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Review Article

CRANKSHAFT FAILURE DUE TO FATIGUE—A REVIEW

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This paper focuses on the failure of crankshaft due to fatigue which are put into service in several applications. Crankshaft is important part in all types of engines employed in applications like aircraft, reciprocating compressor, marine engine, vehicle engine as well as diesel generator. The failure of crankshaft is due to fatigue resulting into cracks on the surface of crankshaft and effect of residual stresses due to fillet rolling process. The motivation behind this paper is to study how fatigue phenomenon leads to the failure of the crankshaft.

Keywords: Fatigue, Crankshaft, Engine failure, Crack

INTRODUCTION

Crankshafts are manufactured with different materials and during its operation due to cyclic loadings cracks are produced on its surface, ultimately resulting into failure of crankshaft due to fatigue. Nature of fatigue failure will be different in each case of engineering application of crankshaft and causes of fatigue are also different. This study summarizes contribution of various researchers toward failure analysis of crankshaft due to fatigue considering different approaches.

WHAT IS FATIGUE FAILURE

Fatigue failure is defined as the time delayed fracture under cyclic loadings. Fatigue failure starts with a crack at some point in the material. The crack is likely to be occur in the following regions. (i) Regions of discontinuity, such as oil holes, keyways, screw threads, etc., (ii) Regions of irregularities in machining operations such as scratches on the surface, stamp mark, inspection mark, (iii) Internal crack due to material defect like blow holes. These regions are subjected to stress concentration due to crack. The crack spreads due to fluctuating stresses, until the cross-section of the component is so reduced that the remaining portion is subjected to sudden fracture. Two distinct areas of fatigue failure are: (a) region indicating slow growth of crack with a fine fibrous appearance, and (b) region

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of sudden fracture with a coarse granular appearance. Thus fatigue failure depends upon number of factors. Such as the number of cycles, mean stress, stress amplitude, stress concentration, residual stresses corrosion and creep.

CRANKSHAFT FAILURE DUE TO FATIGUE—A REVIEW

This study is presented after extensive literature survey of crank shaft failure due to fatigue.

Literature Review of Different Applications of Crankshaft

Silva (2003) has investigated the crack produced in the two crankshafts of diesel van which were used for 30,000 km and then grinding is done. After machining both the crankshafts lasted only for 1000 km and resulting into the Journal damage. Due to wrong grinding process small fatigue crack developed along the centre of journal causing journal damage. The cracks are sharp and invisible in nature. The study was also supported by examining the various failure modes of crankshaft.

Becerra *et al.* (2011) has studied 4-Cylinder reciprocating compressor used in bus climate control system. Visual investigation material and Hardness analysis are carried out along with simulation which consists of various sub-models such as thermodynamic model of refrigeration cycle, Torque dynamical model, Finite Element Model, and lumped system model. The study reveals that stress in the compressor is controlled by torque dynamics and the effect of gas force on stress is negligible. FEM gives maximum stress value whereas lumped system model shows that failure area is keyway. The visibility of crack is consistent with torque overload and it is important to redesign the exhaust valve to reduce gas forces, power consumption, and pressure drop.

Jiménez Espadafor *et al.* (2009) has studied failure of 4-stoke 18 V diesel generator crankshaft used in electrical power plant. The crankshaft is running at speed of 1500 r.p.m before failure it has worked for 20,000 hrs of life. Failure of crankshaft was seen along the web between second journal and second crank pin. The presence of the beach mark shows fatigue fracture was produced along with a thin and hard zone which was found in the template surface showing crack initiation.

Fonte and Freitas (2008) has taken a case of marine engine crankshaft failure which was similar to the diesel generator crankshaft studied by Jiménez Espadafor in which cracks are produced on the crankpin fillet due to bending and and elevation of crack appears to be semi elliptical in shape. Time required for the progression of crack from its start to the failure of crankshaft is calculated by taking into account main engine operation. This shows that the progression of the crack is fast, i.e., bending stress is higher than the main engine service life. Ultimately cause of failure of crankshaft is external which can be concluded from the absence of surface defects. It may also note that the torsional vibrations also adds stresses in the crankshaft.

Infante *et al.* (2013) has also worked on finding out the causes of failure of aircraft engine crankshaft. The research was oriented about the failure of the crankpin journal due to fatigue. The investigation shows that the presence of beach mark and also striation marks. To analyse the crack initiation and crack propagation on the fractured surface optical and electronic microscopic technology was used.

Katari *et al.* (2011) has considered 3 different crankshafts made up of same material , i.e., forged steel which is used in train. The investigation shows that crankshaft failure is due to fatigue which is supported through examination of mechanical properties of crankshaft material. The failure regions showing semi-elliptical fracture indicating progressive fracture growth. Cracks are produced due to combined effect of mechanical and thermal fatigue load.

Literature Review of Crankshaft Based on Material, Stresses and Durability

Bhaumik *et al.* (2002) has also worked on finding out the causes of failure of transport aircraft crankshaft. The fracture is produced in the journal nos. 2 and 3 and initiation of fracture is due to rubbing action between journal and bearing due to axial load on the shaft. Further surface contact between these two results into excess pitting and spalling on web region.

Pandey (2003) has done investigation of crankshaft made up of forged carbon steel and resulting into premature failure in the web regions. Different types of tests are conducted for the evaluation of material properties. The analysis shows that to avoid such failure along the discontinuity in web regions machining and grinding need to be done carefully and it has been also suggested that fillet radius must be increased.

Chien *et al.* (2005) has undergone fatigue failure analysis of cast iron crankshaft and area where bending is occurred is studied, along with residual stresses produced due to fillet rolling process. The study revels that there are two different analysis done: i) In this area under bending without considering residual stresses is analysed by considering 2-D Elastic FEA. ii) In this residual stress distribution along the fillet regions is analysed by 2-D Elastic-Plastic FEA. Both analysis shows that the fatigue crack produced may propagate through residual stress zone in the fillet regions.

Changli Wang *et al.* (2005) has presented unusual crankshaft failure which has been occurred during a trial conducted only for 20 minutes. The main reason behind the failure of crankshaft is improper assembly resulting into initiation of four cracks surrounding the oil hole.

Xuanyang Lei *et al.* (2007) has presented work for the effect of presence of slant crack in the crankpin of crankshaft and model for vibration analysis is developed. Methodology used for such study consists of FEM model of crankshaft having slant crack in crankpin, derived relation for beam element, and non-linear equation of motion. The effect of crack depth on the transient response is investigated and numerical data validates for the simulation of the motion of the cracked crankshaft.

Bayrakceken *et al.* (2007) has presented his work on the single cylinder diesel engine crankshaft used in the agricultural vehicles. The study shows that two different cases of crankshaft failure has been investigated and in both cases slight design differences were mentioned. As the failure mechanism for both the crankshafts is due to fatigue only.

Castro *et al.* (2007) Crankshafts are manufactured by means of forging process and this paper shows that effect of nitriding time on the wear behaviour of an AISI H13 Hot work steel used for crankshaft forging dies. The time required for nitriding is between 1 to 24 hrs and sliding distance varied between 450 to 1500 meter. Analysis shows that wear rate changes as a function of sliding distance and at the same time coefficient of friction does not changes with nitriding time. The laboratory test shows that increased in the nitriding time and thus nitriding layer gives durability to forging dies.

Simon Ho *et al.* (2009) has presented his work on the crankshaft fillet rolling process optimisation. As crankshaft fillet rolling process is used to improve fatigue life of crankshaft, for this with the help of analytical method for the optimisation of fillet rolling process and to increase the durability. With the help of non-linear Finite Element Analysis stress produced are calculated for rolling process, based upon stress intensity factor meta- model has been developed. The meta-model method uses various factors such as fillet radius, rolling angle, force, etc. The Monte Carlo Simulation technique and Hooke-Jeeves direct pattern search method are used for the optimal design and durability of the crankshaft. Durability design is also depends upon the largest equivalent stress intensity factor, hence as mentioned above meta-model is generated with this equivalent stress intensity factor.

Choi and Pan (2009) has presented residual stresses and bending stresses distribution during fillet rolling process and for the fatigue test. First set of study is followed as simple plain strain finite element model with uniaxial and cyclic loading in the ABAQUS software and second set of study is followed as 2-Dimensional plain strain finite element model in ABAQUS. Study reveals that compressive hoop stress produced is also more and crack initiation in critical regions are similar to that of experimental values of the bending test for crankshaft regions.

Becerrra Villanueva *et al.* (2011) this research focuses mainly on the detection of cracks in large crankshafts in order to avoid loss and increase the durability. The procedure for crack detection consist of FEM model developed for crack growth and resulting into crankshaft stiffness with crack depth. It is important to note that all the results generated are purely based upon real engine data.

Gül Cevik and Riza Gürbüz (2013) has summarised the fatigue behaviour of fillet rolled diesel engine crankshaft. Author has investigated fillet rolled and un-rolled conditions of the crankshaft. Fatigue limiting stress value is determined with the help of FEM. Since test shows that the stress value is between 200 N/mm^2 to 810 N/mm^2 which is nothing but significant increase in the fatigue limits.

Zhenpeng *et al.* (2013) has presented complicated work related to the analysis of dynamic and lubricating properties Dynamic

Table 1: Summary of Literature Review

S. No.	Researcher	Year	Methodology	Investigating Parameter
1.	F. S. Silva	2003	Experimental	Crack
2.	J. A. Becerra	2010	FEM, Experimental	Crack
3.	F. Jiménez Espadafor	2009	FEM, Experimental	Stress, stress concentration factor
4.	M. Fonte	2008	Experimental	Crack
5.	V. Infante	2013	Experimental	Crack
6.	A. Katari	2011	Experimental	Crack
7.	S. K. Bhaumik	2001	Experimental	Crack
8.	R. K. Pandey	2002	Analytical, Experimental	Crack
9.	W. Y. Chien	2004	FEM, Experimental	Stress, stress concentration factor
10.	Changli Wang	2004	Experimental	Crack
11.	Xuanyang Lei	2005	Experimental	Vibration with Crack
12.	H. Bayrakceken	2006	Experimental	Crack
13.	G. Castro	2007	Experimental	Heat Treatment
14.	Simon Ho	2008	Experimental	Durability
15.	K. S. Choi	2008	FEM, Experimental	Stress, stress concentration factor
16.	J. A. Becerrra Villanueva	2011	FEM,Experimental	Durability
17.	Gül Cevik	2012	FEM,Experimental	Fatigue limit
18.	H. E. Zhenpeng	2013	FEM,Experimental	Contact Identification

properties which are affecting lubrication system are studied with the help of tribology, Finite Element Method (FEM), Finite Difference Method (FDM), multi-body dynamics method, and Component Mode Synthesis method (CMS).

CONCLUSION

This paper summarises fatigue failure phenomenon which is observed in engine crankshaft. Crankshaft may be used for different applications made up of different materials as mentioned at the beginning of this paper, but the nature of the crack initiation and its propagation along the various elements of crankshaft viz. Bearing, journal. Fillet or along the oil hole is same. As shown in Table 1 the authors from different background have studied not only about crack but also about durability, bending and residual stresses. The study of crankshaft failure not only limited to crack but along with that various aspects such as vibration characteristics, durability , fatigue limit, dynamic as well as lubrication characteristics. Fatigue failure is the cause associated with material and hence while investigating all these different cases of crankshaft failure different metallographic tests were conducted of the failure regions through which various mechanical properties of material are evaluated and which helped to find the failure mode of the crankshaft. The study of this fatigue behaviour is correlated through number of experimentations, analytical calculations as well as the various Finite Element Model. With these Finite Element

Model built in this case with the application of correct boundary conditions various results are obtained which are also very handy for each and every type of fatigue behaviour of the crankshafts.

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