A REVIEW OF OPTIMIZATION AND ANALYSIS OF CRANKSHAFT FOR PASSENGER CAR.

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Abstract : The main objective of this study is to investigate weight and cost reduction opportunities for a crankshaft. Crankshaft is large volume production component with a complex geometry in the Internal Combustion (I.C) Engine. This converts the reciprocating displacement of the piston into a rotary motion of the crank. This report shows the design overview, analysis and optimization. More particularly it consists of static structural analysis of a four-cylinder diesel engine crankshaft of TATA Indica Vista car. It identifies and solves the problem by using the modelling and simulation techniques. The modelling of the crankshaft is created by using SOLID WORKS/CATIA software and then simulate the crankshaft for static structural analysis. Finite element analysis is performed to obtain the variation of stress of the crankshaft by using ANSYS software. The objective involves modelling and analysis of crankshaft so as to identify the effect of stresses on crankshaft to compare various materials and to provide possible solution.

***Keywords* – Crankshaft, Optimization, Analysis, Weight Reduction, CATIA, ANSYS.**

I. INTRODUCTION

Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four links mechanism. 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. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output.
Crankshaft must be strong enough to take the downward force of the power stroke without excessive bending, so the reliability and life of the internal combustion engine depend on the strength of the crankshaft largely. And as the engine runs, the power impulses hit the crankshaft in place and then another.
In this study the finite element analysis has been performed on the crankshaft in order to optimize weight and manufacturing cost. The material for crankshaft is medium carbon steel. Other alternate material on which analysis has to be perform are structural steel and malleable cast.

1.1 Function of Crankshafts in IC Engines:

The crankshaft, connecting rod, and piston constitute a four bars slider-crank mechanism, which converts the sliding motion of the piston (slider in the mechanism) to a rotary motion. Since the rotation output is more practical and applicable for input to other devices, the concept design of an engine is that the output would be rotation. In addition, the linear displacement of an engine is not smooth, as the displacement is caused by the combustion of gas in the combustion chamber. Therefore, the displacement has sudden shocks and using this input for another device may cause damage to it. The concept of using crankshaft is to change these sudden displacements to a smooth rotary output, which is the input to many devices such as generators, pumps, and compressors. It should also be mentioned that the use of a flywheel helps in smoothing the shocks.

1.2 Function of Crankshafts in IC Engines:

The crankshaft is an important component of an engine, as it occupies large space in engine as well as it is subjected to shock and fatigue loads. Thus, material of crankshaft should be tough and fatigue resistant. The crankshafts are generally made of carbon steel, special steel or special cast iron. The crankshafts are made of drop forging or casting process but the former method is mainly common. The surface of crankpin is hardened by case carburizing nitriding or induction hardening as well.

Manufacturing a crankshaft of this size with a constant relative accuracy and precision machine tools always require high precision components and need to be fabricated with extreme precision. This will significantly increase the cost of producing such machine tools. Therefore, current industry practice tends to downsize the machine tool used to produce small volume objects, i.e. small machine for small products.

For shortening the processing time while minimizing manufacturing costs prompt their manufacturers to look for new, innovative solutions in a design. These include portable machines, also called mobile. In the design of machine structure selection of best structural combination is important task, which will affect on the design outcome and manufacturing time and quality of product.

1.3 Need and scope:

The future enhancement of automobiles there is been need to study of the various components of vehicles. Along which there shall be change in the design as per the necessity of the operation. The study of crankshaft will help to study the various parameter Forces acting on the crankshaft such to avoid failure and enhance safety. By this study we can able to find the new design and optimized product. This can help to make the same product with light weight with same quality. Similar to this the all other component can also be designed which will contribute in good quality component and lighter in weight this will not only decrease the cost of raw material but also increase the efficiency of car due to its light weight property.

II. RESEARCH METHODOLOGY:

In order to understand the importance of Optimization and analysis of crankshaft in system, and in order to attempt a consolidation of this non-consensual concept, a comprehensive literature review was carried out using scientificliteraturedatabases,journalarticles,booksandotherdocumentation,asthesourceofthe utilized secondary data. Furthermore, the literature review was conducted considering the following Rinkle garg and Sunil Baghl. [1] have 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 performances. Balamurugan et al [2] has been studied the Computer aided Modelling and Optimization of crankshaft and compare the fatigue performance The Three-dimensional model of crankshaft were created by solid edge software and then imported to Ansys software. Gu Yingkui, Zhou Zhibo. [3] have 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 broke. Abhishek Choubey, and Jamin Brahmbhatt. [4] have been analyzed crankshaft model and 3-dimentional model of the crankshaft were created by SOLID WORKS Software and imported to ANSYS software. The crankshaft maximum deformation appears at the center of crankpin neck surface. The maximum stress appears at the fillets between the crankshaft journals and crank cheeks and near the central point journal. The edge of main journal is high stress area.

R. J. Deshbhratar, and Y.R Suple. [5] have been analyzed 4- cylinder crankshaft and model of the crankshaft were created by Pro/E Software and then imported to ANSYS software the maximum deformation appears at the canter of crankshaft surface. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks, and near the central point. The edge of main journal is high stress area. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So, this area prone to appear the bending fatigue crack.

III. SOLUTION PROCEDURE AND PARAMETERS:

1. Stresses Analysis:

The crankpin is like a built-in beam with a distributed load along its length that varies with crank position. Each web like a cantilever beam subjected to bending & twisting. Journals would be principally subjected to twisting.

1. Bending causes tensile and compressive stresses.
2. Twisting causes shear stress.
3. Due to shrinkage of the web onto the journals, compressive stresses are set up in journals & tensile hoop stresses in the webs.

2. Materials and Manufacturing Processes:

Metal Forming fundamentals and applications carried out by Altan et al (1) on multi-cylinder crankshaft is considered to have a complex geometry, which necessitates proper workpiece and die design according to material forgeability and friction to have the desired geometry. The main objective of forging process design is to ensure adequate flow of the metal in the dies so that the desired finish part geometry can be obtained without any external or internal defects. Metal flow is greatly influenced by part or dies geometry. Often, several operations are needed to achieve gradual flow of the metal from an initially simple shape (cylinder or round cornered square billet) into the more complex shape of the final forging.

The major crankshaft material competitors currently used in industry are forged steel, and cast iron. Comparison of the performance of these materials with respect to static, cyclic, and impact loading are of great interest to the automotive industry. A comprehensive comparison of manufacturing processes with respect to mechanical properties, manufacturing aspects, and finished cost for crankshafts has been conducted by Zoroufi and Fatemi (23)

Nallicheri et al. (14) performed on material alternatives for the automotive crankshaft based on manufacturing economics. They considered steel forging, nodular cast iron, micro-alloy forging, and austempered ductile iron casting as manufacturing options to evaluate the cost effectiveness of using these alternatives for crankshafts.

3. Failure Analysis of Crankshaft:

Another crack detection method was introduced by Baxter (3). He studied crack detection using a modified version of the gel electrode technique. This technique could identify both the primary fatigue cracks and a distribution of secondary sites of less severe fatigue damage. The most useful aspect of this study is that the ELPO film can be applied before or after the fatigue test, and in both cases, the gel electrode technique is successful at detecting fatigue damage. As can be seen, a fatigue crack of length 2.2 cm exists along the edge of the fillet, which the markings from this technique clearly identify.

Fatigue crack growth analysis of a diesel engine forged steel crankshaft was investigated by Guagliano and Vergani (8) and Guagliano et a (9) They experimentally showed that with geometry like the crankshaft, the crack grows faster on the free surface while the central part of the crack front becomes straighter. Based on this observation, two methods were compared; the first considers a three-dimensional model with a crack modelled over its profile from the internal depth to the external surface. In order to determine the stress intensity factors concerning modes I and II a very fine mesh near the crack tip is required which involves a large number of nodes and elements, and a large computational time. The second approach uses two dimensional models with a straight crack front and with the depth of the real crack, offering simpler models and less computational time.

Osman Asi (15) performed 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.

4. Design Considerations:

An analytical tool for the efficient analysis of crankshaft design has been developed by Terry M. Shaw (21) Cummins Engine Co., Inc. Ira B. Richter - Cummins Engine Co., Inc. (13). Finite element models are generated from a limited number of key dimensions which describe a family of crankshafts. These models have been verified by stress and deflection measurements on several crankshaft throws

Steve Smith (19) provided a simple method to understand how well a crankshaft can cope with power delivery by monitoring crankcase deflection during powered dyno runs. The data made available supports engineering decisions 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; Empirical tests are needed to challenge model predictions. Residual imbalances along the length of the crankshafts are crucial to performance. Utilizing crankcase deflection analysis to improve crankshaft design and engine performance.

An analysis of the stress distribution inside a crankshaft crank was studied by Borges et al. (4). The stress analysis was done to evaluate the overall structural efficiency of the crank, concerned with the homogeneity and magnitude of stresses as well as the amount and localization of stress concentration points. Due to memory limitations in the computers available, the crank model had to be simplified by mostly restricting it according to symmetry planes. In order to evaluate results from the finite element analysis a 3D photo elasticity test was conducted.

The influence of the residual stresses induced by the fillet rolling process on the fatigue process of a ductile cast iron crankshaft section under bending was studied by Chien et al. (5) 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 surface.

5. Durability Assessment on Crankshaft:

Durability assessment of crankshafts was carried out by Zoroufi, M. and Fatemi, A., (22) includes material and component testing, stress and strain analysis, and fatigue or fracture analysis. Material testing includes hardness, monotonic, cyclic, impact, and fatigue and fracture tests on specimens made from the component or from the base material used in manufacturing the component. Component testing includes fatigue tests under bending, torsion, or combined bending-torsion loading conditions. Dynamic stress and strain analysis must be conducted due to the nature of the loading applied to the component. Nevertheless, performing transient analysis on a three-dimensional solid model of a crankshaft is costly and time consuming.

Henry et al. (10) presented a procedure to assess crankshaft durability. This procedure consists of four main steps. The first step is modelling and load preparation that includes mesh generation, calculation of internal static loads (mass), external loads (gas and inertia) and torsional dynamic response due to rotation. The second step is the finite element method calculation including generating input files for separate loading conditions. Third step is the boundary condition file generation. The final step involves the fatigue safety factor determination. This procedure was implemented for a nodular cast iron diesel engine crankshaft.

6. Computer Aided Analysis of Crankshaft:

A review of Crankshaft Lightweight Design and Evaluation based on Simulation Technology is presented by Sheng Su, et al. (18) In order to reduce fuel consumption and emission and improve efficiency, it is essential to take lightweight design into consideration in concept design phase and layout design phase. Crankshaft is one of the most important components in gasoline engine, and it is related to durability, torsional vibration, bearing design and friction loss, therefore lightweight crankshaft must meet the needs to see to it that the final design is satisfactory.

An advanced method for the calculation of crankshafts and sliding bearings for reciprocating internal combustion engines is presented by Elena Galindo et al. (7) The indeterminate method provides a valid tool for the design of crankshafts and sliding-bearings, and enables calculation to come closer to real performance of same. In general, the results furnished by the indeterminate method allow for use of a wider range of criteria in the choice of fundamental design parameters. Other aspects not taken into account in this model, such as main bearing elastic deformation or cylinder block stiffness, would make for a more accurate picture of the integrated performance of the crankshaft-bearing unit as a whole.

Development of an engine crankshaft in a framework of computer-aided innovation by A. Alberset al. (2) describes the conceptual framework of a general strategy for developing an engine crankshaft based on computer-aided innovation, together with an introduction to the methodologies from which our strategy evolves. It begins with a description of two already popular disciplines, which have their roots in computer science and natural evolution: evolutionary design (ED) and genetic algorithms (GAs). A description of some optimization processes in the field of mechanical design is also presented. The main premise is the possibility to optimize the imbalance of a crankshaft using tools developed in this methodology. This study brings together techniques that have their origins in the fields of optimization and new tools for innovation.

Humberto Aguayo Téllez et al. (12) is described for determining the design unbalance of crankshafts and also the recommended procedure for a balanced design strategy on Computer aided innovation of crankshafts using Genetic Algorithms. The use of a search tool for solutions is suggested based on Genetic Algorithms (GA). GAs have been used in different applications, one of them is the optimization of geometric shapes, a relatively recent area with high research potential. The interest towards this field is growing, and it is anticipated that in the future mechanical engineering will be an area where many application.

Chunming Yang et al. (6) are proposed for design optimization on crankshaft by new particle swarm optimization method (NPSO). It is compared with the regular particle swarm optimizer (PSO) invented based on four different benchmark functions. Particle swarm optimization is a recently invented high-performance optimizer that is very easy to understand and implement. It is similar ways to genetic algorithms or evolutionary algorithms, but requires less computational bookkeeping and generally only a few lines of code. Each particle studies its own previous best solution to the optimization problem, and its group's previous best, and then adjusts its position accordingly. The optimal value will be found by repeating this process.

7. Cost Reduction:

A study was performed to examine the cost reduction opportunities to offset the penalties associated with forged steel, with raw material and machinability being the primary factors evaluated by Hoffmann et al.(11) Materials evaluated in their study included medium carbon steel SAE 1050 (CS), and medium carbon alloy steel SAE 4140 (AS); these same grades at a sulphur level of 0.10%, (CS-HS and AS-HS); and two micro-alloy grades (MA1 and MA2). The micro-alloy grades evaluated offered cost reduction opportunities over the original design materials. The micro-alloy grade could reduce the finished cost by 11% to 19% compared to a quenched and tempered alloy steel.

The automotive crankshaft, one of the more metal intensive components in the engine, provides an attractive opportunity for the use of alternate materials and processing routes. A systematic cost estimation of crankshafts is provided in the work of Nallicheri et al. (14). Dividing the cost of crankshafts into variable and fixed cost, they evaluate and compare the production cost of crankshafts made of nodular cast iron, austempered ductile iron, forged steel, and micro alloyed forged steel. The common variable cost elements are named as the costs of material, direct labor, and energy. The common elements of fixed cost are named as the costs of main machine, auxiliary equipment, tooling, building, overhead labor, and maintenance.

IV. CONCLUSIONS:

For a crankshaft following are the major consideration.

1. In the crankshaft, the crack grows faster on the free surface while the central part of the crack front becomes straighter.
2. Fatigue is the dominant mechanism of failure of the crankshaft.
3. Comparative study needs to be applied for the selection of material and manufacturing process so as to have cost
4. effectiveness and shape with fewer defects respectively.
5. Accurate stresses are critical input to fatigue analysis and optimization of the crankshaft.
6. Residual imbalances along the length of the crankshafts are crucial to performance. Utilizing crankcase deflection analysis to improve crankshaft design and engine performance.

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