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A Review on Modelling, Analysis and Optimization of Crankshaft

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Abstract—*The crankshaft is one of the most important mechanical components of IC Engine. It transforms the reciprocating motion of the piston into rotary motion. Crankshafts are connected to the piston through the connecting rod and consist of webs and pins. Designing and Analysis of a crankshaft is essential for sound engineering design. This paper is a review of various CAD-based modelling methods that can be employed for modelling a three-dimensional crankshaft model of various engine specifications; various static and dynamic analysis FEA based methods are also reviewed in this paper to get a feasible crankshaft by ANSYS. Weight of any mechanical component plays a vital role in it's working efficiency and economy and crankshaft as being one of the most essential components of the engine should have lightweight for all kinds of application with the best economy so weight optimization techniques used by various researchers by shape or geometrical changes of crank web and crankpin to get enough weight reduction in the crankshaft is reviewed in this paper. Material selection for crankshaft is also a crucial step as it directly affects the fatigue strength of a crankshaft; typically materials like forged steels are used in crankshaft manufacturing which is reviewed in this paper. The weight reduction is of utmost importance for all researchers who have been focusing on optimization of crankshaft for same they have utilized various optimization techniques including shape and geometrical optimization as well as the topological aspect of optimization as well which is quite effective in a reduction in weight from 2% to as high as 18% with all condition satisfying the allowable design conditions. The importance of the computer-based FEA techniques is of utmost importance nowadays compared to analytical analysis techniques which are concluded by the various researchers that have been covered in this review paper.*

Keywords: *Crankshaft, Finite Element Analysis, CAD Modelling, ANSYS, Optimization.*

1. INTRODUCTION

In this fast pace era requirement of lightweight, cost-efficient and reliable automotive is an urge. The internal combustion should have an effective life with reliability, which is directly related to the strength of a crankshaft. Various researchers from various engineering organizations have focussed on optimization of the design of crankshaft which will improve fuel efficiency and cost economy. The strength of Crankshaft should be high because it has to bear high load gas pressure transferred from the piston cylinder. This paper focuses on various studies/researches done in design optimization of the crankshaft. Various solid modelling techniques used for high-end modelling of the crankshaft and structural static and dynamic analysis have been reviewed from various studies by different scholars. As the crankshaft is a high volume manufacturing component so optimization of the same is essential for productivity.

The crankshaft is one of the most essential rotating components of an Internal Combustion Engine which transforms the reciprocating motion of the piston to rotary motion, is connected to the piston by a connecting rod. It consists of crank webs and crankpins, the crankpins are connected to the bigger end of the connecting rod. Typically materials like cast or forged steels are used in crankshaft manufacturing. Various components like valvetrain, lube system, cooling system, and charging system are also crankshaft-driven. Based on driveline packaging and requirements rotation of crankshaft can be either clockwise or anticlockwise direction.

Various components of the crankshaft are

i. Main bearing journals
ii. Rod bearing journals/Crankpins
iii. Crankshaft throws / Webs
iv. Counterweights
v. Oil passages

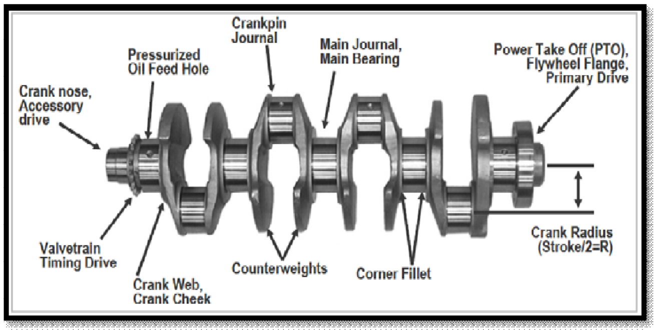

Figure 1 – Components of Crankshaft

2. LITERATURE SURVEY

2.1 CAD Modelling

In solid modelling software is used to create a mathematical representation of a three-dimensional object or shape. These three dimensional solid models are widely useful in a variety of industries for better manufacturing. Various CAD-based solid modellers produce high-end solid models which makes the analysis more efficient and easier with accuracy for various CAM tasks like flexible manufacturing etc. Various Solid Modelling software includes Solidworks [3,8,9], Pro-E [1,7], Catia [2,4,5,6], Creo, and many more.

Yu Ding and Xiaobo Li [1] in their research have used PRO-E modeling software for creating a single-cylinder marine diesel engine for the crankshaft. P. Thejasree, G.Dileep Kumar and S. Leela Prasanna Lakshmi [2] in their research have used CATIA V-5 modelling software for creating a single-cylinder crank throw of the four-stroke engine of Tata Indica passenger car. Jaimin Brahmbhatt and Prof. Abhishek Choubey [3] in their study have used Solidworks modelling software for modelling of a stroke diesel engine crankshaft. Ambati Babi Reddy and Reddy Sreenivasulu [4] in their research have used CATIA V5 modelling software for preparing a solid model four-stroke single-cylinder petrol engine. B. Vijaya Ramnath, C.Elanchhezhim, J.Jeykrishnan, R.Ragavendar, RK Rakesh, J.Surjay Dhamodar, A Danasekar [5] have used reverse engineering for collection of engine component design data. They used CMM for measurement of desired data for modelling of the crankshaft. They used CATIA modelling software for modelling of three-dimensional crankshaft of dimensions obtained using CMM by reverse engineering. Surekha S. Shelke, Dr. CL Dhamejani, and AS Gadhave [6] in their research have prepared the solid crankshaft of BAJAJ Pulsar 150 CC by using CATIA modelling software. VC Shahane and RS Pawar [7] in their research have created a solid model of the crankshaft using PRO- E modelling software. Shimelis Mekuria Edo, Mukesh Kumar, Ajeet Kumar and Atul Kumar [8] in their research have created a solid model of the crankshaft of single-cylinder engine by Solidworks 2014 modelling software. Pawan Kumar Singh, Dr. L. P. Singh, Vicky Lad and Anil Kumar Vishwakarma [9] in their research have used Solidworks 2016 modelling software for creating a solid crankshaft of Delta Integrale 2.0 16V Engine.

2.2 Finite Element Analysis

Finite Element Analysis is a numerical analysis technique with the utilization of various flexible analysis tools to find approximate solutions to various mathematical engineering problems. Problems of engineering from various domains like Structures, Heat flow, fluid flow, etc can be analyzed to gain approximate numerical solution. In this paper, research by various scholars on structural and dynamic analysis of crankshaft will be emphasized. Various finite element analysis software is Abaqus, ANSYS, LS-DYNA, Nastran, MATLAB, and many more.

Finite Element Analysis involves four major steps for solving any problem -

i. Preliminary Decisions,
ii. Pre-Processing,
iii. Solution and
iv. Post-Processing.

2.3 Static Analysis

Yu Ding and Xiaobo Li [1] in their research have used ANSYS workbench for FEM calculation to analyze the strength of a single-cylinder marine diesel engine. They have considered 42CrMo material for analysis. They considered surface load on crankpin inspite of concentrated load which resembles more like the actual working of the crankshaft but ignored torque acting. They have further compared the stress calculated by FEM with conventional stress calculation and concluded that FEM is calculation is safer for evaluation of crankshaft strength.

P. Thejasree, G.Dileep Kumar and S. Leela Prasanna Lakshmi [2] in their study have used ANSYS workbench for static analysis to get deformation and stress distribution on crankpin. They have used 8 nodes solid element for meshing of the model with mesh size 3 mm. In static analysis, they found that the maximum stress concentration is at fillets of crankpin and the main journals.

Jaimin Brahmbhatt and Prof. Abhishek Choubey [3] have utilized ANSYS workbench for static analysis. They considered 42CrMo4 forged steel as the material of crankshaft for analysis. After deformation analysis was done it was found that the crankpin neck surface center had maximum deformation. The fillet which is located between the crankshaft journal and the crank cheek has maximum stress. Also, maximum stress is observed near the central point journal. They compared both finite element analysis results with theoretical results and found that FEA is a time-saving technique for analysis with accuracy.

Ambati Babi Reddy and Reddy Sreenivasulu [4] have performed the static analysis of crankshaft of four-stroke single-cylinder petrol engine using ANSYS workbench and have used four different materials namely SAE1045, SAE1040, Cast Iron, Forged Steel, Titanium for the analysis and compared them on basis of maximum equivalent stress, maximum elastic strain, and total deformation to find the most suitable material. After their research, SAE1040 and forged steel crankshafts were the safest after static analysis.

B. Vijaya Ramnath, C.Elanchhezhim, J.Jeykrishnan, R.Ragavendar, RK Rakesh, J.Surjay Dhamodar, A Danasekar [5] in their study have used ANSYS workbench for static analysis. They have used three different materials namely cast iron, forged steel, and aluminum alloy for analysis. They did a static structural analysis of the three materials to found the most feasible material for crankshaft manufacturing. In their investigation, they found that forged steel is the most feasible of the three materials.

Surekha S.Shelke, Dr. CL Dhamejani, and AS Gadhave [6] in their research have analyzed crankshaft by using ANSYS FEA workbench. They used Carbon Steel 41Cr4 as the material of crankshaft. The application of load was vertically downward on crankpin of 40815 N. The von mises stress on the crankshaft was found to be within limit i.e less than yield strength. They further did shape optimization of crankshaft for weight reduction.

VC Shahane and RS Pawar [7] in their research have performed static structural analysis of crankshaft using ANSYS workbench for obtaining the safest crankshaft. They did a static structural analysis of structured steel for both existing crankshafts by design parameters used and also of the optimized crankshaft and found that maximum deformation occurs at web edges of counterweight and fillets between journal and crank cheek. Further, they compared existing crankshaft with optimized crankshafts and found that all are statically safe.

Shimelis Mekuria Edo, Mukesh Kumar, Ajeet Kumar and Atul Kumar [8] in their research have done static structural analysis using ANSYS workbench. The material considered by them is AISII045 forged steel. In analysis, they have compared how the change in geometry of crank web and crankpin affects the bending stress and the shear stress with a reduction in weight of crankshaft. They concluded that as the crank web size decreases from 20.5 mm to 19.2 mm the bending stress increases till 72.23 MPa which is less than the allowable stress while the inner crankpin diameter increases from 18 mm to 18.75 mm the shear stress also increases. The stresses induced are within the allowable limit so the design is safe in both the cases.

Pawan Kumar Singh, Dr. L. P. Singh, Vicky Lad and Anil Kumar Vishwakarma [9] in their research have done static analysis using ANSYS 16 workbench to identify the area of maximum deformation and maximum stress and verified the model for safety of design by comparing the theoretical and FEA obtained values of von misses stress and shear stress. The material considered by them is cast iron. They found that maximum deformation is at the neck of crankpin and maximum stress is at the fillet area between the crankshaft journal and around the central point journal. They found their design to be safe by comparing the theoretical and FEA stress results.

2.4 Dynamic Analysis

P. Thejasree, G.Dileep Kumar and S. Leela Prasanna Lakshmi [2] have used ADAMS software to simulate the crankshaft dynamically to determine velocity, acceleration, and load acting on it.

Jaimin Brahmbhatt and Prof. Abhishek Choubey [3] in their study have performed dynamic analysis for a more realistic estimation by harmonic analysis by determining static state response to harmonic loads.

Ambati Babi Reddy and Reddy Sreenivasulu [4] in their study have performed the Modal analysis to check the dynamic response of crankshafts for four different materials. In their research, they concluded that forged steel is found to be least prone to damage and noise because of its low vibrational characteristics.

VC Shahane and RS Pawar [7] in their research have done a dynamic analysis of crankshaft using ANSYS workbench. They did a modal analysis of the existing and the optimized crankshafts to evaluate the natural frequency and mode shapes which helped them to evaluate the safety of crankshafts design in the actual situation under dynamic loads. After dynamic analysis, they found that case 4, case 5 and case 6 created by them were not safe design under dynamic loads.

2.5 Optimization

P. Thejasree, G.Dileep Kumar and S. Leela Prasanna Lakshmi [2] in their study have optimized the crankshaft by cutting material from crank web and crankpin by three concepts. In case 1 material was removed from counterweight, in Case 2 material was removed in form of semicircular shape from the web and reducing web thickness and in Case 3 material was removed in form of rectangular shape from the web and reducing web thickness. They found that Concept 2 developed by them has shown 1.6 kg reduction in weight i.e 12.8% reduction without much increase in stress.

B. Vijaya Ramnath, C.Elanchhezhim, J.Jeykrishnan, R.Ragavendar, RK Rakesh, J.Surjay Dhamodar, A Danasekar [5] in their study have reduced the shaft diameter, extended the drill hole and cut to rectangular slots on the web. They further carried out a static structural analysis of optimized crankshaft for three different materials. They found that there is a weight reduction of 18 % and forged steel is most suitable. Various alternative methods of manufacturing can be used for reducing cost and process time for manufacturing.

Surekha S.Shelke, Dr. CL Dhamejani, and AS Gadhave [6] in their further study have done topological optimization of the crankshaft by ALTAIR Optistruct software. The high stressed region is removed and further static analysis of the optimized crankshaft was conducted. They found that there was a mass reduction from 3.5kg to 2.95 kg which is a 19% reduction in the mass of crankshaft.

VC Shahane and RS Pawar [7] in their research have brought changes in crankshaft geometry in six different ways and performed both static and dynamic analysis of the optimized crankshafts to check whether their design is safe both statically and dynamically. In case 1 crankpin diameter is reduced and drilled a hole in crankpin of 20 mm diameter. In case 2 dimensional changes in the counterweight geometry with angle 120– 220. Case 3 is the amalgamation of case 1 and case 2. In Case 4, 5 mm of material is removed from the web from both sides of counterweight geometry. Case 5 is a combination of case 1 and 4. Case 6 is a combination of case 1, case 2, and case 4. They found that all optimized crankshafts were statically safe. But only case 1, case 2, and case 3 were safe dynamically also safe. Also, there was weight reduction in all cases prepared by them but for purpose of real application only Case 1(2.9% weight reduction), Case 2(0.7% weight reduction) and Case 3(4.3% weight reduction) can be considered, of which Case 3 is most optimal and safe.

Shimelis Mekuria Edo, Mukesh Kumar, Ajeet Kumar and Atul Kumar [8] in their research have decreased the crank web size from 20.5 mm to 19.2 mm inner and increased the crankpin diameter from 18 mm to 18.75 mm. They did a static analysis of both and found that the bending stress increases till 72.23 MPa which is less than the allowable stress when crank web size is decreased with the reduction of crank web weight to 3.64% while as the inner crankpin diameter increases the shear stress also increases with reduction in weight of crankpin to 0.3%, reduction in weight of journal is 0.22%. The stresses induced are within the allowable limit so the design is safe in both the optimized cases. Overall there is a reduction of 4.15 % weight of crankshaft with safe design.

Table 1 - Overview of Modelling, Analysis and Optimization [1-9]

Reference	Software Utilized	Materials Considered	Weight Reduction
[1] Yu Ding, Xiaobo Li	Pro-E Ansys (Static)	42CrMo	-
[2] P.Thejasreea, G.Dileep Kumar, S.Leela Prasanna Lakshmi	Catia Ansys (For both static and Dynamic)		12.8%
[3] J Brahmbhatt, A Choubey	Solidworks Ansys (For both static and Dynamic)	42CrMo forged steel	-
[4] Ambati Babi Reddy Reddy Sreenivasulu	CATIA Ansys (For both static and Dynamic)	SAE1045 SAE3140 Cast Iron Forged Steel Titanium	-
[5] B.Vijaya Ramnath, C.Elanchhezhim, J.Jeykrishnan, R.Ragavendar, R.K Rakesh, J.Surjay Dhamodar, A Danasekar	CATIA Ansys (Static)	Cast iron forged steel Aluminium alloy	18%
[6] Surekha S. Shelke, Dr.C.L. Dhamejani, A. S. Gadhave	CATIA Ansys (Static)	Carbon Steel 41Cr4	19%
[7] V.C. Shahane, R.S. Pawar	PRO-E Ansys (Static)	Structural steel	Case 1 2.9% Case 2 0.7% Case 3 4.3%
[8] Shimelis Mekuria Edo, Mukesh Kumar, Ajeet Kumar Atul Kumar	Solidworks Ansys (For both static and Dynamic)	AISII045 forged steel	4.15%
[9] Pawan Kumar Singh, Dr.L.P. Singh, V Lad, A.K Vishwakarma	Solidworks Ansys (Static)	Cast Iron	-

3. CONCLUSION

1. As the crankshaft is produced in large volume so an optimized design of crankshaft is necessary to increase the fuel efficiency and overall cost of the engine.
2. Reverse engineering for crankshaft development is playing a key role in today's era replacing the conventional methods of dimensioning.
3. Application of various stress and fatigue finite element analysis techniques are more effective, cost-efficient, and faster compared to manual analysis techniques.
4. Topological optimization of the crankshaft is also important to reduce the unnecessary area which will reduce the crankshaft weight and hence total production cost of the crankshaft industry will reduce and more economy can be generated.

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