Design and Optimization of Four Cylinder Engine Crankshaft

Prasad P. Gaware[1], Prof. V. S. Aher[2]

[1] PG Scholar, Mechanical Engineering Department, AVCOE, Sangamner, Maharashtra, India
[2] Professor, Mechanical Engineering Department, AVCOE, Sangamner, Maharashtra, India

ABSTRACT

Crankshaft is major component used in I.C engine which converts reciprocating displacement of piston in to rotary motion with a four link mechanism. Crankshaft experiences large number of loads during its service period. Crankshaft should able to take large downward force of power stroke without excessive bending. To optimize crankshaft four materials are checked for weight and cost optimization. First the theoretical design is prepared. The model of crankshaft is created in PRO E software. This model is meshed and boundary conditions (B.C) are applied. Also various experiments are performed on these materials to investigate various properties. These results are compared to find out optimum material.

Keyword : - *FEA, PRO-E, I.C Engine.*

1. INTRODUCTION

Crankshaft is important component with a complex geometry in the engine. The crankshaft consists of the shaft parts revolve in the main bearing; big ends of the connecting rod are connected to the crank pins, the crank arms or webs, which connect the crankpins, and the shaft parts. Since the crankshaft experiences a large number of load cycles during its service period, fatigue performance and durability of this component has to be considered in the design process. Design and development of crankshaft is major issue in industry because it is main power transmitting element. Our aim is to manufacture less expensive component with minimum weight and high fatigue strength. Improvement in engine will give small engines with less weight and high power output. Crankshaft of an I.C engine should able to sustain high downward force with negligible bending. The reliability and life of the internal combustion engine depend on the strength of the crankshaft largely. As the engine runs, the power s trokes hit the crankshaft in one place and then another .The crankshaft is the main part of the crank train or crank assembly, which latter converts the reciprocating motion of the pistons into rotary motion. It is subjected to both torsional and bending stresses, and in modern high-speed, multi-cylinder engines these stresses may be realty increased by resonance, which not only renders the engine noisy, but also may fracture the shaft. In addition, the crankshaft has both supporting bearings (or main bearings) and crank pin bearings, and all of its bearing surfaces must be sufficiently large so that the unit bearing load cannot become excessive even under the most unfavorable conditions . At high speeds the bearing loads are due in large part to dynamic forces-inertia and centrifugal forces [1].

Fig.1 shows crankshaft which is a central component of any internal combustion engine and is used to convert reciprocating motion of the piston into rotatory motion or vice versa. Crankshafts come in many shapes and sizes from small ones found in two-stroke small engines to giant ones found in diesel engines in ships. The crankshaft main journals rotate in a set of supporting bearings ("main bearings"), causes the offset rod journals to rotate in a circular path around the main journal centers, the diameter of which is twice the offset of the rod journals. The diameter of that path is equal to the engine "stroke": is the distance the piston moves up and down in its cylinder. The big ends of the connecting rods ("con rods") contain bearings ("rod bearings") which ride on the offset rod journals. The crankshaft consists of the shaft parts which revolve in the main bearings, the crankpins to which the big ends of the connecting rod are connected, the crank arms or webs (also called cheeks) connects the crankpins and the shaft parts.

During operation, crankshafts are subjected to following stresses:

- Bending stresses due to stroke of pistons.

- Torsion stresses due to rotation of crankshaft and force transmission to drive train, which then transmit motion to various services.

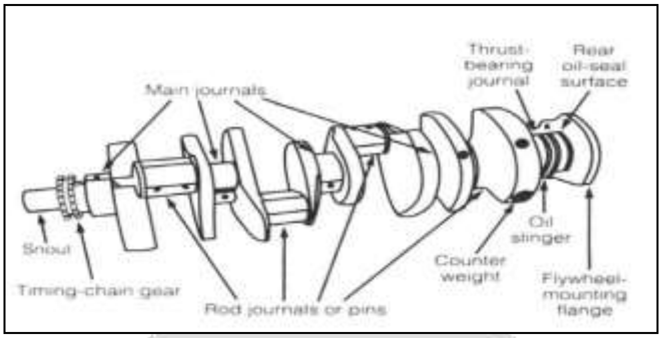

Fig-1 Typical crankshaft

Owing to reciprocating motion of the pistons, bending forces on crankshaft are always cyclic in nature. Therefore, the stress behavior is more complicated due to constant fatigue factor hence need of higher fatigue resistance in the component. Another major consideration is friction of bearing surfaces during operation. The piston arms have to slide past the crankshaft surface. For that roller bearings are used between the sliding surfaces. The lubrication is another important parameter to be considered because the Internal Combustion Engine attains 4000-5000 rpm speed in normal operation. The crankshaft contains holes for lubrication system. Crankshaft material should able to sustain its mechanical properties in wild range of temperatures as operating temperature of inner part of I.C engine is extremely high. Crankshaft is generally connected to flywheel in order to reduce pulsating behavior of engine. In some cases vibration dampers are also used to reduce vibration [3].

2. LITERATURE REVIEW

Solanki et al. [1] presented literature review on crankshaft design and optimization. The materials, manufacturing process, failure analysis, design consideration etc. were reviewed. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of the automobile specifications with cost and size effectiveness.

Jian Meng et al. [2] 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.

Rajesh M. Metkar et al.[3] have evaluated FEM based fracture mechanics technique to estimate life of automobile crankshaft of single cylinder diesel engine.

Xiaorong Zhou et al. [4] prepared Crankshaft Dynamic Strength Analysis for Marine Diesel Engine, described the stress concentration in static analysis of the crankshaft model. The stress concentration is mainly occurred in the fillet of spindle neck and the stress of the crankpin fillet is also relatively large. Based on the stress analysis, calculating the fatigue strength of the crankshaft will be able to achieve the design requirements.

Montazersadgh and Fatemi et al. [5] choose forged steel and a cast iron crankshaft of a single cylinder four stroke engine. Both crankshafts were digitized using a CMM machine. Load analysis was performed and verification of results by ADAMS modeling of the engine. At the next step, geometry and manufacturing cost optimization was performed. Experimental stress and FEA results showed close agreement, within 7% difference.

YV. Mallikarjuna Reddy et al. [6] has work on Design, Analysis and Optimization of a 6 cylinder Engine Crank shaft This paper deals with; the problem occurred in six cylinders four stroke engine crankshaft. It consist of static structural analysis of six cylinder engine crank shaft. It identifies and solves the problem by using the modeling and simulation techniques.

Rinkle Garg et al. [7] conducted a static analysis on a cast iron crankshaft from a single cylinder four stroke engine. Finite element analysis was performed to obtain the variation of the stress magnitude at critical locations. Three dimensional model of the crankshaft was created in Pro-E software. The load was then applied to the FE model and boundary conditions were applied as per the mounting conditions of the engine in the ANSYS. Results obtained from the analysis were then used in optimization of the cast iron crankshaft.

Balamurugan et al. [8] done computer aided modeling and optimization analysis of crankshaft to evaluate and compare the fatigue performance. They compared two crankshafts, cast iron and forged steel, from a single cylinder four stroke engines. Finite element analysis was performed to obtain the variation of stress magnitude at critical locations. The dynamic analysis was done analytically and was verified by simulation in ANSYS.

Jaimin Brahmbhatt et al. [9] conducted a dynamic simulation on a crankshaft from a single cylinder 4- stroke diesel engine. A three-dimension model of diesel engine crankshaft is created using SOLID WORKS 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 is done for finding critical location in crankshaft.

R.K.Goel et al. [10] performed the FEA of four cylinder diesel engine and also founded maximum stress point region was at the knuckle of the centre main journal shaft and crank arm.

3. FINITE ELEMENT ANALYSIS:

3.1 Engine Specifications:

Following are specifications of engine whose crankshaft is to be optimized.

Table-1 Engine Specifications

Type	4 Cylinder Petrol engine
No of cylinders	4
Bore/Stroke	86 mm/ 68 mm
Compression Ratio	18 : 1
Max. Power	8.1 HP @ 3600rpm
Max. Torque	16.7 Nm@ 2200rpm
Maximum Gas pressure	25 Bar
Capacity	1200 cc

3.2 Results from theoretical calculations:

Gas force on piston: FP= π/4 XD2Xp.
Diameter of crankpin calculated by Mc = π / 32 (dc)3σb
Length of crankpin calculated by Lc = Fp / (dc . pb)
Diameter of shaft, Ms = π/32x(ds) 3 x σ b
Diameter of crank pin =44 mm
Length of the Crank pin =33 mm
Diameter of shaft =60 mm
Web Thickness (Left & Right Hand)= 35mm
Web Width (Left & Right Hand) =65 mm.

3.3 Finite Element Analysis:

3.3.1 FEA Model:

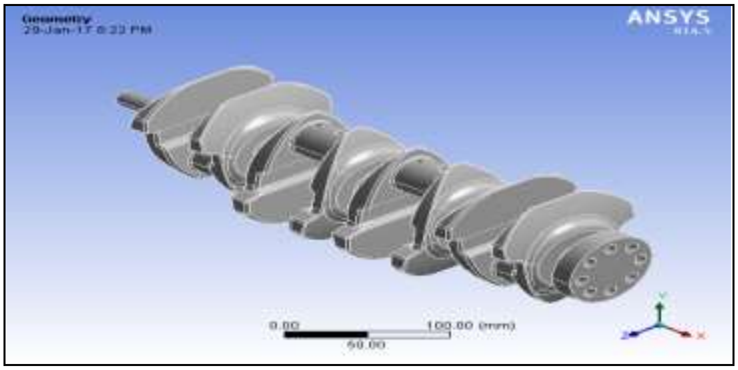

Fig-2 Crankshaft Model

By using above design parameters the crankshaft model is created in software and imparted in ANSYS software for Analysis. This model is then discretized and boundary conditions are applied for analysis. Meshed model is given as below

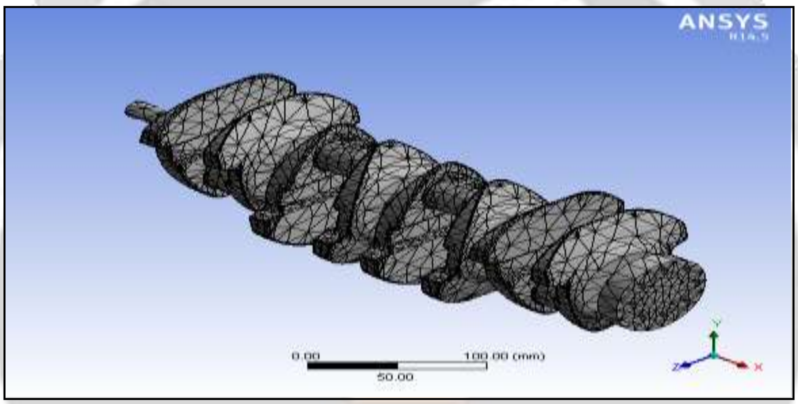

Fig-3 Meshed Model

3.3.2 Analysis by changing material properties:

First properties of Cast Iron are applied and the Deformation and Von Misses Stresses are obtained from FEA. Total deformation and von Misses stresses obtained. These results are shown in figures below.

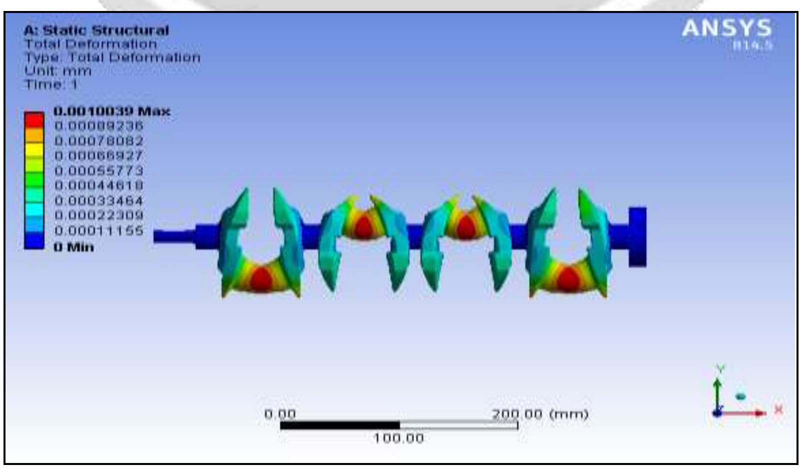

Fig-4 Total Deformation of Cast Iron

Fig shows the total deformation on cast iron crankshaft. The detailed min and maximum deformation are seen in model.

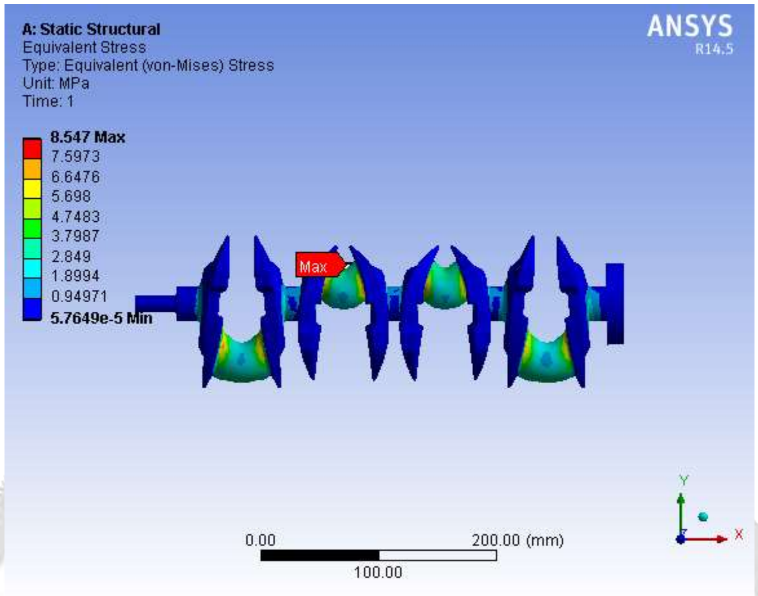

Fig-5 Von misses stress for Cast Iron

3.4 FEA Results:

3.4.1 Input Parameters

Following properties are applied to the model for each material according to these properties finite element analysis results are obtained for each material

Table-2 Material properties input for Finite Element Analysis

Sr. No	Material	Young's mod(N/mm2)	Poisson's ratio	Density (Kg/m3)
1	SAE 4340	1.90E+05	0.270	7670
2	EN308	2.05E+05	0.300	7740
3	Cast Iron	1.78E+05	0.300	7197
4	Structural Steel	2.10E+05	0.277	7800

3.4.2 Finite Element Analysis Results

The FEA result for each material is tabulated as below

Table-3 Finite Element Analysis Results

Sample No.	Material Identification	Maximum Von Misses (N/mm^2)	Maximum Deformation (mm)	Mass (Kg)
1	Cast Iron	8.547	1.003E-03	4.421
2	EN30B	9.9714	8.7169E-04	4.589
3	SAE 4340	8.7373	9.247E-04	4.712
4	Structural Steel	9.4017	8.6326E-04	4.792

4. EXPERIMENTS PERFORMED

4.1 Tensile Test:

The tensile test is carried out on Universal Testing Machine. Longitudinal tension specimens are taken for each material as per requirement of machine. Yield Stress, Ultimate tensile Strength, Elongation, Elongation at yield, Load at peak, Elongation at peak etc. are found out by using tensile test.

Results from tensile test are tabulated as below.

Table-4 Tensile test results

Sr. No	Material Identification	Yield Strength(N/mm^2)	Ultimate Tensile Strength (N/mm^2)	% Elongation
1	SAE 4340	488.75	1010.17	16.60
2	Cast Iron	NA	221.31	NA
3	Structural Steel	362.16	589.32	23.26
4	EN30B	572.33	1029.71	17.20

4.2 Hardness Test:

The Hardness of each material is obtained from Brinell hardness test. The hardness of each material in terms of BHN is tabulated as below

Table-5 Hardness test results

Sr. No.	Sample Material	BHN
1	SAE 4340	260

2	Cast Iron	169
3	Structural Steel	174
4	EN30B	296

5. COMPARISON OF RESULTS

For above finite element analysis and experimentation of four different materials we compare result of stresses & deformation to select suitable material of crankshaft which is fulfill all crankshaft requirements.

1. Material No.4 i.e.EN-30B is meeting the maximum no of requirements.
2. Though it is not conforming the minimum mass of the body, but difference between minimum mass available and the mass when EN-30B is used is 0.168 kg which can be neglected for optimum design.
3. Also EN-30B is better in experimental results as compared to other materials.
4. EN-30B will give optimum results as compared to the other materials given in the case study.

6. CONCLUSION

1. Results show the improvement in the strength of the crankshaft as the maximum limits of stresses. The value of von-misses stresses that comes out from the analysis is less than material yield stress so our design is safe.
2. The weight of the crankshaft reduced. Thereby, reduces the inertia force.
3. As the weight of the crankshaft is decreased so decrease the cost of the crankshaft and increase the engine performance.
4. Above Results shows that FEA results conformal matches with the theoretical calculation so we can say that FEA is a good tool to reduce the time consuming theoretical work
5. The experimental results & FEA results matches with theoretical calculations is practical proof of above work.
6. Material EN-30B is meeting the maximum number of requirements.

6. REFERENCES

[1] Solanki, K. Tamboli, M.J.Zinjuwadia, Crankshaft Design and Optimization- A Review, National Conference on Recent Trends in Engineering & Technology 2011,

[2] Jian Meng., Yongqi Liu., Ruixiang Liu., “Finite Element Analysis of 4- Cylinder Diesel Crankshaft, ” I.J. Image, Graphics and Signal Processing, 2011, 5, 22-29.

[3] Rajesh M. Metkar, Vivek K. Sunnapwar , Subhash Deo Hiwase, Vidya Sagar Anki, Mahendra Dumpa, “Evaluation of FEM based fracture mechanics technique to estimate life of an automotive forged steel crankshaft of a single cylinder diesel engine”, Procedia Engineering 51 , 2013, 567 – 572

[4] Xinglong Zhou, “Modelling and simulation of flexible slider-crank mechanism with clearance for a closed high speed press systems” Mechanism and Machine Theory,74(2014) 10-30.

[5] H. Montazersadgh, A. Fatemi, “Project Report on Stress Analysis and Optimization of Crankshafts Subject to Dynamic Loading” The University of Toledo. (2007)

[6] Y V. Mallikarjuna Reddy, T .Vijaya Devi. Design ,Analysis and Optimization of a 6 cylinder Engine Crank shaft

[7] Rinkle Garg, Sunil Baghla “Finite Element Analysis and Optimization of Crankshaft Design” International Journal of engineering and Management Research, Vol-2, Issue-6,2012, 26-31

[8] M. Balamurugan, R. Krishnaraj, M. Sakthivel, K. Kanthavel, D. Marudachalam, R. Palani, (“Computer Aided Modeling and Optimization of Crankshaft” International Journal of Scientific & Engineering Research, 2011, vol 2 , issue 8.

[9] Jaimin Bramhbhatt, Abhishek Choubey, “Design and analysis of srankshaft for single cylinder 4-Stroke diesel engine”, International Journal of Advanced Engineering Research and Studies, 2012,88-90.

[10] R.K.Goel, H.Sharma, Annima Panwar, “Stress Analysis and Optimization of crankshaft using CAE Tools”, International Journal of Mechanical Engineering and Robotics Research, 2014.