Review paper on Static Structural Analysis and Simulation to Obtain Stress Magnitude at Critical Location of Crankshaft in Internal Combustion Engine

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Abstract - This study presents a static structural analysis and simulation to determine the stress magnitude at critical locations of a crankshaft in an internal combustion engine. The crankshaft, a crucial component in engine performance, experiences significant mechanical stresses due to the forces exerted by the pistons during operation. The analysis was performed using finite element analysis (FEA) to model the crankshaft's behavior under static load conditions. A crankshaft model was created in Pro/ENGINEER and subsequently imported into ANSYS software for simulation. The primary objective was to identify the stress distribution across the crankshaft and pinpoint areas of potential failure. The results reveal that the stress concentrations occur at specific critical locations, which are prone to fatigue failure under prolonged cyclic loading. By comparing the stress magnitudes in forged steel and cast iron crankshafts, it was found that the forged steel crankshaft exhibited lower strain levels, indicating better performance and higher durability under static loads. This analysis supports the conclusion that the forged steel crankshaft is not only capable of withstanding the applied stresses but also suitable for mass production, potentially leading to cost reductions. The findings of this study contribute to the optimization of crankshaft design, enhancing the overall efficiency and reliability of internal combustion engines.

Key Words- Crankshaft, Static Structural Analysis, Finite Element Analysis (FEA) , Stress Distribution ,Internal Combustion Engine Forged Steel

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 link 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. This study was conducted on a single cylinder four stroke cycle engine. Two different crankshafts from similar engines were studied in this research. The finite element analysis was performed in four static steps for each crankshaft. Stresses from these analyses were used for superposition with regards to static load applied to the crankshaft. Further analysis was performed on the forged steel crankshaft in order to optimize the weight and manufacturing cost. Figure 1.1 shows a typical picture of a crankshaft and the nomenclature used to define its different parts.

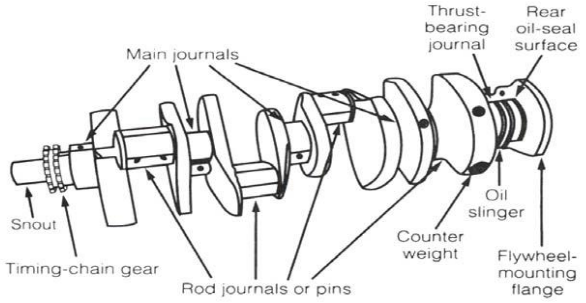

Figure 1.1 Typical crankshaft with main journals that support the crankshaft in the engine block. Rod journals are offset from the crankshaft centerline.

1.1 FUNCTION OF CRANKSHAFTS IN IC ENGINES

The crankshaft in an internal combustion (IC) engine serves several critical functions:

1. Conversion of Motion: The primary function of the crankshaft is to convert the reciprocating (up and down) motion of the pistons into rotary motion. As the pistons move up and down within the cylinders, the crankshaft, connected to the pistons via connecting rods, rotates, creating the rotary motion needed to drive the vehicle's wheels.
2. Power Transmission: The crankshaft transmits the power generated by the combustion of fuel in the engine cylinders to the drivetrain, which ultimately powers the vehicle's wheels. This rotary motion is what drives the vehicle forward.
3. Timing: The crankshaft also plays a key role in maintaining the engine's timing. It is connected to the camshaft through a timing belt or chain, ensuring that the intake and exhaust valves open and close at the proper times during the engine's operation.
4. Supporting Engine Balance: By incorporating counterweights, the crankshaft helps in balancing the engine. This reduces vibrations and ensures smooth engine operation, enhancing the overall performance and longevity of the engine.
5. Driving Other Engine Components: The crankshaft drives other essential components of the engine, such as the oil pump, water pump, alternator, and in some cases, the supercharger. These components are critical for the engine's cooling, lubrication, and electrical systems.

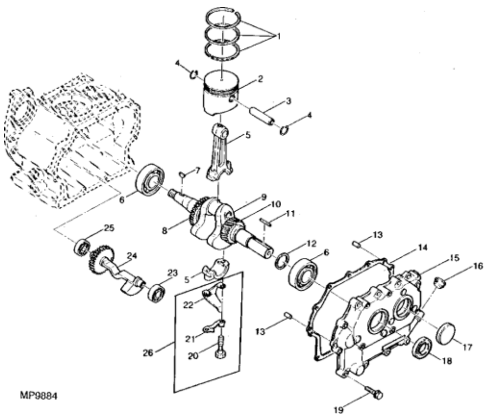

Figure 2. Exploded View Of A Single Cylinder Engine Showing The Crankshaft Mounting In The Engine.

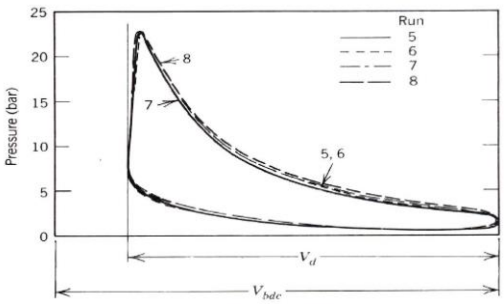

Figure 3. P-V diagram at constant delivery ratio

2. THE MOTIVATION:

The motivation behind studying and optimizing the crankshaft in internal combustion engines arises from the critical role it plays in engine performance and overall vehicle efficiency. As the crankshaft is responsible for converting the piston's linear motion into rotary motion, any improvement in its design can significantly impact engine durability, power output, and fuel efficiency. Additionally, with the increasing demand for lighter and more fuel-efficient engines, there is a pressing need to develop crankshafts that are both lightweight and cost-effective while maintaining high fatigue strength and durability. This study is driven by the desire to meet these demands, leading to the production of more efficient, smaller, and powerful engines that align with industry and environmental standards.

Objectives:

1. Analyze Crankshaft Performance: To conduct a detailed analysis of crankshaft performance under different load conditions using finite element analysis (FEA) to understand the stress distribution and identify areas for potential improvement.

2. Compare Different Crankshaft Designs: To evaluate and compare the performance of two different crankshaft designs from similar engines, focusing on stress, durability, and weight

3. Optimize Weight and Cost: To optimize the weight and manufacturing cost of a forged steel crankshaft, ensuring that it meets the required fatigue strength and functional requirements while reducing material usage and production expenses.

4. Enhance Engine Efficiency: To contribute to the development of lighter, more compact engines with improved fuel efficiency and higher power output by refining crankshaft design.

5. Support Industry Innovation: To provide insights and data that can aid the crankshaft production industry in developing more advanced, cost-effective designs that meet the evolving demands of modern engines.

3. LITERATURE REVIEW

Literature review is undertaken to know the work executed by research workers in the concern area of research. The information of work is available in books, research papers published in National and International Journals, papers presented in conferences, the Post Graduate and Doctoral research work. The information about the research work can be searched through websites, search engines likes goggles, reference books, compandex (engineering index in the form of compact disc) and engineering index. Engineering index provides information about research papers published in referred journals and presented in National and International Conferences. The review of literature is one of the important aspects in the research process which helps researcher to get acquainted with the subject matter under study and future channelize efforts in desirable direction. It also provides necessary guideline and helps the researcher to approach to his research problem.

This chapter takes brief account of research work by changing the material of crankshaft, for the analysis of stress, strain ,deformation etc.

Zoroufi and Fatemi. presents a literature survey focused on fatigue performance evaluation and comparisons of forged steel and ductile cast iron crankshafts. In their study, crankshaft specifications, operation conditions, and various failure sources are discussed. Their survey included a review of the effect of influential parameters such as residual stress on fatigue behavior and methods of inducing compressive residual stress in crankshafts. The common crankshaft material and manufacturing process technologies in use were compared with regards to their durability performance. This was followed by a discussion of durability assessment procedures used for crankshafts, as well as bench testing and experimental techniques. In their literature review, geometry optimization of crankshafts, cost analysis and potential cost saving opportunities are also briefly discussed.

Myung Rae, Dae Yoon, and S. Hyuk explained The stress analysis and modal analysis of a crankshaft finite element method . Three-dimension models of crankshaft and crankthrow were created using Pro/ENGINEER software The finite element analysis (FEM) software ANSYS was used to analyse the vibration modal and the distortion and stress status of the crankthrow.

Chien W.Y., Pan. J., Close D., and Ho S. compare the durability of crankshafts from two competing manufacturing processes, as well as to perform dynamic load and stress analysis, and optimization. The crankshafts used in the study were forged steel and ductile cast iron from a one-cylinder gasoline engine.

Jensen, E.J. performed an experimental study to determine the load applied to a V8 crankshaft. The load determination in this study started with the selection of the crankshaft sections to be investigated.

A theoretical study followed by experimental results was conducted by **Fergusen, C.R.** to calculate the stress concentration factor in a diesel engine crankshaft. They conducted experimental tests by mounting strain gages at high stress concentration areas (crank fillet). A three dimensional model of the crankshaft was generated and numerical calculation was performed according to linear-elastic properties of the material and different loading conditions.

Henry et al. was introduced A detailed procedure of obtaining stresses in the fillet area of a crankshaft, in which FEM and BEM (Boundary Element Method) were used. Obtained stresses were verified by experimental results on a 1.9 liter turbocharged diesel engine with Ricardo type combustion chamber configuration. The crankshaft durability assessment tool used in this study was developed by RENAULT. The software used took into account torsional vibrations and internal centrifugal loads. Fatigue life predictions were made using the multiaxial Dang Van criterion. The procedure developed is such it that could be used for conceptual design and geometry optimization of crankshaft.

Guagliano et al. [2] conducted a study on a marine diesel engine crankshaft, in which two different FE models were investigated. Due to memory limitations in meshing a three dimensional model was difficult and costly. Therefore, they used a bi dimensional model to obtain the stress concentration factor which resulted in an accuracy of less than 6.9 present error for a cantered load and 8.6 present error for an eccentric load. This numerical model was satisfactory since it was very fast and had good agreement with experimental results.

Payer et al. [3] developed a two-step technique to perform nonlinear transient analysis of crankshafts combining a beam-mass model and a solid element model. Using FEA, two major steps were used to calculate the transient stress behaviour of the crankshaft; the first step calculated time dependent deformations by a step-by-step integration using the new mark beta method. Using a rotating beam mass model of the crankshaft, a time dependent nonlinear oil film model and a model of the main bearing wall structure, the mass, damping and stiffness matrices were built at each time step and the equation system was solved by an iterative method. In the second step those transient deformations were enforced to a solid element model of the crankshaft to determine its time dependent stress behaviour. The major advantage of using the two steps was reduction of CPU time for calculations. This is because the number of degrees of freedom for because the number of degrees of freedom for solid element model for step

two needed only to be built up once In order to estimate fatigue life of crankshafts.

Williams, J. [6] 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.

Prakash et al. [4] performed stress and fatigue analysis on three example parts belonging to three different classes of engines In order to estimate fatigue life of crankshafts. The classical method of crankshaft stress analysis (by representing crankshaft as a series of rigid disks separated by stiff weightless shafts) and an FEMbased approach using ANSYS code were employed to obtain natural frequencies, critical modes and speeds, and stress amplitudes in the critical modes. A fatigue analysis was also performed and the effect of variation of fatigue properties of the material on failure of the parts was investigated. This was achieved by increasing each strain-life parameter ($\sigma f'$, $\varepsilon f'$, b and c) by 10% and estimating life. It was shown that strength and ductility exponents have a large impact on life, e.g. a 10% increase of *b* leads to 93% decrease in estimated life.

Borges et al. explain A geometrically restricted model of a light automotive Crankshaft. The geometry of the crankshaft was geometrically restricted due to limitations in the computer resources available to the authors. The FEM analysis was performed in ANSYS software and a three dimensional model made of Photoelastic material with the same boundary conditions was used to verify the results. This study was based on static load analysis and investigated loading at a specific crank angle. The FE model results showed uniform stress distribution over the crank, and the only region with high stress concentration was the fillet between the crank-pin bearing and the crank web.

4. CONCLUSION:

Based on the results and analysis, the following conclusions can be made:In this project, the crankshaft model was initially created using Pro/ENGINEER software, after which the model was imported into ANSYS for further analysis.The analysis results, which include the stresses and deflections experienced by the crankshaft under static load, are detailed in the table. The strain observed in the forged steel crankshaft is lower than that of the cast iron crankshaft. Given that the forged steel crankshaft successfully withstands the static load, it is deemed structurally sound. Consequently, the forged steel crankshaft is suitable for the forging process, and mass production can lead to cost reductions

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