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Analysis of Crankshaft

Pratiksha M. Nargolkar[1]

[1]Pillai HOC College of Engineering and Technology, Rasayani
Pratiksha.nargolkar[at]gmail.com

Abstract: ***Crankshaft is the most imperative, outsized and exposed component of an internal combustion engine. In this work a 4-cylinder diesel engine crankshaft is used for analysis. For analysis a crankshaft is modeled using software PRO-E and further analyzed by using software Ansys R15.0. FEA method is used to conduct static as well as dynamic analysis of the crankshaft in which the torque is applied on the drive end. Various analysis on the crankshaft are conducted, such as Equivalent principal elastic strain, Maximum shear stress, Equivalent Von misses stress. The analysis will be carried out to obtain the variation of stress magnitude at critical locations. Drive end, rear end and other critical locations of the connecting rod are targeted based upon the industrial practices and the literature review surveyed. Based upon the results obtained some critical conclusions will be derived. As a comparative stress analysis for both static as well as dynamic cases will be performed, stress distribution and response levels will be linked together with the help of the results obtained. These results will be additionally compared with theoretical results with the help of failure theories. Detailed insight will be provided for future research and developments in the field of crankshaft.***

Keywords: Crankshaft, Crankpin, FEA, Static analysis, Dynamic analysis, Theoretical analysis

1. Introduction

Crankshaft is one of the main components with an intricate geometry in the engine, which supports the movement of the piston with the help of a link mechanism placed in an internal combustion engine [1]. Bending stresses and torsional stresses act upon the crankshaft due to various forces caused due to variable gas pressure during working of the engine [2].Crankshaft is not only important but also difficult because of its design. For any production industry to design and develop the crankshafts is always crucial task but very complex and difficult to assure inexpensive crankshaft with least weight, apt strength and other important functional requirement.

A. Function of Crankshaft

The main operation of a crankshaft is to absorb power from the burning of the gases in the combustion chamber which is in turn is transferred by the crankshaft because of the piston pin, piston and the connecting rod. The crankshaft exchanges the reciprocating motion of the piston in the cylinder to the rotary motion of the flywheel [2].

B. Working Principal of Crankshaft

The crankshaft revolves about its axis of equilibrium, generally with some bearing journals riding on exchangeable bearings held in the engine block. The crankshaft is connected with flywheel to complete the need of continuous power to the vehicle. Crankshaft provides energy in pulsation form but flywheel converts it into continuous form by storing it during power stroke and delivering at remaining strokes.

C. Load on Crankshaft

Different types of load sources act on the crankshaft which is as follows.

Inertia of the rotating components which apply forces on the crankshaft. These applied forces are directly proportional to speed of engine. These forces are also depends on the acceleration of rotating parts.

In a cylinder the gas combustion occur due to which the force applied on the crankshaft and it will become another cause of loading. The pressure which is applied to the upper part of the slider is transport to the joined between crankshaft and connecting rod. This load can vary by changing the dimensions of slider crank mechanism [2].

D. Failure of Crankshaft

During the service engine crankshafts and shafts are subjected to a significant number of cyclic loading. Due to the sudden overloads, improper engine operating, engine maintenance and fatigue failures can arise in the crankshaft which results from the cyclic loadings with stress levels lower than yield or ultimate strength of material. Due to fatigue the power shafts are more common failures which are the most highly stressed component [12]. The factor that leads undesirable loss of functionality of component is determined by the failure analysis process. Many future failures in material selection, design process, the manufacturing process as well as low cost maintenance can be avoided with the help of failure and laboratory testing. For any accurate and reliable analysis the studies of failure as well as the knowledge of its operating history are of more essential. It is known that a worst of all is to learn with catastrophic failures which can lead to a loss of lives, as well as high economic costs. The crankshaft is mechanical component of circular section which is used to transmit power which is used to transmit power which is widely used in many engine parts. The crankshaft converts the reciprocating displacement of a piston to the rotary motion which is having the complex geometry. During the service life of crankshaft experiences a large number load cycles which is the main focus of designers and researchers while designing the crankshaft. Due to the bending the crankpin, web, fillets or main fillet journal subjected to the crack in the crankshaft which is undergoing the fatigue failure as well as the crack also occur due to an inaccurate fillet radius or a wrong rectification of crankpin and the main journal fillets of crankpin and the main journal fillets. The crack initiation, crack propagation and the final fracture which are the different region or stages in which the fatigue failure is occur in the component. Due to the high stress concentration at micro notches, defects or inclusion on a material surface, pitting, scratches, inadequate machining or heat treatment, slip bonds or dislocations intersecting a surface as a result of previous cyclic loading or work hardening so that the crack initiation may be caused. The crack propagation is a crack growth before a final fracture being the appearance smooth and brilliens. The final fracture is an event when a material cannot bear an applied stress.[12]

2. Literature Survey

Farzin H Montazersadgh et al. proposed dynamic analysis and were investigated the effect of torsional load and the variation of stress magnitude at critical location by using the finite element analysis techniques.[1]

Amarjeet Singh et.al. Analyzed and optimized strength, the main intention of this method was conducted static analysis on four cylinder engine crankshaft. In this method after getting out the stress results, the critical points identified were the knuckle of crank arm and extreme left bearing.[2]

Jian Meng et al Revived and analyzed crankshaft model and crank throw. The crankshaft distortion was mainly bending distortion under the lower frequency. Higher deformation was located at the link between main bearing journal, crankpin and crank cheeks.[3]

GuYingkui et.al Researched a three-dimensional model of a diesel engine crankshaft demonstrated with the help of PRO/E software. Using Ansys software, the maximum stress are were found which were mainly concentrated in the knuckles of the crank arm, the main journal and the crank arm & connecting rod journal.[4]

Xiaorong et.al performed review on the crankshaft. The review, crankshaft terms, operation conditions and various failure sources are conversed. They analyzed the effect of influential parameters such as residual stress on fatigue behavior and techniques of persuading compressive residual stress in crankshafts.[5]

Guagliano et.al studied on a marine diesel engine crankshaft by using Finite element analysis to determine the stress concentration. In this numerical model analysis was validated with experimental results. As compared to the experimental results, the FEA results were more precise and acceptable [6]

Henry et.al determined the stress in the fillet zone of crankshaft by using Finite element analysis method. The achieved stresses were tested by experimental result on a 1.9 liter turbocharged diesel engine with Richard kind of combustion chamber.[7]

Prakash et al studied the stress and fatigue analysis of crankshaft by using the classical method and FEM based approach using Ansys. From this analysis the result obtained stated that the strength and ductility exponents have great effect on life.[8]

Borges et al studied the stress distribution on the crankshaft by using the FEA by applying ANSYS software to determine the stress concentration.The FEA model gives the identical stress dissemination over the crankshaft and the stress concentration is high in the fillet between the crank pin bearing and the crank web.[9]

Zoroufi and Fatemi et al studied the dynamic load analysis of the crankshaft. By using the FEA analysis software both static and dynamic analysis were performed. The comparison between the results obtained from numerical method and experimental method was presented and critical zone of stress concentration is occurred on the fillet area of crankshaft.[10]

M.Fonte and P.Duarte et al studied the two damaged crankshaft of single cylinder diesel engines which are used in agricultural services for several purpose are focused. In this the crankshaft are failed after 100h in service. To determine the root cause of failure of a crankshaft the failure mode analysis is used and results are compared with the finite element analysis by applying ANSYS software in order to find the critical regions where the high stress concentrations are present and the failure is mostly occurred in crankpins. Due to the high stress concentration and high stress gradients the critical zone is occurred on the fillet area of crankshaft.[11]

Anand and Parthasarathy et al performed the finite element analysis by using the analysis software Ansys and the static and dynamic analysis were conducted on the crankshaft which is made up of EN-19 steel and Nitriding coated EN-19 steel. The total deformation, Von misses stress and shear stress were finding out. The material has been tested by using various mechanical testing such as tensile test, hardness test, thermal expansion test. The result obtained was also discussed in before and after hardening of intruding process.[12]

Andrzej and Tomasz et al to solved the three dimensional thermal and mechanical problem they developed one programme. Mathematical model of crankshaft deformation was developed in the condition of heat treatment by considering elastic-plastic deformation and phase transformation process. In this paper, it was shown that during phase transformation, the cooling process is considered by three time changing the detection of bending of crankshaft and stress sign of it. It is done due to nonlinearity of thermal deformation during phase transformation and unloading of metal after the temperature become uniform.[13]

M.Fonte and V.Infante et al performed the analysis on two different damaged crankshafts. Out of these one obtained from diesel engine of mini backhoe and second one from an automobile vehicle. The connecting rod, crankcase and motor block damage due to the diesel motor suffered a serious mechanical damage after three years and 5000 hours in its service. While studying both the crankshafts were failed due to the crack which was present in crankpin-web. Both the crankshafts were observed with the help of scanning electron microscope analysis and finding out the zone where the cracks were initiated. According to this technique both the crankshafts were failed due to the fatigue.[14]

3. Theoretical Analysis by using Theories of Failure

According to the geometry of crankshaft, a throw was selected due to symmetry about vertical axis. This will simplify the geometry and complex calculations can be avoided.

A. Deformation

In real practice angular loads acting on the crankshaft, these loads can be converted in to horizontal and verticals loads.
Horizontal Load

, $\sin 25 = \frac{y}{833}$ ……..………………………..…………1

Vertical Load
$\cos 25 = \frac{x}{833}$ ………………………………...……..2

To determine maximum deformation, the reactions are taken on the bearings of throw. The distance was taken as 81mm. The vertical and horizontal loading diagram as shown in figure 1 and figure 2.

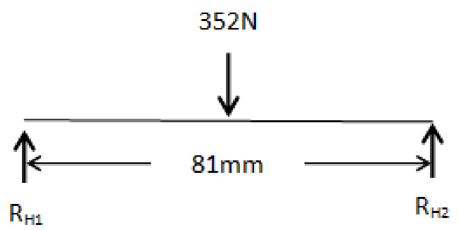

Figure 1: Horizontal Loading Diagram

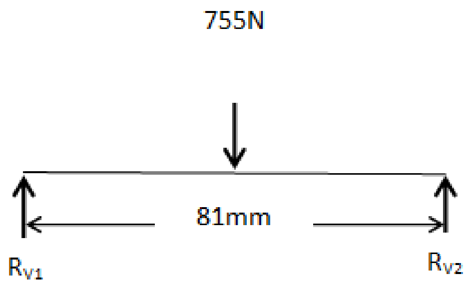

Figure 2: Vertical Loading Diagram

The maximum deformation for simply supported beam is given by following equation [15],

$\delta_{max} = \frac{FL^3}{48EI}$……………………………………………..3
E= Modulus of elasticity = 2 × 105 N/mm^2
Vertical Force, FV = 755 N
Horizontal Force, FH= 352 N
Total Force, FT= 833 N
L = Length of Beam = 81 mm.
I = Moment of Inertia for solid circular shaft
$=\frac{\pi}{64}d^4$
=73661.75 mm^4

Therefore,
δ_{max} (Vertical) = 0.000567399 mm
δ_{max} (Horizontal) = 0.000264535 mm
δ_{max} (Total) = 0.000626017 mm

B. Maximum Torsional Shear Stress Theory

Maximum Torsional Shear Stress [15]

$\tau = \frac{16T}{\pi d^3}$………………………………..4
d = diameter of shaft = 35 mm
T = Torque or torsional moment
T=833×cos(25)×31.5=23781.063N.mm
τ = 2.82486 N/mm2

Here 31.5mm is the distance between center and load, but its angular load multiplying by cos25.

C. Resultant Axial Stress and Direct Stress

σx = σb ± σ [15]..5
σb = bending stress= $\frac{32M}{\pi d^3}$ [15]
σ = compressive direct stress=$\frac{4F}{\pi d^2}$ [15]

To avoid the shaft of different cross section, the length between ends is taken as 71mm that is from counter web. Hence distance between reactions of simply supported beam is 53mm.

Therefore, (B.M)max = 755×26.5=20007.5N.mm

The vertical load is greater than the horizontal load so that the maximum bending moment is occurred at vertical beam.

E. Maximum Principle Stress Theory

The maximum principle stress is as follows [15]

$\sigma_{max} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau^2}$……………………………….6
σx= Resultant Axial Stress
σx =$\frac{32M}{\pi d^3}$ -$\frac{4F}{\pi d^2}$= 3.9685 N/mm^2
Therefore, σmax = 5.43636 N/mm^2
E. Maximum Shear Stress Theory:

In the maximum shear stress theory the maximum torque is given as below [15]

$\tau_{max} = \frac{16T_e}{\pi d^3}$……………………………….7
Where,
Te =Equivalent Torque
$=\sqrt{(k_b M)^2 + (k_t T)^2}$ ……………………………….8
Kb and kt = Combined shocked and fatigue factor of bending and torsion respectively = 1[15]
Te = Equivalent Torque = 32997.14 N.mm
Therefore, τmax = 3.69163 N/mm2
F. Distortion Energy Theory
Von-misses stress [15] as follows,
$\sigma_v = \frac{32M_{ev}}{\pi d^3}$……………………………………….9
Mev= Equivalent Bending Moment = 26803.27 N.mm

Therefore, σv= 6.3671 N/mm^2

4. Numerical Analysisby using Ansys R 15.0

A. Prepare a Model

For modeling of actual physical specimen ANSYS design modeler is used. In order to comparison, dimensions used in modeling the plates in ANSYS 15 were the same as the experimental work. Design modeler in ANSYS Workbench provides a sketcher based environment for solid modeling. In this 4-cylinder engine crankshaft has been used for the analysis. Material used is Nodular cast Iron it has good fluidity, low melting point, castability, excellent machinability as well as wear resistance. It also has high strength, hardness, toughness, workability and hardenability. It encompasses 3-4% C, 1.8-2.8% Si, Graphite. Also density - 7700kg/m³, Elastic- Young's modulus- 2 e11 N/m², Poisson's ratio 0.28. Due to higher complexity and nonlinearity, Ansys R15.0 has been used. First the solid model is developed in Ansys R15.0.At a time load of 833 N was applied which has been validated through combustion phenomenon.

1. This is load corresponding to combustion pressure of 101 bar or 10.1 MPa
2. Load is averaged over a cycle as combustion phenomenon lasts for 25 to 30 degree of crank revolution indeed.
3. 2/3 load has been transferred to crankshaft. This load is for worst possible situation.
4. Generally load is much less than this.

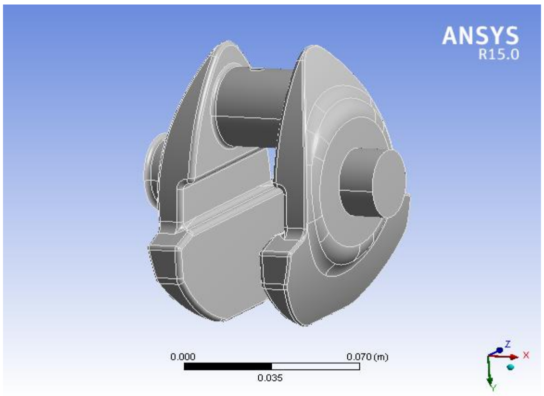

Figure 3: Model of Crankshaft

B. Mesh Model

Type of element: Quad+ Tetrahedrons
Number of nodes: 43982
Number of elements: 4416

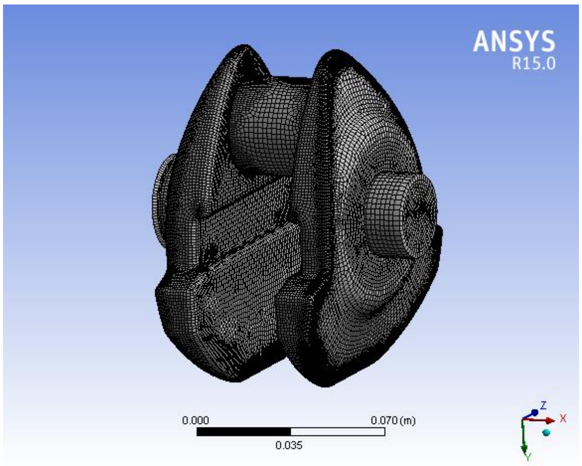

Figure 4: Mesh Model of Crankshaft

C. Applying Loads and Boundary Conditions

All degrees of freedom of the nodes were fully constrained and loading force is applied at the upper surface. The loading and boundary conditions are applied. After application of loading and boundary condition, 'solve' the model for next step.

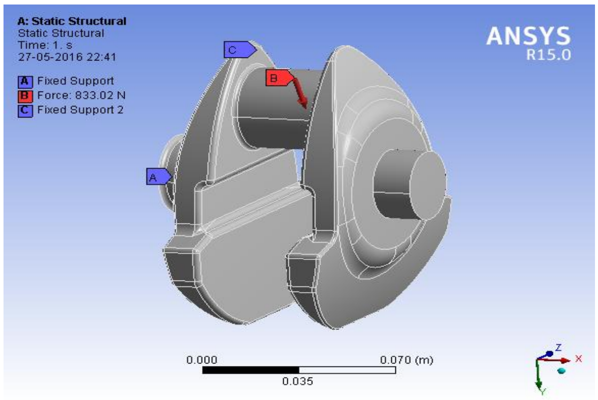

Figure 5: Applying Boundary Conditions

D. Solution and Post Processing of Static analysis

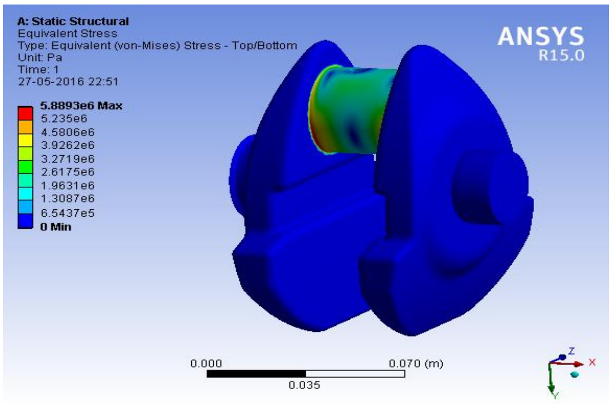

Figure 6: Equivalent Von Misses Stress

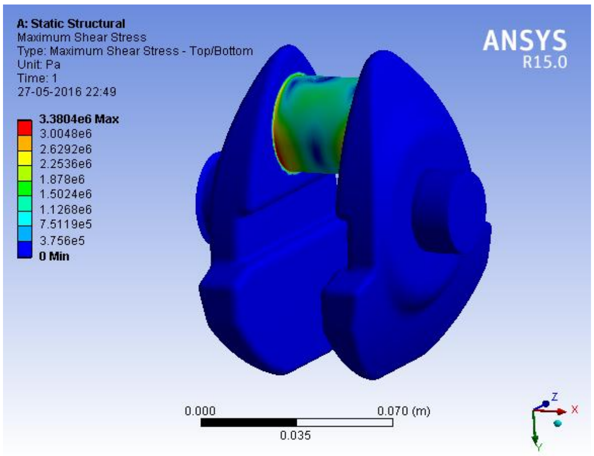

Figure 6: Maximum Shear Stress

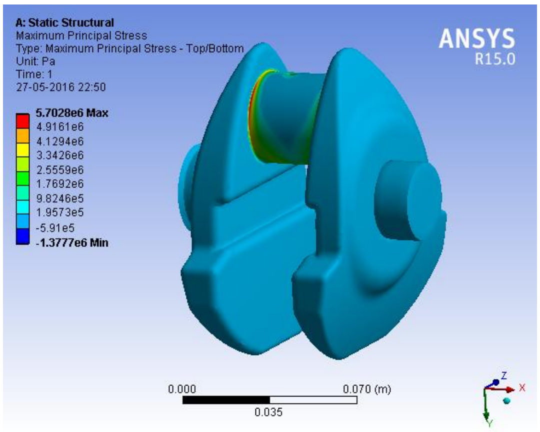

Figure 7: Maximum Principle Stress

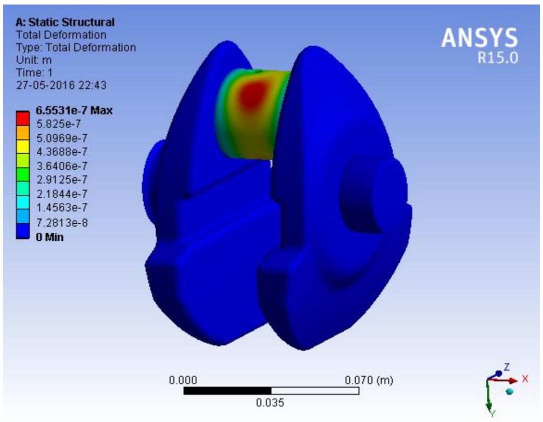

Figure 8: Total Deformation

E. Solution and Post Processing of Dynamic Analysis

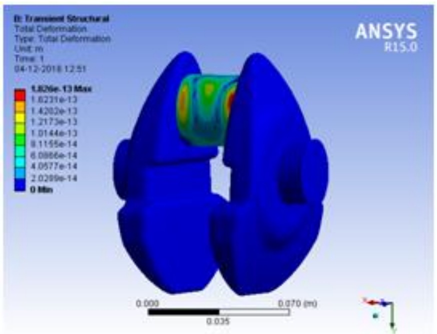

Figure 9: Total Deformation

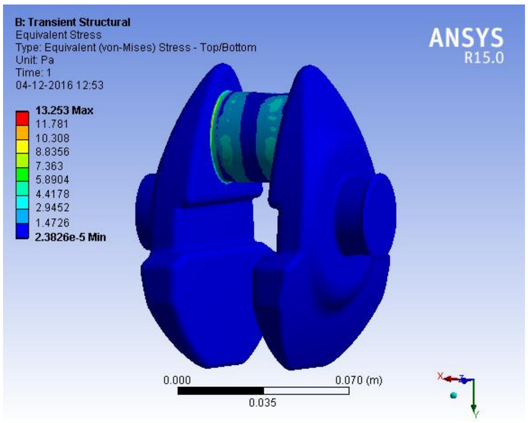

Figure 10: Equivalent Von Misses Stress

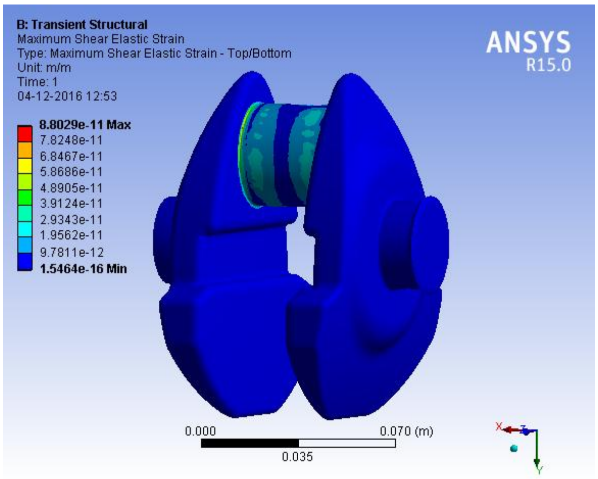

Figure 11: Maximum Shear Elastic Strain

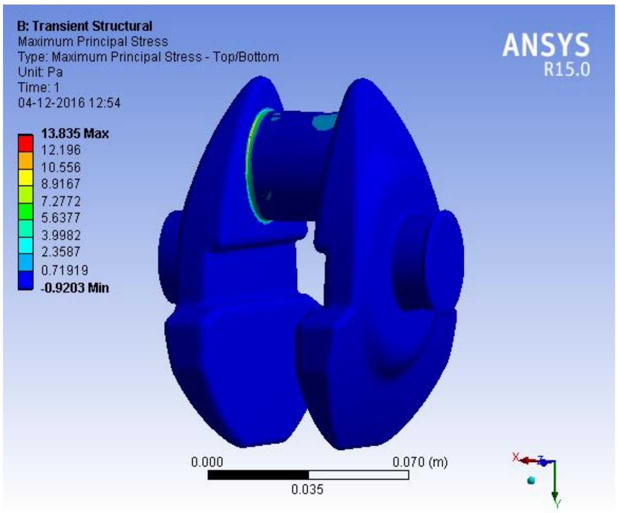

Figure 12: Maximum Principle Stress

5. Result and Discussion

In FEA analysis the torque which is ranging from 40-50 Nm was applied on the drive end of crankshaft by using analysis software Ansys R15.0 the various values are obtain such as maximum principal stress, maximum shear stress, total deformation, equivalent von mieses stress; from this stress concentration is high at the fillet area and all the stress values are less than the permissible stress value. Also this result is obtained from FEA method which is validated with theoretical analysis. The comparison between theoretical results and FEA results as shown below.

Table 1: Comparison Between Theoretical and FEA Values

Parameters	Theoretical	Static	Dynamic
Maximum Principal Stress (N/mm2)	5.43636	5.7028	13.835
Maximum Shear Stress (N/mm2)	3.69163	3.3804	6.8772
Total Deformation (mm)	0.00062601	0.0006553	0.0000018
Equivalent Von Misses Stress (N/mm2)	6.3671	5.8899	13.253

6. Conclusion

The present work is to be performed for static as well as dynamic analysis of crankshaft for 4 cylinder inline engine and various stresses are finding out. A theoretical approach is presented to find the maximum deformation, maximum shear stress, equivalent Von Misses stress and maximum principle stress values induced in the crank shaft. Because of complexity in geometry, it is reduced to single throw by principle of symmetry about vertical axis. The material of existing crankshaft is nodular cast iron and applied force per cylinder is taken as 833 N at an angle of 25º with vertical axis. Various shaft failure theories applicable to above conditions are applied and theoretical values are determined. The various stresses values obtaining from theoretical analysis which is compared with finite element analysis, the values are same. From the above analysis it is found that the failure is due to the fatigue and crankshaft is failed at the crankpin which is the critical zone where the crack can initiated.

The future scope will be to refine the mesh size of crankshaft and to change loading conditions for the crankshaft and it can also be perform by using dynamic analysis.

References

[1] Mr. Farzin H. Montazersadgh and Ali Fatemi, “Dynamic Load and Stress Analysis of a Crankshaft’’, SAE International2007-01-0258.

[2] Mr. Amarjeet Singh, Vinod Kumar Mittal and Surjit Angra, “Strength Analysis and Optimization Methods for four Cylinder Engine Crankshaft Based on CATIA and ANSYS”, Applied Mechanics and Materials Vols. 592-594 (2014) PP 1789-1793.

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

[4] Gu Yingkui, Zhou Zhibo. “Strength Analysis of Diesel Engine Crankshaft Based on PRO/E and ANSYS, ” Third International Conference on Measuring Technology and Mechatronics Automation, 2011

[5] Xiaorong Zhou., Ganwei Cai., Zhuan Zhang. Zhongqing Cheng., 2009, “Analysis on Dynamic Characteristics of Internal Combustion Engine Crankshaft System, ” International Conference on Measuring Technology and Mechatronics Automation

[6] Guagliano, M., Terranova, A., and Vergani, L., 1993, “Theoretical and Experimental Study of the Stress Concentration Factor in Diesel Engine Crankshafts, ” Journal of Mechanical Design, Vol. 115, PP. 47-52

[7] Henry, J., Topolsky, J., and Abramczuk, M., 1992, “Crankshaft Durability Prediction – A New 3-D Approach, ” SAE Technical Paper No. 920087, Society of Automotive Engineers

[8] Prakash, V., Aprameyan, K., and Shrinivasa, U., 1998, “An FEM Based Approach to Crankshaft Dynamics and Life Estimation, ” SAE Technical Paper No. 980565, Society of Automotive Engineers

[9] Borges, A. C. C., Oliveira, L. C., and Neto, P. S., 2002, “Stress Distribution in a Crankshaft Crank Using a Geometrucally Restricted Finite Element Model”, SAE Technical Paper No. 2002-01-2183, Society of Automotive Engineers

[10] Zoroufi, M. and Fatemi, A., "A Literature Review on Durability Evaluation of Crankshafts Including Comparisons of Competing Manufacturing Processes and Cost Analysis", 26th Forging Industry Technical Conference, Chicago, IL, November 2005.

[11] Mr. Basavaraj S. Talikoti, Dr. S.N.Kurbet, Dr. V.V.Kuppast, “A Review on Vibration Analysis of Crankshaft of Internal Combustion Engine”, International Research Journal of Engineering and Technology, December 2015.

[12] M. Font, P. Duarte, V. Infante, “Failure Mode Analysis of Two Crankshafts of a Single Cylinder Diesel Engine”, Engineering Failure Analysis 56 (2015) PP.185-193. [10] Zoroufi, M. and Fatemi, A., "A Literature Review on Durability Evaluation of Crankshafts Including Comparisons of Competing Manufacturing Processes and Cost Analysis", 26th Forging Industry Technical Conference, Chicago, IL, November 2005.

[13] Anand, S and Parthasarathy, C, ” Analysis of Multi-cylinder Crankshaft for IC-Engine”, International Journal of Recent Scientific Research, Vol. 5, Issue, 3, PP.706-711, March 2014.

[14] Andrzej Milenin, Tomasz Rec, Maciej Pietrzyk, “ Model of Curvature of Crankshaft Blank During the Heat Treatment After Forging”, 11th International conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014.

[15] V.B. Bhandari, “Design of Machine Elements, ” MC Graw, Hill Education, 4th Edition