A Review on Finite Element Analysis of the Crankshaft of Internal Combustion Engine

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Abstract -
Crankshaft is a mechanical component with a complex geometry which transforms reciprocating motion into rotary motion; hence crankshaft plays a key role in its functioning. The crankshaft is connected to the piston through the connecting rod. The journals of the crankshaft are supported on main bearings, housed in the crankcase. The design of the crankshaft and analysis study is the most important process for an effective engine design and engine performance improvement in the internal combustion engine. The crankshaft is subjected to different pressure load with respect to crank angle and therefore the study the crankshaft subjected to different performance conditions is the most significant for an effective design in the internal combustion engines.

Key Words: Crankshaft, Structural Analysis, Dynamic Analysis, Computer Aided Design, ANSYS Software.

1. INTRODUCTION

The advancement in industry and technology leads to the need of low cost and highly reliable product. Internal combustion engine is one of the most important devices in the industry which converts chemical energy into mechanical energy. Consequently, there is a constant requirement of highly efficient and durable internal combustion engines in the market. Crankshaft plays a pivotal role in its functioning. Stress evaluation, fatigue calculation and vibration analysis are the most important for satisfactory working performance and life of engine. Modal analysis gives information about the vibration structure characteristics. Fatigue analysis gives an idea of life of the components whereas stress intensities and critical stresses are evaluated using structural analysis, therefore Finite Element Analysis is the most effective technique for designing the crankshaft which helps engineers to improve the existing crankshaft design and as well as to find out the best optimized crankshaft design. Finite Element Analysis (FEA) has been developed into a key indispensable technology in the modeling and simulation of various engineering systems. Since last decade advent of powerful finite element analysis packages have proven effective tool to accurately analyze them. FEM enables to find critical locations and quantitative analysis of the stress distribution and deformed shapes under loads. However detailed modeling and specialized knowledge of FEM theory are indispensable to perform these analyses with high accuracy.

2. Literature Review Summary

Authors studied the design analysis of crankshafts for different types of internal combustion engines. Furthermore crankshaft optimization have been studied using finite Element Analysis under different performance conditions like structural, dynamic, thermal and fatigue analysis.

Below are the summary of several research papers studied by different authors.

2.1 Computer aided modeling and optimization of Crankshaft

Summary: In this research paper, the author studied the optimization crankshaft in the area of fatigue to evaluate and compare the fatigue performance of two competing manufacturing technologies for automotive crankshafts namely forged steel and ductile cast iron

Conclusion: The Author analyzed static analysis of both forged steel and ductile cast iron crankshaft and observed that forged steel withstands the static load better from static analysis of view, therefore the author recommended to replace cast iron crankshaft by forged steel crankshaft.

2.2Dynamic load and stress analysis of a crankshaft

Summary: In the above research paper, the author studied a dynamic simulation of crankshaft for single cylinder four stroke engine. Dynamic analysis was done analytically and verified by simulation in ADAMS. Furthermore, static analysis versus dynamic load analysis has been discussed. In addition, above stress comparison from FEA and strain gauges of a crankshaft in a bench test are presented.

Conclusion: According to authors, the dynamic loading analysis of the crankshaft results is more realistic stresses whereas static analysis provides an overestimate results. Furthermore, experimental and FEA results showed close agreements within 7% difference.

2.3Finite element analysis approach for crankshaft optimization

Summary: Authors calculated optimization of crankshaft by considering the effect of for its weight. Referred to topology and shape technique, optimization of crankshaft was done. Optimization was carried out under static load condition. In addition to above the optimized geometry is reanalyzed under inertia and gas force using finite element analysis software.

Conclusion: Authors concluded that the basic optimization study resulted in approximately 11% of weight reduction. Furthermore authors suggested to validate the optimized crankshaft design considering on another performance criteria in detail to know the effect of approved optimization under static loading.

2.4Finite element analysis of 4-cylinder diesel crankshaft

Summary: Authors evaluated stress intensities and the natural frequencies of a 4-cylinder crankshaft using finite element method. By using structural static analysis, stress intensities at different locations are calculated and considering free vibration theory, the natural frequencies and different modes are evaluated. Referred to the analytical results calculated using FEA software are compared with theory basis.

Conclusion: Authors experienced that the considerable amount of deformation, which is bending in nature occurred under the influence of lower frequency and stress is observed at the centre of the main bearing journal and crankpin of the crankshaft.

2.5Parametric optimization of four cylinders engine crankshaft

Summary: Authors investigated the effect of the dimensional parameters on stiffness and frequency of the crankshaft. Stated to different parametric set considered by the author the parametric optimization of crankshaft was done using ansys by considered the customized macros script.

Conclusion: Authors experienced that results shows that higher the frequency, higher the stiffness; as frequency is directly proportional to stiffness and inversely proportional to mass. Moreover the author observed that by reducing the mass and increasing stiffness the maximum stiffness achieved.

2.6 Finite element analysis and optimization of crankshaft of Briquette machine

Summary: The Author objective of this work was to calculate various failure modes occurred in crankshaft of Briquette machine subjected to cyclic loads and also improve the overall design of crankshaft. The author used FEA tool for calculation of various failure modes and study the optimization technique of the crankshaft geometry. The Author worked on shape optimization technique with considered the different aspects such as a hole diameter, fillet radius, height or width of a component.

Conclusion: Authors observed that shape optimization is one of the major criteria for improvement various different modifications in the crankshaft optimization

2.7 Design and stress analysis of crankshaft for single cylinder 4-stroke diesel engine.

Summary: Authors simulated the crankshaft under static and dynamic loading condition using ansys software to find out the stress variation in the crankshaft and natural frequencies and it's mode shapes. The boundary conditions applied as per engine specifications and stresses are evaluated by software and theoretical basis.

Conclusion: Authors concluded that stresses are over safe with comparison with theoretical basis especially in static analysis hence authors performed dynamic analysis for realistic results. Furthermore authors experienced that maximum stresses appears at the fillet between crankshaft journal and crank cheeks.

2.8 Crack analysis of a gasoline engine crankshaft

Summary: The author studied the failure analysis of the crankshaft used in a gasoline engine. The crack propagation in the crankshaft examined with mechanical and metallurgical properties of the crankshaft material. However the author observed that fatigue failure due to contact of journal and bearing surface which leads growth of crack. This contact resulted from defective lubrication or high operating oil temperature during working condition.

Conclusion: The Author examined that carbon contents is slightly higher than as per technical of material and experimental results proved that defective lubrication is main cause of failure in the crankshaft in fatigue.

2.9 Finite element analysis and optimization of crankshaft

Summary: Authors studied the failures in the solid geometry of the crankshaft by using ansys software under structural analysis. Moreover optimization of the crankshaft was done by considered geometrical changes in the crankshaft without influence in the connecting rod and engine block fitment.

Conclusion: Authors validated optimized results of the crankshaft with existing crankshaft results. Also authors concluded that limits of stresses and deformation are safe as per material specifications.

2.10 Frequency comparison and optimization of forged steel and ductile cast iron crankshafts.

Summary: The Author compared the crankshaft with two different materials in the area of free vibration using finite element analysis approach. The author designed the crankshaft using Catia software and solid geometries are imported in the ansys software for dynamic calculation to know the natural frequencies of the crankshaft. As per material details weight of cast iron is greater than forged steel; hence the author further studied optimization method by considering weight criteria and reduced weight 15% in ductile cast iron & 14% in forged steel.

Conclusion: The Author observed that resonance frequency is far away from operating condition hence possibility of resonance is very rare.

2.11 Modal analysis of a single cylinder 4-stroke engine crankshaft.

Summary: The Author analyzed modal analysis of the crankshaft by two different method i.e. free-frequency and frequency method using catia frequency analysis software. When the crankshaft under oscillating system then there is no any external forces acting on the crankshaft hence the author calculated natural frequencies and resonant frequency.

Conclusion: The Author concluded that resonant frequency value is far higher than operating frequency of engine hence practically the possibility of resonance is very rare.

2.12 Optimization of a forged steel crankshaft subjected to dynamic loading.

Summary: Authors studied optimization of a forged steel crankshaft by considering different factors, geometry, material and manufacturing process. However the optimization process shown that 18% of weight reduced with increased fatigue strength and reduced the cost of the forged steel crankshaft.

Conclusion: Author performed optimization study on the crankshaft which confirmed result 18% reduced weight of the forged steel crankshaft. In addition to above author suggested fillet rolling manufacturing process to induce the residual stress especially in the fillet area help in result improve the fatigue life of the crankshaft.

2.13 Review on optimization of crankshaft.

Summary: Authors evaluated and compared the fracture in the crankshaft. However authors demonstrated the optimization of the crankshaft with consideration of counterweight profile in the crankshaft. Balancing simulation of the crankshaft is used to predict the unbalance in the crankshaft.

Conclusion: Authors suggested that use the optimized design, which can replace by existing design of the crankshaft by without changes in the existing engine block and the connecting rod.

2.14 Crankshaft design methodology for diesel engines.

Summary: The Author studied design procedure for the crankshaft for diesel engines. The design of the crankshaft is the most challengeable due significant effect of vehicle payload, lower weight requirements, higher efficiency and longer durable life. Moreover the author presented flow chart for design considerations and proposal dimensions of the crankshaft.

Conclusion: The Author recommended to verify the results especially for strength with FEA software's. In addition torsional vibration measurements are important to know damper requirements and transient analysis results helps to reduced vibration and noise of the engine.

2.15 A Crankshaft system model for structural dynamic analysis of internal combustion engines.

Summary: The Author described the system model for analyzing the dynamic behaviour of an internal combustion engine. The Author described two level dynamic sub structured technique to predict the dynamic response using finite element method. Additionally experimental results compared with numerical results hence these numerical results proved capabilities and significance in the engine crankshaft design.

Conclusion: The Author validated crankshaft system model for inline five and six cylinder engine in dynamic and static analysis incorporation with general Motors.

2.16 Modelling and analysis of I.C Engine crankshaft by using different materials and loads.

Summary: The Author evaluated the crankshaft design methodology with the effect of different materials and its influence on the component. The main design criterion of the crankshaft is enough strength and rigidity. Also vibration should be minimum subjected to the critical speed and minimum weight subjected to the engine performance.

Conclusion: The Author validated best material recommended for the crankshaft using ansys software by evaluating static structural analysis of the crankshaft.

2.17 Theoretical and experimental analysis of torsional and bending effect on four cylinders engine crankshafts by using finite element approach.

Summary: The Author studied FEM analysis of the crankshaft under torsional and bending vibration hence natural frequencies and rigid body mode shapes analyzed using ansys and Holzer method. However in dynamic analysis customized macros are used, which help to convert user input pressure crank angle with the excitation force. The author used Pro/e software to build up solid geometry of the crankshaft and Hypermesh and ansys software used for mesh & solver purpose. Dynamic results are validated analytically & experientially.

Conclusion: The Author recognized experimental results and analytical results are similar. The critical stress region is plotted due to effect of radial force and tangential force.

2.18 Durability analysis of light weight crankshafts design using geometrically restricted finite element simulation techniques for camless engines.

Summary: The Author performed durability analysis of the crankshaft for single cylinder four stroke camless engine using FEA software Nastran with various static loads. However FEA results are verified with strain gauges which are attached at different location. These results are used further for fatigue life calculation and optimization study of the crankshaft.

Conclusion: The Author experienced 7% difference in the analytical and experimental results and also in dynamic analysis results are more realistic whereas in static analysis stresses are overvalued.

2.19 Study of fillet stresses on crankshaft and its natural frequency.

Summary: Authors calculated the crankshaft torsional vibrations using numerical solutions method and studied the causes of failure in the crankshaft. The analysis of the crankshaft was done using Holzer iterative method for to achieve the natural frequencies.

Conclusion: Authors calculated stress intensities and critical locations on the crankshaft. Furthermore Authors validated natural frequencies of assembly of the crankshaft by numerical method which shown that failure of the crankshaft initiated at fillet region.

2.20 Experimental and Analytical Modal Analysis of a crankshaft.

Summary: Authors worked on experimental analysis and analytical modal analysis of the multi cylinder engine crankshaft. Experimental modal analysis (EMA) was done using Fast Fourier Transform (FFT) using frequency response functions (FRFs) or impulse response functions (IRFs) in time domain. Additionally modal analysis was done by finite element approach using Nastran software and FEA results were compared with experimental modal analysis.

Conclusion: Authors concluded that modal analysis frequencies calculated analytically are agreed with experimental modal analysis test.

2.21 Simulation of stress distributions in crankshaft sections under fillet rolling and bending fatigue tests.

Summary: Authors studied the residual stress and the bending stresses near the fillet of the crankshaft section under fillet rolling and bending fatigue test. Computational analysis was done using simple plain strain finite element modal under uniaxial monotonic and cyclic loading condition based on anisotropic hardening rule. Moreover the critical locations for fatigue crack initiation as per stress distributions based on anisotropic hardening rule appear to agreed with the experimental observation in fatigue bending test of the crankshaft sections.

Conclusion: Authors observed that the plastic response of the material follows input stress strain data for anisotropic hardening rule; whereas plastic response depends the input strain ranges of the stress strain data. Furthermore author remarked for cast iron material, if deformation is more, void or crack nucleation and growth occurs due to existence of graphite particles.

3. CONCLUSIONS

Referred to many research papers and technical books design concept and different optimization techniques of the crankshaft is understood and familiar with the applications of experimental methods. As a part dissertation curriculum by studying the design and optimization methods of the crankshaft and various experimental methods which are used for experimentation of the crankshafts will help me in master curriculum.

4. FUTURE SCOPE

Reviewing different research papers further studies in the crankshaft design and optimization will do especially in the area of geometry optimization with thought and effect of changes in the geometry with different geometrical combinations in the crankshaft by using finite element analysis approach.

ACKNOWLEDGEMENT

The author would like to thank Mr. Sanjay Kandlikar and Mr. Mangesh Wazalwar of MAN Diesel & Turbo India Pvt. Ltd. for the support extended during dissertation curriculum.

REFERENCES

[1] C.M.Balamurugan, R. Krishnaraj, Dr. M. Sakthivel, K. Kanthavel, Deepan Marudachalam M.G, R. Palani,"Computer aided Modeling and Optimizationof Crankshaft," International Journal of Scientific & Engineering Research, vol. 2, Issue 8, Aug-2011, ISSN 2229-5518.

[2] Farzin H. Montazersadgh and Ali Fatemi, "Dynamic Load and Stress Analysis of a Crankshaft," SAE International-2007-01-0258.

[3] Shailesh Ganpule, Sachin Mate, Uday R. Gokhale, "Finite Element Analysis Approach for Crankshaft Optimization," Altair CAE user conference innovation through simulation,Aug-2006.

[4] Jian Meng, Yongqi Liu, Ruixiang Liu, "Finite element analysis of 4-cylinder diesel crankshaft," I. J. Image, graphics and Signal Processing, Published Online Aug-2011in MECS.(http://www.mecs-press.org/),PP. 22-29

[5] Priya. D. Shah, Prof. Kiran. K. Bhabhor, "Parametric Optimization of four Cylinder Engine Crankshaft," International Journal of Engineering Science Invention, Vol.3, Issue 6, June-2014, PP. 38-43

[6] Ramkumar R, Lenin V. R, Krishnaraju A, "Finite Element Analysis and Optimization of Crankshaft og briquette Machine," International Journal of Technology(IJEET), Vol.21, Mar-2015.

[7] Amit Solanki, Jaydeepsinh Dodiya, "Design and Stress Analysis of Crankshaft for Single cylinder 4-stroke diesel Engine,"International Journal and Research in Applied Science and Engineering Technology, Vol.2, Issue V, May-2014, ISSN 2321-9653.

[8] Ali Keskin, Kadir Aydin, "Crank Analysis Of A Gasoline Engine Crankshaft,"Gazi University Journal of Science, Vol.2, 2010, ISSN 487-492.

[9] Rinkle Garg, Sunil Baghla, "Finite element analysis and optimization of crankshaft Design," International Journal of Engineering and Management Research, Vol.2, Issue 6, Dec-2012 ISSN 2250-0758(http://www.ijemr.net), PP. 26-31

[10] K. Thriveni, Dr. B. Jaya Chandraiah, "Frequency comparsion and Optimization of Forged Steel and Ductile Cast Iron crankshafts," International Journal of Engineering Science Invention, Vol.2, Issue 11, Nov-2013 ISSN 2319-6720.

[11] K. Thriveni, Dr. B. Jaya Chandraiah, "Modal analysis of A Single Cylinder 4-Stroke Engine crankshaft," International Journal of Scientific and Research Publications, Vol.3, Issue 12, Dec-2013 ISSN 2250-3153.

[12] Farzin H. Montazersadgh and Ali Fatemi, "Optimization of forged Steel Crankshaft subjected to Dynamic Loading," SAE International-2008-01-0432.

[13] Sagar Khatri, Dipak Kharde, Kiran Varpe, "Review on Optimization of crankshaft," International Journal of Advanced Technology in Engineering and Science, Vol.4, Issue 4, Mar-2016 ISSN 2348-7550.

[14] K Pandiyan, Dr. Ashesh Tiwari, "Cankshaft Design Methodology for Diesel Engines," International Journal of Innovative research in Science, Engineering and Technology, Vol.4, Issue 8, Aug-2015 ISSN 2319-6710.

[15] Zissions P.Mourelatos –"A crank shaft system model for structural dynamic analysis of internal combustion engines".

[16] Karri Venkata sanyasi Amarendra Kumar, Bapiraju Bandam, "Modelling and Analysis of I.C Engine Crankshaft by Using Different Materials and Loads," International Journal & Magazine of Engineering Technology, Management and Research, Vol.1, Issue 12, Dec-2014 ISSN 2348-14850.

[17] R. G. Desavale,A. M. Patil, "Therotical and Experimental analysis of Torsional and Bending Effect on Four Cylinder Engine Crankshafts by Using Finite Element Approach," International Journal of Engineering Research, Vol.2, Issue 6, Oct-2013 ISSN 2319-6890. PP. 379-385

[18] Kanwar J. S. Gill,Pali Roshal, "Durability Analysis of Lightweight crankshafts Design Using Geometrically restricated Finite Element Simulation Techniques for Camless Engines" International Conference of Advance

Research and Innovation", Feb-2014 ISBN 978-93-5156-328-0

[19] Ajazul Haque, Deepak Dubey, J. C. Jain, "Study of the fillet on crankshaft and its Natural Frequency," International Journal of Research in Engineering and Technology, ISSN 2321-7308

[20] C. Azoury. A. Kallassy, B. Combes, I. Moukarzel, R. Boudet, "Experimental and Analytical Modal Analysis of a Crankshaft,"IOSR Journal of Engineering , Vol.2(4), Apr-2012 ISSN 2250-3021. PP. 674-684

[21] K. S. Choi, J. Pan, "Simulation of stress distribution in crankshaft sections under fillet rolling and bending fatigue tests," International Journal of Fatigue, Apr-2008, ISSN 544-557

[22] Singiresu S. Rao, "Mechanical Vibrations", Fifth Edition, Copyright 2011, Pearsom Education.

[23] Kripal Singh,"Automobile Engineering Vol I and Vol II"

[24] R. S Khurmi, " Machine Design", S. Chand Publication

[25] T. Stolarski, Y. Nakasone, S. Yoshimoto, "Engineering Analysis with ANSYS Software"

[26] Nitin S. Gokhale, Sanjay S. Deshpande, Sanjeev V . Bedekar,"Practical Finite Element Analysis"

[27] J. S. Mehata, A. S. Kailey,"Mechanical Vibrations"

[28] Ganeshan. V,"Internal Combustion Engines"

[29] Dr. Kripal Singh,"Automobile Engineering"

[30] Choudhary S. K,"Elements of workshop Technology"

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