IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727
PP 85-89
www.iosrjournals.org

Review: Design, Analysis and Optimization of 4-Cyliner Diesel Engine Crankshaft using Aluminum Alloy

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Abstract: *Crankshaft is an important component in an engine assembly. Crankshaft consists of two web sections and one crankpin, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism. This paper is related to design and finite element analysis of crankshaft of 4 cylinder diesel engine of heavy vehicle like truck. Engine capacity is 3785.1cc. The finite element analysis in ANSYS software by using three materials based on their composition viz. FG260, FG300 and Aluminum based alloy material. The parameter like von misses stress, deformation; maximum and minimum principal stress & strain were obtained from analysis software. The results of Finite element shows that the Aluminum based composite material is best material among all. Finally the results are validated through experimentation on Izod-Charpy impact testing, Pin on disc Wear test and Metallurgical Microscope.*
Keywords: *Crankshaft, Finite Element Analysis, Wear Test, Aluminum Alloy, von misses stress.*

I. Introduction

In various mechanical engineering applications the most widely used machine elements is Shaft. The crankshaft, impeller shaft, propeller shafts, camshafts etc. use shaft. Crankshaft is one of the most important moving parts consisting of two web sections and one crankpin that convert the piston reciprocating displacement to a rotary motion with a four link mechanism. Crankshaft experiences large forces from gas combustion. This force is applied to the top of the piston and since the connecting rod connects the piston to the crank shaft, the force will be transmitted to the crankshaft. The magnitude of the forces depends on many factors which consist of crank radius, connecting rod dimensions, and weight of the connecting rod, piston, piston rings, and pin. Since the crankshaft experiences a large number of load cycles during its service life, fatigue performance and durability of this component has to be considered in the design process. So the life of internal combustion engine and reliability depend on the strength of the crankshaft largely and as the engine runs, the power impulses hit the crankshaft in one place and then another. Failures of shafts not only result in replacement cost, but also in process downtime. The one of the most common causes of shaft failure is fatigue fracture. Fatigue failures are important considerations in mechanical designs. To determine the stress, geometry and dimensions Analysis, evaluations and engineering principles are employed in the design. To ensure the life of engine, strength calculation of crankshaft becomes a key factor. Traditionally beam and space frame model were used to calculate the stress of crankshaft but in these models the number of node is limited. With the development of computer, more and more design of crankshaft has been utilized finite element method (FME) to calculate the stress of crankshaft.

II. Literature Review

Wei Li, Qing Yan, and Jianhua Xue [1] this paper analyzed through the chemical composition, mechanical properties, macroscopic feature, microscopic structure and theoretical calculation methods. The analysis results show that the crankshaft which has obvious fatigue crack belongs to fatigue fracture. The crankshaft fatigue fracture was only attributed to the initiation and propagation of the fatigue cracks on the lubrication hole under cyclic bending and torsion.

M. Fonte, P. Duarte, V. Anes, M. Freitas, L. Reis [2] The fatigue strength and its correct assessment play an important role in design and maintenance of marine crankshafts to obtain operational safety and reliability. Crankshafts are under alternating bending on crankpins and rotating bending combined with torsion on main journals, which mostly are responsible for fatigue failure. The commercial management success substantially depends on the main engine in service and of its design crankshaft, in particular. The crankshaft design strictly follows the rules of classification societies. The present study provides an overview on the assessment of fatigue life of marine engine crankshafts and its maintenance taking into account the design improving in the last decades, considering that accurate estimation of fatigue life is very important to ensure safety of components and its reliability. An example of a semi-built crankshaft failure is also presented and the probable root case of damage, and at the end some final remarks are presented.

M. Fonte, V. Anes, P. Duarte, L. Reis, and M. Freitas [3] this paper reports a failure mode analysis of a boxer diesel engine crankshaft. Crankshafts are components which experiment severe and complex dynamic loadings due to rotating bending combined with torsion on main journals and alternating bending on crankpins. High level stresses appear on critical areas like web fillets, as well as the effect of centrifugal forces and vibrations. Since the fatigue fracture near the crankpin-web fillet regions is one of the primary failure mechanisms of automotive crankshafts, designers and researchers have done the best for improving its fatigue strength. The present failure has occurred at approximately 2000 manufactured engines, and after about 95,000 km in service. The aim of this work is to investigate the damage root cause and understand the mechanism which led to the catastrophic failure. Recommendations for improving the engine design are also presented.

M. Fonte, P. Duarte, L. Reis, M. Freitas, V. Infante [4] in this paper investigation is carried on two damaged crankshafts of single cylinder diesel engines used in agricultural services for several purposes. Recurrent damages of these crankshafts type have happened after approximately 100 h in service. The root cause never was imputed to the manufacturer. The fatigue design and an accurate prediction of fatigue life are of primordial importance to insure the safety of these components and its reliability. This study firstly presents a short review on fatigue power shafts for supporting the failure mode analysis, which can lead to determine the root cause of failure. The material of these damaged crankshafts has the same chemical composition to others found where the same type of fracture occurred at least ten years ago. A finite element analysis was also carried out in order to find the critical zones where high stress concentrations are present. Results showed a clear failure by fatigue under low stress and high cyclic fatigue on crankpins.

B. Kareem [5] in this study, mechanical crankshaft failures for automobiles are evaluated based on experts' opinion. This was done using data obtained using techniques based on oral interviews and questionnaire administration on mechanical failure of crankshafts from the experts working in the areas of automobile maintenance and crankshafts reconditioning. The data collected were analyzed using statistical methods based on probability. With this technique, probability of failure for each category of automobiles namely private, commercial cars and buses were evaluated. The results obtained show that private cars had lowest failure rate at the initial stage while commercial buses had the highest failure rate. At later periods all categories of automobile crankshafts considered had their failure rates converged steadily with stable reliability. Application of 6-sigma continuous improvement tool to the process indicated a further reliability improvement through improved oil lubrication system, especially in the thrust bearing. This showed that increased enlightenment campaign among the various stakeholders in automobile industries will improve on the choice of reliable mechanical crankshafts.

Xiaoping Chen, Xiaoli Yu, Rufu Hu, Jianfen [6] Crankshaft fatigue problem has long been a headache and frequent phenomenon in combustion engine which attracts various efforts especially including fundamental fatigue experimental data. In this paper, the rational experimental method is employed to study the crankshaft fatigue phenomenon based on a customized experiment platform, mimicking the real-world crankshaft working condition physically. Then, based on the experiment data, the statistical regression analysis of eight commonly used hypothesis distributions is conducted. The degrees of fitting effects of the chosen statistical model are evaluated individually. Results show that the three-parameter Weibull distribution model fits the data best which may be used as the fundamental model in future analysis. This study provides a solid foundation for better understanding the mechanism of crankshaft fatigue phenomenon.

A. Ktari, N. Haddar, H.F. Ayedi [7] a failure investigation has been conducted on three cases of failed diesel engine crankshafts used in train and made up of forged carbon steel. The chemical composition and the mechanical properties of the crankshafts material including tensile properties, micro-hardness and toughness were evaluated. The crankshafts examination shows that all failures occurred after a fatigue process. The failure zones comprise the fractured surfaces observation, show the presence of beach marks with semi-elliptical shape surrounding the fracture origins indicate its progressive growth character. The cracks initiation can occur as a result of mechanical and thermal fatigue loads, due to the high stress concentration on fillet radius and the unusual friction between journals and bearings, respectively. Nevertheless, the cracks propagation was only attributed to the mechanical fatigue produced under cyclic bending and torsion loadings.

J.A. Becerra, F.J. Jimenez, M. Torres, D.T. Sanchez, E. Carvajal [8] Analysis of the compressor revealed that the torsional dynamic controls the stress in the crankshaft and that the influence of the gas forces on the crankshaft stress is only minor. The appearance of the fracture was consistent with a torque overload. The maximum stress in the crankshaft, as obtained from the FEM and lumped model was located in the keyway, and this location belongs to the fracture surface in most of the broken crankshafts. The influence of the stress concentration factor imposed by this geometry is therefore very high. The compressor speed range was found to continuously cross the three lower resonance frequencies. The exhaust valve of the compressor should be redesigned in order to reduce gas forces, power consumption and pressure drop.

Gustavo Rocha da Silva Santos, Guilherme Vinícuis França dos Santos [9] this work presents the design of a crankshaft for a lightweight mono-cylinder spark-ignition four-stroke internal combustion engine using topology optimization. The topology optimization method implies the use of FE analysis combined with an optimization algorithm to find the optimum mass distribution of the crankshaft to minimize the component weight while satisfying manufacturing and maximum stress (yield strength) constraints. In addition, the application of this method allows control over the crankshaft natural frequencies by avoiding a spectrum around a specified Eigen frequency where no resonance occurs. This leads to a reduction of its torsional vibration, which is the leading cause of crankshaft failure. This methodology modifies the traditional mechanical design by placing structural analysis before the CAD design.

M. Fonte, M. de Freitas [10] case study of a catastrophic failure of a web marine crankshaft and a failure analysis under bending and torsion applied to crankshafts are presented. A microscopy (eye seen) observation showed that the crack initiation started on the fillet of the crankpin by rotary bending and the propagation was a combination of cyclic bending and steady torsion. The crack front profile approximately adopts a semi-elliptical shape with some distortion due to torsion and this study is supported by a previous research work already published by the authors. The number of cycles from crack initiation to final failure of this crankshaft was achieved by recording of the main engine operation on board, taking into account the beach marks left on the fatigue crack surface. The cycles calculated by the linear elastic fracture mechanics approaches showed that the propagation was fast which means that the level of bending stress was relatively high when compared with total cycles of main engine in service. Microstructure defects or inclusion were not observed which can conclude that the failure was probably originated by an external cause and not due to an intrinsic latent defect. Possible effects of added torsional vibrations which induce stresses are also discussed. Some causes are analyzed and reported here but the origin of the fatigue fracture was not clearly determined.

F. Jiménez Espadafor, J. Becerra Villanueva, M. Torres García [11] this paper analyses a catastrophic crankshaft failure of a four-stroke 18 V diesel engine of a power plant for electrical generation when running at a nominal speed of 1500 rpm. The rated power of the engine was 1.5 MW, and before failure it had accumulated 20,000 h in service operating mainly at full load. The fracture occurred in the web between the 2nd journal and the 2nd crankpin. The mechanical properties of the crankshaft including tensile properties and surface hardness (HV1) were evaluated. Fractographic studies show that fatigue is the dominant mechanism of crankshaft failure, where the beach marks can be clearly identified. A thin and very hard zone was discovered in the template surface close to the fracture initiation point, which suggests that this was the origin of the fatigue fracture. A finite element model of the crankshaft has predicted that the most heavily loaded areas match the fractured zone.

Osman Asi [12] this paper describes the failure analysis of a diesel engine crankshaft used in a truck, which is made from ductile cast iron. The crankshaft was found to break into two pieces at the crankpin portion before completion of warranty period. The crankshaft was induction hardened. An evaluation of the failed crankshaft was undertaken to assess its integrity that included a visual examination, photo documentation, chemical analysis, micro-hardness measurement, tensile testing, and metallographic examination. The failure zones were examined with the help of a scanning electron microscope equipped with EDX facility. Results indicate that fatigue is the dominant mechanism of failure of the crankshaft. It was observed that the fatigue cracks initiated from the fillet region of the crankpin-web. The absence of the hardened case in the fillet region and the presence of free graphite and no spheroidal graphite in the microstructure of the crankshaft made fatigue strength decrease to lead to fatigue initiation and propagation in the weaker region and premature fracture.

Changli Wang, Chengjie Zhao, and Deping Wang [13] a crankshaft cracked in a strange manner when test running was performed for only 20 min. Four cracks were found on the edge of the oil hole. Using mechanical analysis, microstructure and metallurgy the reason of this event has been revealed. Force of friction caused by improper crankshaft repair and assembling is main factor of the failure. Why friction occurs, how the crack initiates and expands and what the process of failure is were studied.

Zhiwei Yu, Xiaolei Xu [14] a failure investigation has been conducted on a diesel-engine crankshaft used in a truck, which is made from 42CrMo forging steel. The crankshaft was nitrided. The fracture occurred in the web between the 2nd journal and 2nd crankpin. The depth of the nitrided layer in various regions of the crankshaft particularly in the fillet region close to the fracture was determined by SEM observation and micro-hardness (HV0.1) measurement, combined with nitrogen content analysis by EDAX. The mechanical properties of the crankshaft including tensile properties, mar hardness (HB) and surface hardness (HV1) were evaluated. Fractographic studies indicate that fatigue is the dominant mechanism of failure of the crankshaft. The partial absence of the nitrided layer in the fillet region close to the fracture makes fatigue strength decrease to lead to fatigue initiation and propagation in the weaker region and premature fracture. The partial absence of the nitrided layer may result from over-grinding after nitrating. In order to prevent fatigue initiation in the fillet the final grinding has to be done carefully and the grinding amount controlled to avoid grinding down the nitrided layer.

F.S. Silva (15) this paper reports an investigation that was carried out on two damaged crankshafts. They were diesel van crankshafts that were sent to be ground, after a life of about 300,000 km each. Some journals were damaged on each crankshaft. After grinding, and assembling on the diesel van, the crankshafts lasted about 1000 km each, and the journals were damaged again. The crankshafts were then sent to be investigated. Different laboratory tests were carried out in order to discover what could have been the cause of the damage. Different typical crankshaft failures were assessed, and will be discussed in this paper. The cause of the damaged journals was found to be a wrong grinding process that originated small thermal fatigue cracks at the center of the journals, on both crankshafts. These almost invisible cracks, with sharp edges, acted as knives originating a very quick damaging of the journal bearings, and as a consequence damaged the journals themselves.

III. Problem Statement

As crankshaft is generally made of ferrous material, it has high density the crankshaft become bulky. Because of bulky crankshaft weight of the engine is increases, hence selecting a new material to reduce the weight of the crankshaft without compromising on the properties of the material.

IV. Objectives

- To design of the crankshaft for the new proposed material.
- To study von misses stresses, deformations and maximum principal stresses.
- To analyze the result of software and experimental tests.
- To reduce the weight of crankshaft.

V. Methodology

- Literature review of various research papers.
- Theoretical calculation of four cylinder diesel engine crankshaft.
- Solid model of four cylinder diesel engine crankshaft.
- Meshing of 3-D entity of crankshaft.
- Finite element analysis in ANSYS14.5
- Computational results.
- Experimentation on material.
- Compare theoretical, FEA and experimental result
- Conclusion.

VI. Conclusion

After doing study of various papers we come to conclude that to reduce the weight of the crankshaft we should use aluminum alloy without compromising the properties of the existing material. By using FEA results we can analyses the von misses stresses, max principal stress and deformation when load is applied considering boundary conditions. Experimental performances will help to analyze the new material.

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