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FAILURE ANALYSIS AND PROCESS IDENTIFICATION FOR A CRANKSHAFT: A REVIEW

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Abstract: Crankshaft is one of the most important moving parts in internal combustion engine. Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston into a rotary motion with a four link mechanism. The paper details the optimization options, their combination under a set of defined constraints and a comparison between the original forged steel crankshaft and the final optimized forged steel component. The main objective of this analysis was to optimize the weight and manufacturing cost of the forged steel crankshaft, which not only reduces the final production cost of the component, but also results in a lighter weight crankshaft which will increase the fuel efficiency of the engine. Geometry, material, and manufacturing processes were optimized using different geometric constraints, manufacturing feasibility and the first step in the optimization process was weight reduction of the component considering dynamic loading. This required the stress range under dynamic loading not to exceed the magnitude of the stress range in the original crankshaft.

Keywords: Design of Crankshaft, Optimization Procedure, failures, Causes of Failures for Crankshaft



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INTRODUCTION

Crankshaft

Crankshaft is among the largest components in internal combustion engines. It is employed in different types of engines, from small one cylinder lawn-mowers to large multi-cylinder diesel engines. Crankshaft is one of the most critically loaded components and experiences cyclic loads in the form of bending and torsion during its service life. This review is performed for optimization of crankshaft by considering various materials used for manufacturing of crankshaft, various manufacturing process used for manufacturing of crankshaft and opportunities available for optimization by various geometric changes in shape of crankshaft. Amongst all materials used for manufacturing of crankshaft the best material is selected and is manufactured by method which is most suitable and will reduce the cost of production. So now the various optimization studies are made on crankshaft made by the selected material manufactured method considered.

Optimization of Crankshaft

The main objective of optimization is to reduce the cost, weight or improve the geometry of component bye effective utilization of resources available. For optimization of crankshaft various studies have been made on material selection and manufacturing process of crankshaft, it is found crankshafts are typically manufactured from forged steel, nodular cast iron and austempered ductile iron (ADI). When forged steels are compared to cast iron and alloyed ductile iron used in crankshafts, the fatigue properties of forged steels are generally found to be better that that of cast iron. Also it is found that by using micro alloy steel it is possible to reduce the cost of production. Therefore replacement of conventional crankshaft by forged steel shaft will also result in optimization of cost. Therefore the optimization of forged steel crankshaft has been made in many research works, which is discussed in this seminar.

Detailed dynamic load and stress analysis of the crankshaft investigated in this study was the subject of another paper. Finite element analysis was used to obtain the variation in stress magnitude at critical locations. The dynamics of the mechanism was solved using analytical techniques, which resulted in the load spectrum applied to the crank pin bearing. The load was applied to the FE model and the boundary conditions were defined according to the engine mount design. The analysis was performed over different engine speeds and as a result the critical engine speed and critical locations on the crankshaft were obtained. Stress variation over the engine cycle and the effect of torsional load in the analysis were also investigated. Results from FE analysis were verified.

Material for Crankshaft

The major crankshaft material and manufacturing processes currently in use are forged steel, nodular cast iron and austempered ductile iron (ADI). Chatterley and Murrell compared fatigue strength of crankshafts made of forged steel, ductile iron and austempered ductile iron by conducting bending fatigue tests. Tests were performed by Chatterley and Murrell on nitrided 1% chromium/molybdenum forged steel, fillet-rolled ductile iron with 700 MPa tensile strength and 2% elongation, and fillet rolled ADI (the austempered version of the ductile iron used). All crankshafts were designed to operate within a 4 cylinder turbo-charged diesel engine. The fatigue tests were carried out on a constant amplitude mechanical stroking machine. The crankshafts were firmly clamped with split clamping blocks across two main bearing journals, with the bending moment being applied by means of a moment arm bolted onto an adapter press-fitted onto either the front (nose) or flywheel end of the shafts. Fatigue strength at ten million cycles of the rolled ADI crankshaft was found to be inferior to the forged steel crankshafts. However, the ADI showed better fatigue strength than ductile iron. So in this project we discussed experimental and modal analysis of 3 cylinder petrol engine forged steel crankshaft.

LITERATURE SURVEY

R.M. Metkar, et al [1], review on fatigue life of crankshaft is to investigate the behavior of crankshaft under complex loading conditions. Automobile industries are always interested to develop a new product which will be innovative and fulfill market expectations. Various other factors also play important role in mechanical fatigue failure of crankshaft, such as, misalignment of crankshaft on assembly, improper journal bearing, and vibration due to some problem with main bearing or due to high stress concentration caused by incorrect fillet size, oil leakage, and overloading, high operating oil temperature. Heat and stresses during contact bearing with repetition of heating and cooling would eventually create thermal fatigue cracks and it will propagate with time.

Rinkle garg and Sunil Baghl [2] has been analyzed crankshaft model and crank throw were created by Pro/E Software and then imported to ANSYS software. The result shows that the improvement in the strength of the crankshaft as the maximum limits of stress, total deformation, and the strain is reduced. The weight of the crankshaft is reduced .There by, reduces the inertia force. As the weight of the crankshaft is decreased this will decrease the cost of the crankshaft and increase the I.C engine performance.

Meng et al. [3] discussed the stress analysis and modal analysis of a 4 cylinder crankshaft. FEM software ANSYS was used to analyze the vibration modal and distortion and stress status of crank throw. The relationship between frequency and the vibration modal was explained by the modal analysis of crankshaft. This provides a valuable theoretical foundation for the optimization and improvement of engine design. Maximum deformation appears at the center of the crankpin neck surface. The maximum stress appears at the fillet between the crankshaft journal and crank cheeks, and near the central point journal. The crankshaft deformation was mainly bending deformation under the lower frequency. Maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So, the area prone to appear the bending fatigue crack.

Jian et al.[4] analyzed three dimensional model of 380 diesel engine crankshaft. They used ProE and ANSYS as FEA tools. First of all, the 380 diesel engine entity crankshaft model was created by Pro E software. Next, the model was imported to ANSYS software. Material properties, constraints boundary conditions and mechanical boundary conditions of the 380 diesel engine crankshaft were determined. Finally, the strain and the stress figures of the 380 diesel crankshaft were calculated combined with maximum stress point and dangerous area. This article checked the crankshaft's static strength and fatigue evaluations. That provided theoretical foundation for the optimization and improvement of engine design. The maximum deformation occurs in the end of the second cylinder balance weight.

Bin et al.[5] investigated the vibration model of 480 diesel crankshaft and the stress analysis of crankpin. Three dimensional models of 480 diesel engine crankshaft and crankpin were created through Pro E software. Finite element analysis software ANSYS was used to analyze the vibration model and the distortion and the stress status of the crankpin. This explains the relationship between the frequency and the vibration model. Stress analysis of crankpin provides the maximum deformation and maximum stress point. The crankshaft deformation was mainly bending deformation under lower frequency. The maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So the bending crack was prone to appear at this area. The maximum deformation appears the bottom of crank cheek. The maximum stress appears at the transition radius of crank cheek and connecting rod journal.

C. M. Balamurugan et.al [6] conduct Computer aided modeling and optimization analysis of crankshaft is to study was to evaluate and compare the fatigue performance of two competing manufacturing technologies for automotive crankshafts, namely forged steel and ductile cast iron. In this study a dynamic simulation was conducted on two crankshafts, cast iron and forged

steel, from similar single cylinder four stroke engines. Finite element analyses were performed to obtain the variation of stress magnitude at critical locations. The dynamic analysis was done analytically and was verified by simulations in ANSYS. Results achieved from aforementioned analysis were used in optimization of the forged steel crankshaft. Geometry, material and manufacturing processes were optimized considering different constraints, manufacturing feasibility and cost. The optimization process included geometry changes compatible with the current engine, fillet rolling and results in increased fatigue strength and reduced cost of the crankshaft, without changing connecting rod and engine block.

Yingkui and Zhibo [7]established three dimensional model of a diesel engine crankshaft by using Pro E software. Using ANSYS analysis tool, the finite element analysis for the crankshaft was conducted under extreme operation conditions and stress distribution of the crankshaft was presented. The crank stress change model and the crank stress biggest hazard point were found by using finite element analysis, and the improvement method for the crankshaft structure design was given. This shows that the high stress region mainly concentrates in the Knuckles of the crank arm & the main journal, and the crank arm and the connecting rod journal, which is the area most easily broken.

Bhumesh J. Bagde and Laukik Raut [8] studied the Structural and Fatigue Analysis of Single Cylinder Engine Crank Shaft the paper deals with, the problem occurred in single cylinder engine crank shaft.

Gu Yingkui, Zhou Zhibo [9] has been discussed a three-Dimensional model of a diesel engine crankshaft were established by using PRO/E software and analytical ANSYS Software tool, it shows that the high stress region mainly concentrates in the knuckles of the crank arm & the main journal and the crank arm & connecting rod journal, which is the area most easily broken.

ABOUT CRANKSHAFT

A thorough conceptual design process for a crankshaft requires input design data from the engine specifications and operating conditions, design task including design for rigidity, static strength and durability, and manufacturing processes and considerations. The preliminary design should be verified for rigidity, deformations, static strength, and fatigue strength under different load-case scenarios (i.e. bending, torsion, and combined bending and torsion loading conditions) 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. While designing the forging process for crankshaft, the grain-flow direction can be aligned with the direction of maximum stress that is applied to the component (along the axis of the shaft and related to bending).

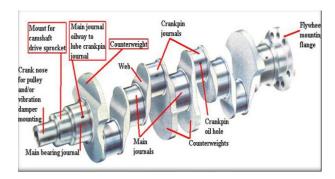


Fig 3.1: Crankshaft nomenclature

Heat Treatment

Flame and Induction Surface Hardening

These are the surface hardening methods for steel having 0.3 to 0.5% carbons without the use of special compounds or gases. The basic principle is to rapidly apply heat to the surface followed by only water quenching. As it is heated locally instead of heating the entire mass, the hardening is greatly reduced and distortion of the journal is avoided.

Flame hardening is carried out by oxyacetylene flame at the surface layer temperature between 993°K and 1173° K. The surface temperature depends on the carbon content equivalent of the different alloying elements in the steel. The heating process is followed by a water-jet quenching operation. Since the actual period for heating and cooling is critical, it is predetermined and is mostly automatically controlled.

Induction hardening is carried out by inducting heat electrically into the surface to be hardened. This case eliminates the danger of either overheating or burning the surface of the metal as with a flame hardening. An induction coil surrounds the journal and carries a high-

frequency current. This induces circulating eddy currents in the journal surface thereby rising of its temperature and heat is mostly confined to the outer surface of the journals. In this process the higher the frequency of the current, the closer the heat is to the skin. The current is automatically switched off when the required temperature is attained and the surface is simultaneously quenched by water jet, which passes through holes in the induction block.

Nitriding Surface-Hardening Process

In this process the journals are heated to 773 K for a predetermined time in an ammonia gas atmosphere, so that the nitrogen in the gas is absorbed into the surface layer. The alloying elements such as chromium, aluminium, and molybdenum, present in the steel, from hard nitrides. Aluminium nitrides form an intensely hard shallow case. Chromium nitrides diffuse to a greater depth than aluminium nitrides. The molybdenum increases harden ability, gives grain refinement, and improves the toughness of the core. This process can use directly the journals ground to their final size as there is no quenching after nitriding thereby avoiding distortion unlike other surface-hardening processes. The slow rate of penetration of the surface makes the cost of the process high for example; it takes 20 hours to produce a case depth of about 0.2 mm.

Carbo Nitriding Surface-Hardening Process

Tuff ride is the best-know salt-bath carbo nitriding process. The crankshaft is immersed in a bath of molten salts at a temperature of about 853 K for a relatively short cycle time of two to three hours. In the process both carbon and nitrogen dissociate from the salts and diffuse into the surface. Since nitrogen is more soluble than carbon in iron, it diffuses further into the material. Hard iron carbides and tough iron nitrides are formed on the surface thereby resistance to wear, galling (surface peeling), seizure, and corrosion are greatly increased. Depending on the steel used, this outer layer is 6 to 16 jam deep with hardness varying from 400 to 1200. Underneath this outer layer, the excess nitrogen goes into solid solution with the iron due to which it is strengthened. This inner diffusion zone forms a barrier which prevents spreading of cracks leading to fatigue failure. This surface-hardening treatment, also known as soft flywheel nit riding, is becoming increasingly popular for both steels the cast irons, and is expected to replace other more expensive processes for the components using plain carbon steels requiring surface hardness and corrosion resistance.

Forging Process and the Influencing Parameters

Forging is the term for shaping metal by plastic deformation. Cold forging is done at low temperatures, while conventional hot forging is done at high temperatures, which makes metal easier to shape. Cold forgings are various forging processes conducted at near ambient temperatures, such as bending, cold drawing, cold heading, coining, and extrusion to produce metal components to close tolerances and net shape.

Warm forging is a modification of the cold forging process where the work piece is heated to a temperature significantly below the typical hot forging temperature, ranging from 500° C to 750° C Compared with cold forging, warm forging has the potential advantages of reduced tooling loads, reduced press loads, increased steel ductility, elimination of need to anneal prior to forging, and favorable as-forged properties that can eliminate heat treatment. The use of the lower temperatures in cold and warm forging processes provides the advantages of reducing and even substantially eliminating the harmful scale or oxide growth on the component as well as enabling the component to be produced to a high dimensional accuracy.

Despite these advantages, cold and warm forging processes have the limitations of close tolerance and net shape of the final component with the work piece. Hot forging is the plastic deformation of metal at a temperature and strain rate such that recrystallization occurs simultaneously with deformation, thus avoiding strain hardening. Since crankshafts have complex geometries, warm and cold forging of the component is not possible. Therefore, crankshafts are manufactured using the hot forging process. In impression (or closed die) hot forging two or more dies are moved toward each other to form a metal billet, at a suitable temperature, in a shape determined by the die impressions. These processes are capable of producing components of high quality at moderate cost. Forgings offer a high strength to weight ratio, toughness, and resistance to impact and fatigue, which are important factors in crankshaft performance. In closed die forging, a material must satisfy two basic requirements: (a) The material strength (or flow stress) must be low so that die pressures can be kept within the capabilities of practical die materials and constructions, and (b) The capability of the material to deform without failure (forgeability) must be sufficient to allow the desired amount of deformation.

By convention, impression and closed die forging are considered to be hot working operations. In most practical hot forging operations, the temperature of the work-piece material is higher than that of the dies. The metal flow and die filling are largely determined by (a) the forging material's resistance to flow and ability to flow, i.e. its flow stress and forge ability, (b) the

friction and cooling effects at the material interface and (c) the complexity of the forging shape. A multi-cylinder crankshaft is considered to have a complex geometry, which necessitates proper work piece and die design according to material forge ability and friction to have the desired geometry.

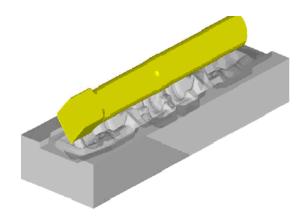


Fig 3.2: crankshaft work piece

Failures in Crankshaft

The most common types of failure are



Figure 3.3 Indents in this crank pin journal resulted in this crankshaft being condemned

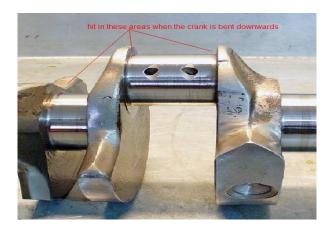


Figure 3.4 Bending of crankshaft



Figure 3.5 Cracking of this crankshaft between the crank pin and the crank web.

Causes of Failures

The most common causes for crankshaft failures are below:

- 1. Loss of effective lubrication. This can be due to contaminated lube oil, failed lube oil pumps, poor quality or incorrect specification lube oil.
- 2. Over speeding of engines, or long term operation in a critical or forbidden rev range.
- 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 fatigue 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. Bearing misalignment, this can be detected early with 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.

CONCLUSION

The optimization process was categorized indifferent stages and paper concludes with the sufficient reduction in weight and ultimately cost. The optimization resulted in an 18% weight reduction of the forged steel crankshaft. This was achieved by changing the dimensions and geometry of the crank counterweights while maintaining dynamic balance of the crankshaft. The optimization that was developed did not require any changes to the engine block or connecting rod. After each optimization step the counter weights were balanced in order to achieve an accurate estimate of the weight reduction. As the weight of the crankshaft is decreased this will decrease the cost of the crankshaft and increase the engine performance.

REFERENCES

- 1. R.M. Metkar, V.K. Sunnapwar and S.D. Hiwase ^{*}A fatigue analysis and life estimation of crankshaft a review "International Journal of Mechanical and Materials Engineering (IJMME), Vol.6 (2011), No.3, 425-430
- 2. Rinkle Garg, Sunil Baghla "Finite Element Analysis and Optimization of Crankshaft Design "International Journal of Engineering and Management Research, Vol.-2, Issue-6, December 2012 ISSN No.: 2250-0758 Pages: 26-31
- 3. Jian Meng, Yongqi Liu, Ruixiang Liu, "Finite Element Analysis of 4-Cylinder Diesel Crankshaft" I.J. Image, Graphics and Signal Processing, 2011, 5, 22-29
- 4. C.M.Balamurugan, R. Krishnaraj, Dr. M. Sakthivel, "Computer Aided Modeling and Optimization of Crankshaft" International Journal of Scientific & Engineering Research Volume 2, Issue 8, August-2011 1 ISSN 2229-5518

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- 5. Farzin H. Montazersadgh and Ali Fatemi, "Dynamic Load and Stress Analysis of a Crankshaft" 2007-01-0258
- 6. K. Thriveni¹ Dr. B. Jaya Chandraiah² "Modeling and Analysis of the Crankshaft Using Ansys Software "International Journal of Computational Engineering Research, Vol, 03,Issue, 5 05/2013
- 7. R. J. Deshbhratar, Y. R. Suple "Analysis & Optimization of Crankshaft Using Fem" International Journal of Modern Engineering Research (IJMER) Vol. 2, Issue. 5, Sep.-Oct. 2012 pp-3086-3088 ISSN: 2249-6645