Review Article Impact Factor: 4.226 ISSN: 2319-507X
Jeevkumar A. Wakode, IJPRET, 2015; Volume 3 (9): 337-346 IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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A FATIUGE ANALYSIS AND LIFE ESTIMATION OF CRANKSHAFT –A REVIEW

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Accepted Date: 05/03/2015; Published Date: 01/05/2015

Abstract: The performance of any automobile, mainly depends on its size and working in dynamic conditions. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of automobiles specifications with cost and size effectiveness. The evaluation of existing literature on crankshaft design and optimization is presented. The materials, manufacturing process, failures analysis, design consideration etc. of the crankshaft are reviewed here.

Keywords: Crankshaft, Analysis

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Access Online On:

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How to Cite This Article:

Jeevkumar A. Wakode, IJPRET, 2015; Volume 3 (9): 337-346

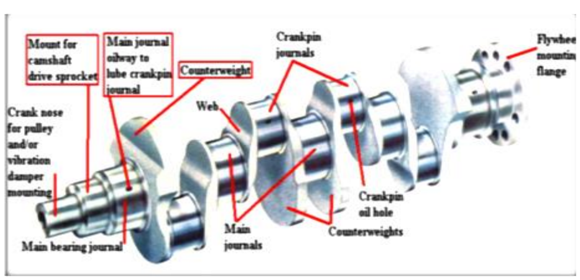
PAPER-QR CODE

INTRODUCTION

Crankshaft is a component having complex geometry that converts linear reciprocating displacement of the piston to a revolving motion. Crankshaft experiences huge number of load cycles through its service life, so its fatigue performance and durability has been considered in the design process. In crankshaft production industry design and development is an important issue, in order to manufacture a cheaper light weight component, proper fatigue life and fulfilling other functional requirements. Catastrophic failures are observed due to the fatigue phenomenon of the damage process caused by the growing of cracks due to the cyclic stress ultimately generate and aggregate micro cracks. It is observed that 85 % of all mechanical failures is due to fatigue which occurs under repeated application of stress which is small to cause failure in single application in elastic region.

II ABOUT CRANSKHAFT

A through conceptual design process for crankshaft requires input design data from the engine specification and operating conditions, design task including design for rigidity, static strength and curability, and manufacturing process and considerations. The preliminary design should be verified for rigidity, deformations, static strength, and fatigue strength under different load case scenarios considering appropriate factors of safety. Other design factors such as lubrication requirements, frequencies of vibration in torsion and bending and engine sound level are to be included afterwards. When the basic requirements of the preliminary design are fulfilled, alternative manufacturing processes should be evaluated to obtain the most feasible and cost effective manufacturing plan. Following preparation of manufacturing plan and simulating the processes, a prototype component should be manufactured and tested to verify the design requirements. Crankshafts are typically manufactured by casting and forging processes. Manufacturing by forging has the advantage of obtaining a homogeneous part that exhibits less number of micro structural voids and defects compared to casting. In addition, directional properties resulting from the forging process help the part acquire higher toughness and strength in the grain flow direction



III. MATERIAL FACTOR

Material is the important parameter which plays important role in fatigue. For high strength crankshaft mostly steel alloy is used. Due to cyclic loading material behaves differently than under monotonic loading. For different type of fatigue loading different types of cyclic material properties are required. Fatigue life of crankshaft may be increased by different alloy and surface treatment. Optimum level of nit riding depth should be at least 400 micrometer and because of nitriding fatigue limit is improved without any design modification. It is also proposed by [Park et al, 2001] that the best combination of crankshaft material with proper surface treatment can be used, which improves the quality and reduces the cost. Induction hardened crankshaft usually have longer fatigue life than other material [Taylor et al, 1999] Forge steel is commonly used as a crankshaft material because of requirement of higher horsepower per liter while selecting material for natural frequency, bearing load and axial displacement which is required for fatigue life estimation.[Mourelatos, 1995] suggested reducing flywheel inertia in order to increase the resonance frequency and second to balance the crankshaft internally in order to eliminate the unbalanced force on the flywheel. Crankshaft again undergoes higher loads at elevated temperature [Halaszi et al, 1999], so now a days thermo mechanical fatigue [TMF] life prediction commonly used in automotive industry due to complex and mechanical strains is used to find fatigue life of engine component. Sehitiglu TFM life prediction model developed by university of Illinois is used to describe the material behavior at different temperature and strain rate. Fatigue life may be carried out by Principal stress criterion by considering largest Principal stress.[Mercer et al,2003].

IV. DESIGN CONSIDERATION

The stress distribution analysis inside a crankshaft crank was studied by Borges et al. This stress analysis was taken out for finding overall structural efficiency of the crank, concerned with homogeneity and magnitude of stresses as well as the amount and localization of stress concentration points. The crank model had to be simplified by mostly restricting computers according to symmetry planes, as the memory limitations in the it. In order to evaluate results from the finite element analysis a 3D photo elasticity test was conducted. The influence of the residual stresses induces by the fillet rolling process on the fatigue process of a ductile cast iron crankshaft section under bending was studied by Chien et al, using the fracture mechanics approach. They investigated fillet rolling process based on the shadowgraphs of the fillet surface profiles before and after the rolling process in an elastic-plastic finite element analysis with consideration of the kinematic hardening rule. A linear elastic fracture mechanics approach was employed to understand the fatigue crack propagation process by investigating the stress intensity factors of cracks initiating from the fillet surface. One simple method provided by Steve Smith to understand how well a crankshaft can cope with power delivery by monitoring crankcase deflection during powered byno runs. The dada made available supports engineering decision to improve the crankshaft design and balance conditions; this reduces main bearing loads, which lead to reduced friction and fatigue, releasing power, performance and reliability. As the power and speed of engines increase, crankshaft stiffness is critical, Model solutions do not give guaranteed results; Emperical tests are needed to challenge model predictions. Residual imbalances along the length of the crankshafts are cruial to performance. Utilizing crankcase deflection analysis to improve crankshaft design and engine performance.

V. FAILURE OF CRANKSHAFT

Important factor in mechanical fatigue failure of crankshaft can be considered as, misalignment of crankshaft on assembly, improper journal bearing, vibration due to some problem with main bearing or due to high stress concentration caused by incorrect fillet size, oil leakage, overloading, high operating oil temperature [Silva,2003]. Thermal fatigue cracks will creates due to heat and stresses during contact bearing with repetition of heating and cooling and it will propagate with time.[Kareem,2007]generated the data gathered by oral interviews and questionnaires on mechanical failures of crankshaft. The data collected were analyzed according to vehicle type using statistical methods. The data collected were analyzed according to vehicle type using statistical methods. The results obtained showed that private cars enjoyed lowest fatigue failure rate at the initial stage while commercial buses had the highest fatigue failures rate.

The most common types of failures are as follows

Damage to journal surface hardening beyond recommended limits

Fig.6.1 Damage to journal surface of hardening

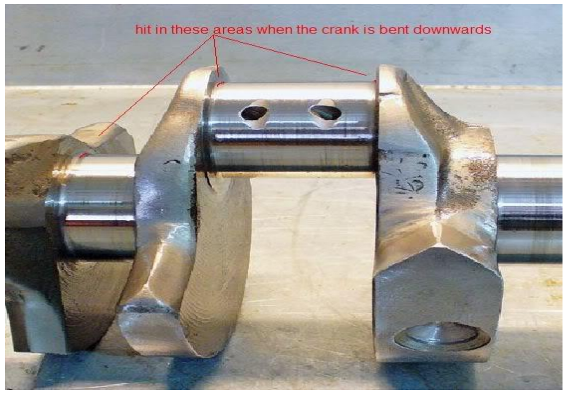


Fig.6.2 Bending of the crankshaft

Cracking of the crankshaft: A potentially serious issue for further engine damage cracks develop at the filler between the journal and the web, particularly between the position corresponding to 10 o'clock and 2 o'clock when the piston is at TDC

CAUSES OF FAILURES

Common failure causes of crankshaft are as follows

1. Insufficient lubrication. This may be due to contaminated lube oil, failed lube oil pumps, poor quality or incorrect specification lube oil.

2. Long term operation in a critical or forbidden rev range or over speeding of engine.

3. Faulty crankshaft damper, designed to remove excessive vibration from the crankshaft. Failure of proper operation can lead to excessive crankshaft vibration and fatigue.

4. Engine power imbalance leading to failure, cyclic loading. This can be caused by poor maintenance or monitoring of engine power, or even poor quality fuel.

5. Hydraulic locking of cylinders, flooding of cylinders with cooling water.
6. Misalignment of bearing, which may find out by proper crankshaft deflection measurement.
7. Design faults, a common problem as more licenses are passed out to new shipyards. Incorrect or blatant ignorance of material compositions or poor manufacture of crankshaft can lead to early failure.
8. Overloading of engine.
9. For propulsion machinery, grounding, and/or fouling of the propeller.

VI EXPERIMENTAL TECHNIQUES

[Paswan and Goel, 2008] examine fatigue results of induction hardened and case hardened 6 cylinder crankshaft. In filleted area strain gauges are positioned. Crankshaft is installed on fixture and clamping, cooler is used to prevent loosening. This fixture is attached to inertial weight and shaker and accelerometer. Crankshaft acts as a tuning fork due to shaker and the arrangement is made in such a way that if there is any failure in it, cycle stops automatically. From the results of twelve crankshaft sample, author found no evidence of failure and predicted that induction hardened crankshaft has longer life than any other material. From the investigation of damage horizontal, six cylinder in line diesel engine crankshaft of public bus was conducted by [Alfares et al,2007] after several failure cases were reported by the bus company. All crankshafts have been used material as forged and nitriding steel. In laboratory investigation the depth of the nitriding layer near facture locations in the crankshaft, particularly at the fillet region where cracks were initiated, wae determined by scanning electron microscope [SEM] equipped with electron dispersive X-ray analysis [EDAX] and was found less. Fractography which is the study of fracture surface of materials indicated that fatigue was the dominant mechanism of failure of the crankshaft. The partial absence of the nitriding layer in the fillet region, due to over grinding, caused a decrease in the fatigue strength which, in turn, led to crack initiation and propagation, and eventually premature fracture.[Alfares et al. 2007] Jung et al. used ductile crankshaft which is commonly used for SUV and lightweight truck. A crankshaft is mounted on fixture and monotonic bending load and frequency was applied to front main bearing. A computer is used to monitor feedback signal when sample is under bending load. When crack initiates and propagates, displacement amplitude also increases also the feedback signal, computer automatically stop the process. After investigating the sample cracks are found initiates around fillet area and propagating rapidly causing failure. Yu et al. used resonance bending Fatigue rest in order to investigate the effect of notch depth and subsequently the fatigue. SAE J434C D5506 cast iron crankshaft section were used in this investigation. Resonant frequency before and after creation of notches were measured. In the experimental set up crankshaft section was attached to heavy steel tine which acts as a tuning fork. The right tin is excited by shaker. During testing oil is applied to filled area. For given bending moment excited by shaker probe, fatigue life is determined when four pin head sized bubble are formed, at this point test was suspended. For result validation a 3 dimensional Finite Element Model of resonant bending system with notched crankshaft was prepared and results of experimental techniques and by using FEM were found in god agreement. The other commonly used experimental method to test bending fatigue limit is rotating bending fatigue test. In this constant bending stress is applied to round sample of crankshaft material along with rotation until its failure. This technique is simple and easy to use. Reciprocating bending testing machines utilize a rotating crank to achieve a nonzero mean stress through positioning of the specimen with respect to the motor, whereas Direct Force Fatigue Testing Machines uses axial load. Staircase method is very commonly used in auto sector for crank shaft fatigue testing and then applies a statistical analysis. In this initial stress amplitude based on experience is applied and sample is tested for survive or failure. When a survival (failures) occurs, then stress amplitude is increased by one stress increment for the next sample. Magnetic particle testing can be utilized on any ferromagnetic material in a variety of forms such as bars, engine components such as crankshaft for in service discontinuities. Magnetic particle testing is a nondestructive method which utilizes the flux leakage arising as a result of surface and near surface discontinuities to detect flaws. A magnetic current or filed is imposed on the part under inspection, a flux leakage at the surface of the part results in accumulation of sprayed iron powder, giving a direct indication of flaw. Ultrasonic testing utilizes sound waves with a frequency greater than 20 kHz to detect flaws and/or material properties. Modern ultrasonic testing can be utilized for finding cracks, de-bonds and laminations; detecting macrostructure variations and anomalies; variations in physical dimensions; and for density, mass and elastic property determinations. Ultrasonic testing can be performed on metals, nonmetals and composites.

VII. APPLICATION OF FEM IN FATIUGE

Now a day's numerical method such as Finite Element Method is used to gives detail information about structure or part. In some of the cases where a large no of degree of freedom involved, it is difficult to find out the behavior with the help of theoretical calculation. In such case FEM is used. It can be treated as excellent tool to analyze and find out fatigue and life estimation of crankshaft by computer simulation. With the FEM time and cost can be reduced for prototyping and to avoid numerous test series when laboratory testing is not available. Sophisticated analysis is required as loading on the crankshaft is complex in nature. Now a day's various Finite Element Methods are commonly used by automobile companies such as MSC-Fatigue, ANSYS, FEMFAT etc to chech durability of their products. Renault company developed a new crankshaft durability assessment tool based on 3D mesh, with an objective to improve fatigue analysis. These approaches calculate fatigue factor of safety through external load calculation, mesh generation, FEM load distribution to calculate stress and then FSF. The crankshaft fillet stresses are highly localized and also the stress distribution inside a crankshaft of automotive engine is very complex. FEM could be is tool for quantitative source of data to find out stress analysis for 6 cylinder inline engine crankshaft was presented by [Payer et al, 1995] which shows that this method is highly sophisticated and sufficient for determining the fatigue behaviors of crankshaft. [Payer et al, 1995] used XFEP finite element program to call cute transient stress behaviors of rotating crankshaft. Solid model of crankshaft is generated automatically considering both flywheel and vibration dampers using a rotating beam mass model of the crankshaft. This model also gives transient deformation of crankshaft.

Distribution and Photo elasticity would be used to validation the results [Borges, et al, 2002] evaluates the overall structural efficiency and magnitude of stresses throughout the crank and found localized stress concentration at crank pin bearing.

VII CONCLUSION

For a crankshaft following are the major consideration.

1. Relative study needs to be applied for the selection fo the material and manufacturing process so as to have cost effectiveness and shape with fewer defects respectively.

2. The central part of the crack front becomes straighter and the crack grows faster on the free surface.

3. Fatigue is the dominant mechanism of failure of the crankshaft.

4. Residual imbalances along with the length of the crankshafts are crucial to performance. Utilizing crankcase deflection analysis to improve crankshaft design and engine performance.

5. Dynamic stress and strain analysis must be conducted due to the nature of the loading applied to the component such as crankshaft.

6. Accurate stresses are critical input to fatigue analysis and optimization of the crankshaft.

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