of crankshaft

2.4 BOUNDARY CONDITIONS

Frictionless support are provided to the crankshaft according to the engine mounting conditions where ball bearing are press fit on it. Figure 4 shows the frictionless support applied to the crankshaft.

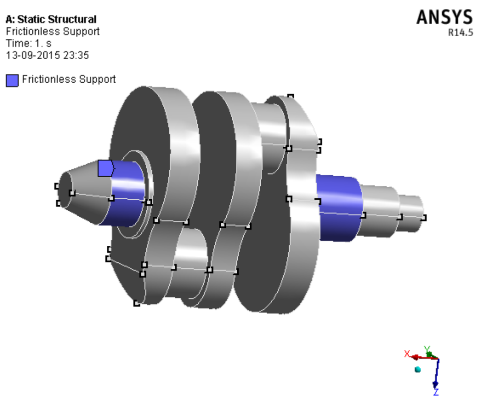

Fig -4: Frictionless support given to crankshaft

2.5 LOADS

During power stroke, combustion take place in combustion chamber which causes crankshaft to rotate. The force is transferred from connecting rod to crankpin and load of 25 KN is acting on crankshaft is shown in Figure 5.

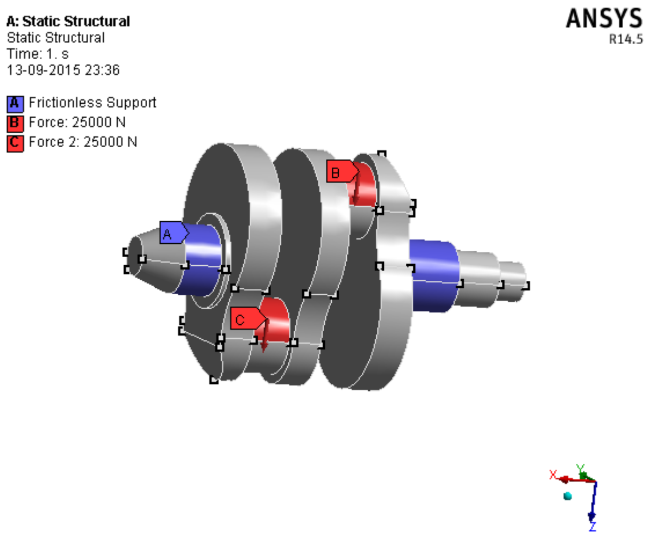

Fig -5: Loads on crankshaft

3. RESULTS AND DISCUSSIONS

3.1 STATIC STRESS ANALYSIS

In static analysis, stress and deformation acting on crankshaft are determined. It is assumed that the load does not vary with respect to time. The results shows the variation of deformation and equivalent von misses stress. The induced stress in crankshaft is well below allowable stress. The maximum stress for the existing design was found to be 166.67 Mpa and that for the preset optimized geometry is 110 Mpa. The maximum total deformation of crankshaft is 0.125mm. Figure 6 shows von misses stress distribution and Figure 7 shows total deformation in the crankshaft for the optimized geometry.

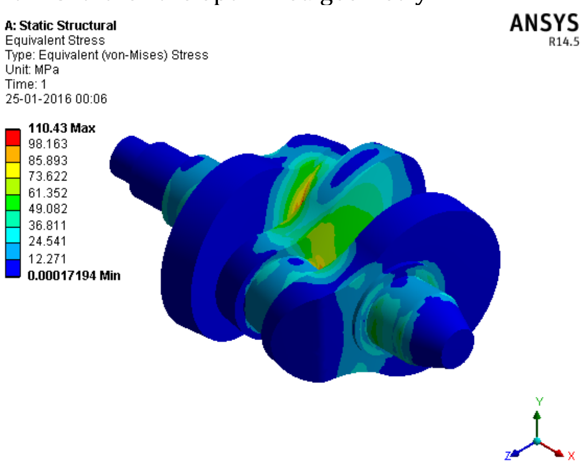

Fig -6: Von misses stress

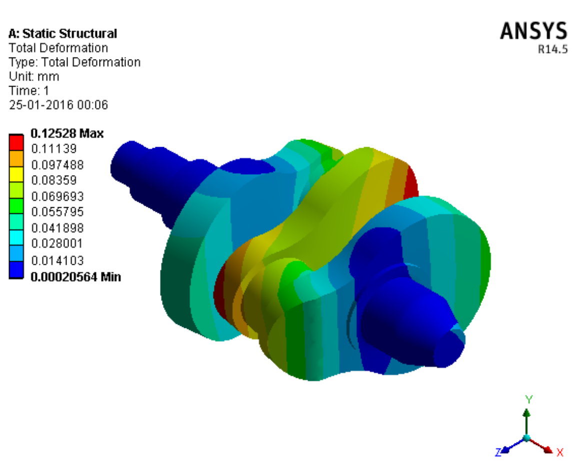

Fig -7: Total deformation

3.2 FATIGUE RESULTS

Fatigue analysis is used to determine the life of the crankshaft under cyclic loading conditions either by stress-life or strain-life approach. Figure 8 shows the fatigue life of the crankshaft. In the present study, stress life approach is used to determine the fatigue life.

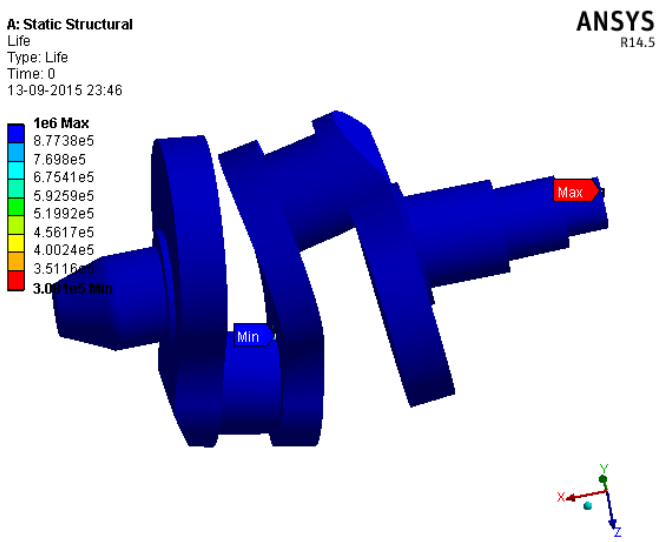

Fig -8: Fatigue life of crankshaft

Fatigue life of crankshaft is 308100 cycles. It is seen that failure occurs at the change in cross section area as stress concentration is maximum in that area. Figure 9 shows the damage at the joint between web and crankpin.

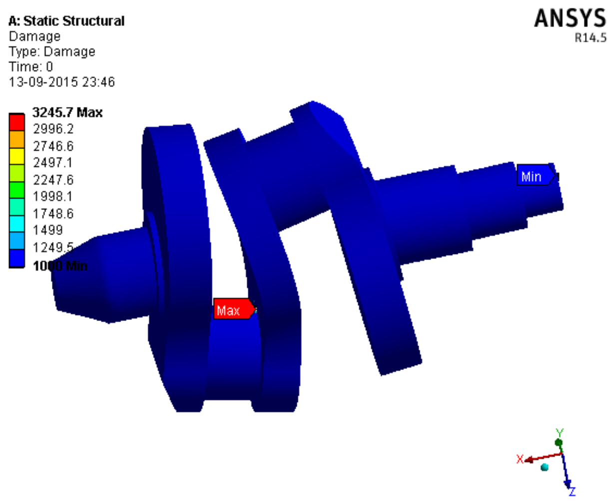

Figure 10 shows fatigue factor of safety. The region under red color shows the failure of the crankshaft due to factor of safety less than 1.5. This can be minimized by increasing the material in portions below 1.5 factor of safety.

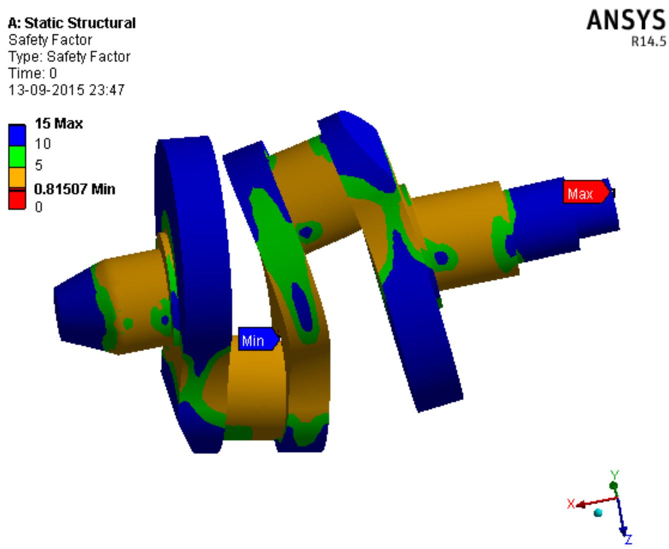

Fig -10: Fatigue factor of safety

3.3 MODAL ANALYSIS

The purpose of this analysis is to calculate the natural frequency of vibration. The frequency with which the object can oscillate without having any load (accept some initial load) is called natural frequency. In present analysis, modal analysis is performed to calculate the natural frequencies at different modes. 6 natural frequencies are calculated, but the natural frequency of mode 1 is very less i.e. 0.11Hz hence it is neglected. The following figure 11 show the natural frequency at mode 2 and table 2 shows the mode shapes and natural frequency at different modes.

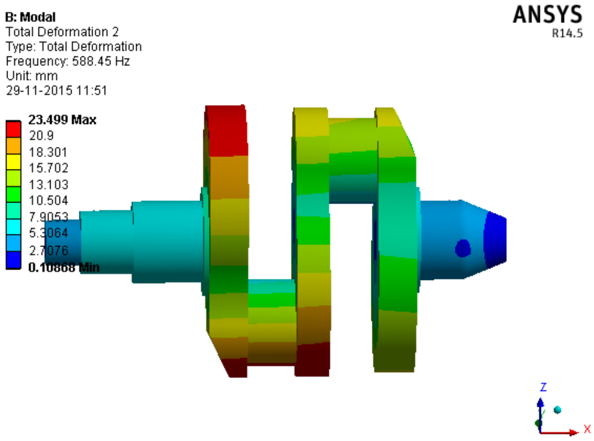

Fig -11: Mode 2

Table -2: Mode shapes and natural frequency

Mode	Frequency (in HZ)
1	0.11
2	588.45
3	1387.1
4	1585.6
5	1710.2
6	2687.5

Here, in modal analysis all 6 modes natural frequency is determined and the maximum natural frequency is 2687.5Hz which is below the resonant frequency 2800 Hz. Hence the crankshaft is safe in given loading and boundary condition.

4. CONCLUSIONS

From the static structural analysis of crankshaft it is observed that the maximum stress is well below the stress in existing geometry of forged steel and deformation is 0.12 m. Hence the crankshaft is safe under the present loading condition of 25KN.

From the fatigue analysis it is observed that the minimum fatigue life is 31e4 cycles. It can also be concluded that fatigue failure will take place in fillet region hence while designing the crankshaft.

In regions with FOS less than 1, it is recommended to increase the thickness in those regions.

Modal analysis resulted in maximum natural frequency to be 2687.5 Hz were as the resonant frequency is 2800 Hz. It concludes that crankshaft is safe in loading and boundary condition.

5. FUTURE SCOPE

- can extend our work in future to study the effect of fracture.
- We can also extend this work in future to study effect of heat and analyzing the thermal effects.

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