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IMPLEMENTATION OF REVERSE ENGINEERING FOR CRANKSHAFT MANUFACTURING INDUSTRY

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Abstract

In this modern world, there are always pressure on the designers and the manufacturers to respond to the consumer needs. Engineering involves designing, manufacturing, constructing, and maintaining of products, systems, service and structures. In this paper, an attempt has been made to derive all the parameters, which are necessary for designing the components of an engine using reverse engineering. Even though lots of methods are available for redesigning, the reverse engineering is selected. Computer aided modeling using CATIA and optimization analysis of crankshaft is used to study was to evaluate and compare the fatigue performance of three different materials of automotive crankshafts, namely forged steel, ductile cast iron and aluminium alloy. In this study a dynamic simulation was conducted on three crankshafts, cast iron and aluminum alloy forged steel; from similar single cylinder four stroke engines. The dynamic analysis was done and was verified by simulations in ANSYS. Geometry, material and manufacturing processes were optimized considering different constraints, manufacturing feasibility and cost.The maximum stress point and dangerous areas are found by the deformation analysis of crankshaft. Possible weight reduction options and their combinations were considered. Thus durability of feasible material and analysis is carried after weight reduction carried to the feasible material. Thus more possibilities of feasible crankshaft are found out.

Keyword: Reverse engineering, CATIA, ANSYS, Optimization

1.0 Introduction

1.1 Reverse Engineering

Reverse engineering (RE) is a new concept that denotes the process of generating engineering design data from existing components. This term is used to describe the process in which product development follows a reverse order. Rather than the conventional production drawing, the existing product is the starting point. RE can be treated as the process of analysing a system to identify the system's components and their interrelationships, create representations of a system in a new modified form, and create the physical representation of the damaged parts. RE is having applications in the following fields like software engineering, automotive, consumer products, microchips, chemicals, electronics, and mechanical designs

B. Vijayaramnath et al [1] done the data acquisition using laser scanner device. The data sculpt software draw profile lines using scanned data. Initially, AHP is carried out to find suitable process among RE, reengineering and conventional design. The result of AHP shows that RE is suitable. In general, the RE can also be used to find the dimensions of broken and damaged parts. Gopinath Chintala and Prasad Gudimetla [2] have found that Ti is best material for gas turbine blades for the centrifugal forces considered in this study as it possesses outstanding

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properties of structural stability when exposed to varying temperature and fatigue loads, and also possesses maximum strength at high temperatures. Bruneliere et al [3] have presented the MoDisco that offers a generic and extensible model-driven reverse engineering (MDRE) framework intended to facilitate the elaboration of MDRE solutions actually deployable within industrial scenarios. Beniere et al [4] have introduced a new formalism to define the topology of the object and compute the intersections between primitives. The proposed method is validated on 3D industrial meshes. Rosen et al [5] have proposed a method for the construction of material models from microstructure images, which can be integrated into a heterogeneous CAD representation. The method utilizes Radon and wavelet transforms to compute a surfacelet representation. PengFei et al [6] have described about an improvement is made to difference expansion technology to make it suitable for two-dimensional (2D) computer-aided design (CAD) engineering graphics. Barbero [7] have found that rather than by employing complex mathematical algorithms, a fit is achieved by drawing a parametric outline that complies with the design intent, and by adjusting the different parameters through successive approximations using commercial CAD software commands. Giovanna Sansoni and Franco Docchio [8] have described a very special and suggestive example of optical three-dimensional (3D) acquisition, reverse engineering and rapid prototyping of a historic automobile, a Ferrari 250 Mille Miglia, performed primarily using an optical 3D whole-field digitizer based on the projection of incoherent light (OPL-3D, developed in our laboratory). Lin et al [9] have applied a developed reverse engineering approach, the modified adaptive model-based digitizing process (MAMDP) to the 3D geometric design of turbine blades. Fatemi et al [10] have studied a dynamic simulation on a forged steel crankshaft from a single cylinder four stroke engine and the dynamic analysis was resulted in the development of the load spectrum applied to the crankpin bearing and the load was then applied to the FE model and boundary conditions were applied according to the engine mounting conditions. Gaska et al [11] have reported many type of errors could be compensated using an approach that includes - probe head errors, machine dynamics errors and, most importantly, machine geometrical errors. Zheng et al [12] the high precision measurement results can be realized by using a low-precision measuring machine without any increase in hardware manufacturing cost. This is of great theoretical value and practical significance for the flexible CMM's further development. Young et al [13] have proposed a CAMP for effectively gauging the inspection points based on the ruled line information of the impeller blade surfaces. Balamurugan et al [14] has conducted a dynamic simulation on two crankshafts, cast iron and forged steel, from similar single cylinder four stroke engines and the finite element analyses was performed to obtain the variation of stress magnitude at critical locations. Shih-Wen Hsiao and Jiun-Chau Chuang [15] have developed 3D product models based on their ideas with polyurethane or polystyrene foam first and the data points on the surface of the product were then measured using a non-contact 3D scan device, and the point clouds for 30 crosssections of these products are obtained based on the measured information

1.2 Measurement using CMM

The crankshaft material which selected doesn't have accurate data. Hence, in this work RE method has been used to obtain the preferable data. A complete data of the product must be built in order to represent the CAD model. The crankshaft consists of different geometric proportionssince they are very intricate in dimensions the CMM requires to handle the parts with greater accuracy. The cloud points are carried in CMM were to be noted.These points should be noted as minimum as possible. Normally the crankshaft of different formation. They have circular, cone and more complex shapes in order.

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2.0 Optimization in material selection

2.1 Crankshaft

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 and the model of the crankshaft has been given in figure 1. 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 with three differentmaterials from similar engines were studied in this research. The finite element analysis was performed in for each crankshaft. Stresses from these analyses were used for superposition with regards to dynamic load applied to the crankshaft. Further analysis was performed on the forged steel crankshaft in order to optimize the weight and manufacturing cost.

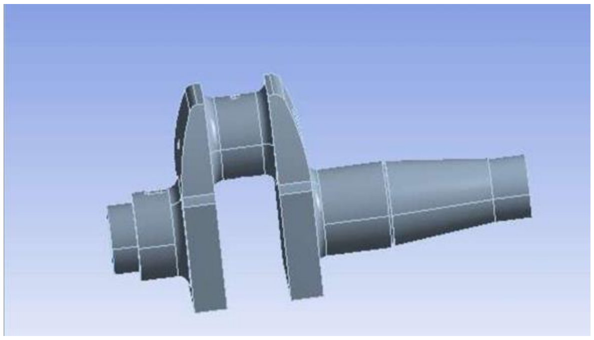

Fig 1. Modeled crankshaft

Table 1. Physical properties of three materials

Properties	Cast iron	Forged steel	Aluminum alloy
Density (kg/m^3)	6800-7800	7800	2600
Poisson's ratio	0.3	0.3	0.3
Young's modulus	1.78e5 MPa	2.21e5 MPa	7.1e5 MPa

The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems, because of its diversity and flexibility. According to crankshaft in engine possess some uniform pressure on the bearing during compression stroke it possesses a 3.5 MPa of uniform pressure due to connecting rod on the top of bearing. This is analysed with help of ANSYS and the total deformation is obtained for three different materials. These are obtained by fixing the lower portion of the crankshaft while pressure is exerted on top of bearing. There is no change in the dimensions acquired using CMM. The dimensions are same for a three different materials hence the component is modeled using CATIA. The static structural analyses are carried for three

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different materials. Their values were compared and tabulated. The properties of the materials have been given in table 1 and the stress, strain and deformation values for the different materials have been given in table 2.

Table 2. Deformation, stress and strain values of materials

Title	Cast iron	Forged steel	Aluminum alloy
Total deformation	1.6304e-003(mm)	1.2543e-003(mm)	3.888-003(mm)
Shear stress	5.4711Mpa	5.1048Mpa	6.024Mpa
Shear strain	8.365e-5	6.0056e-5	6.9967e-5

Thus, after comparison of three different materials the forged steel has been selected as a feasible material. Thus forged steel is selected as a feasible material. Further optimization is carried in the material by reducing its weight to 18%. The weight reduced component is also checked for durability, performance and efficiency.

3.0 Optimization in weight reduction

The main objectives were reducing the weight and manufacturing cost while improving or maintaining the fatigue performance of the original component. In addition, the bending stiffness has to be kept within permissible limits.The optimization carried out in this work was not based on only the typical geometrical optimization techniques. This is because variables such as manufacturing and material parameters could not be organized in a mathematical function according to the set of constraints such that the maximum or minimum could be defined. Instead, each optimization step was approximated based on improving fatigue resistance while considering manufacturing feasibility and maintaining dynamic balance with an aim of reducing the weight and the final cost of the component. Several cases of geometric modifications were considered. Weight reduction is carried in bearing by reducing the diameter so that the material is reduced at some extent. The area in which the material weight is reduced is more concentrated area in which uniform pressure is created due to connecting rod at compressing stage. For further optimisation material from crank web thickness is removed.A significant percentage of the weight in the crankshaft is in the crank counterweight or web mass. Therefore, reducing the weight of this section could result in an improvement in weight reduction of the component. Hence there is some changes in geometrical dimensions and the component is remodeled once again using CATIA and has been given in figure 2.

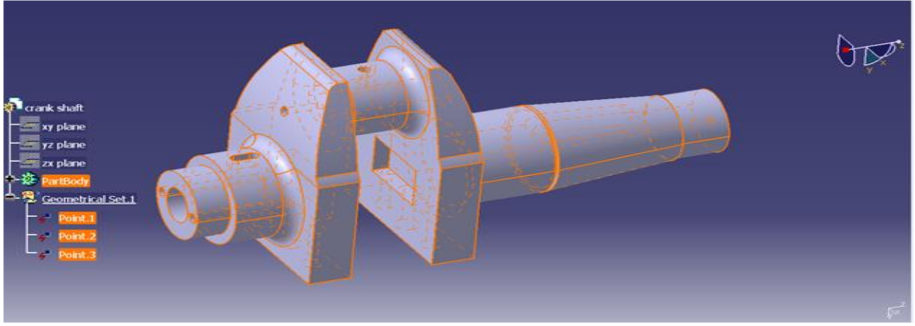

Fig 2. Possible metal machined area

The above diagram in which the possible material removal is carried out in crank bearing by reducing the diameter and two rectangular slots according to the centre of axis and counter weight actions are performed is tabulated in table 3.

Table 3. Geometric optimisation of crankshaft

S. no	Title	Existing dimensions	Optimized dimensions
1	Shaft diameter	40mm	35mm
2	Two rectangular slots	-	10,20mm
3	Drill hole	15mm	Extended to 7mm

The drill hole is extended in order to withstand the balancing counter weights due to weight reduction. These modifications reduce the weight of the original crankshaft by 18%. The final optimized geometry is modeled. It should be noted that the fatigue strength of the optimized crankshaft is significantly higher than the original crankshaft due to a slight increase in the stress range of 7% at the fillet and a significant increase on the order. After weight reduction the feasible material which we found that forged steel is suitable for better performance and durability after comparison with different material is considered here. Thus same ANSYS operations were carried out after weight reduction is done on forged steel material. Thus the results are calculated and tabulated. Thus the values obtained after weight reduction is compared to the previous material comparison in order to check whether the deformation is within permissible limits. These values were tabulated in table 4.

Table 4. Comparison after weight reduction

S no	Title	Cast iron	Aluminum alloy	Forged steel	Forged steel after weight reduction
1	Total deformation	1.6304e-3mm	3.888e-3mm	1.2543e-3mm	1.4377e-3mm
2	Shear stress	5.4711Mpa	6.024 Mpa	5.1048Mpa	4.3351Mpa
3	Shear strain	8.3675e-5	6.9967e-5	6.0056e-5	5.1e-5

Thus comparing above results the feasible material after weight reduction is doesn’t very much in their performance, efficiency, and durability. Thus forged steel is suitable material for crankshaft. An optimization study was performed on a forged steel crankshaft that considered the geometry, performance, manufacturing process, and cost. A major constraint of this optimization was for the optimized crankshaft to replace the original crankshaft in the engine without any changes to the engine block or the connecting rod. An optimization in the geometry included local changes at different locations on the crankshaft, which were then combined to obtain the final optimized geometry.

4.0 Manufacturing and Cost Reduction

4.1 Forging Parameters

Forging is the term for shaping metal by plastic deformation. Cold forging is doneat 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 workpiece is heated to a temperature significantly below the

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typical hot forging temperature, ranging from 500º C to 750º 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. Despite these advantages, cold and warm forging processes have the limitations of close tolerance and net shape of the final component with the workpiece. 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.

4.2 Casting Parameters

Casting is a manufacturing process by which a molten material such as metal or plastic is introduced into a mold, allowed to solidify within the mold, and then ejected or broken out to make a fabricated part. Casting is used for making parts of complex shape, such as crankshafts, that would be difficult or uneconomical to make by other methods (such as machining from solid material). Sand-mold casting is adaptable to a very wide range of alloys, shapes, sizes, and production quantities. Hollow shapes can be produced in these castings through the use of cores. Sand-mold casting is by far the most common casting process used in the industry; some estimates are that as many as 90% of industrial castings use the sand-mold casting process

4.3 Cost reduction

The material's alternatives for the automotive crankshaft is based on manufacturing economics. Steel forging, nodular cast iron, micro-alloy forging, and austempered ductile iron casting are considered as manufacturing options to evaluate the cost effectiveness.. They concluded that the production volume of the crankshaft and the requirements of the engine are predominant 34 factors in cost effective production route for this application. If the design requires better mechanical properties, then other alternatives must be considered.

At production volume above 200,000 parts/year, microalloyed steel forgings offered the most cost effective high performance crankshaft. They attributed this to the die and machining tool lives, which are improved for the microalloyed steel forging, but at lower than 200,000 parts/year production volume the cost savings obtained do not compensate for higher raw material cost of the microalloyed forged steel. ADI crankshafts were cost effective at low production runs (below 180,000 parts/year). Sensitivity with respect to volume production was evaluated. Based on their assumptions, raw material was about 30% of the final cost, whereas, machining cost was 47% for the forged steel crankshaft. The raw material cost of the microalloyed steel forging crankshaft was 38%, which is higher than that of forged steel, but the machining percentage cost was 43% which reduced the cost of the final component. In addition, the heat treatment process was eliminated for the microalloyed steel crankshaft, which was 3.5% of the final cost of the forged steel, resulting in further final cost reduction.

5.0 Conclusion

A complete optimization and reverse engineering process is carried in all aspects of performance, manufacturing and cost reduction. The following conclusions can be drawn from the analysis carried in this study

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1. The crankshaft is reverse engineered using CMM device for unknown datas. The crankshaft in which the unknown datas are considered for possible optimization.
2. The crankshaft is normally manufactured from cast iron, where as in our study three different materials which possess different properties are selected and they are simulated in ANSYS for structural analysis.
3. Thus the structural analysis gives detailed study about those materials and their deformation and stress and strain factors. The durability and performances of each material is found out.
4. Thus forged steel is selected as a feasible material, further optimization is carried in the material by reducing its weight to 18%. The weight reduced component is also checked for durability, performance and efficiency.
5. By selecting a alternative methods of manufacturing, suitable material will help in reducing cost in manufacturing process.

Thus the crankshaft has been reverse engineered and feasible material has been identified.

References

[1] B.Vijaya Ramnath, C.Elanchezhian and R. Kesavan(2011),” Reverse engineering system for generator engine parts”, Int. J. Collaborative Enterprise, Vol. 2, Nos. 2/3, 2011.
[2] GopinathChintala and Prasad Gudimetla (2014),” Optimum material evaluation for gas turbine blade using Reverse Engineering (RE) and FEA”, Procedia Engineering 97 (2014) 1332 – 1340.
[3] Hugo Bruneliere, Jordi Cabot, Gregoire Dupe, Frederic Madiot (2014),” MoDisco: A model driven reverse engineering framework”, Information and Software Technology 56 (2014) 1012–1032.
[4] Roseline Beniere, Gerard Subsol, Gilles Gesquiere, Francois Le Breton, William Puech (2013),” A comprehensive process of reverse engineering from 3D meshes to CAD models”, Computer-Aided Design 45 (2013) 1382–1393.
[5] David W. Rosen, NaminJeong, Yan Wang (2013),” A method for reverse engineering of material microstructure for heterogeneous CAD”, Computer-Aided Design 45 (2013) 1068–1078.
[6] Peng Fei , Lei Yu-zhou, Long Min, Sun Xing-ming (2011),” A reversible watermarking scheme for two-dimensional CAD engineering graphics based on improved difference expansion”, Computer-Aided Design 43 (2011) 1018–1024.
[7] Basilio Ramos Barbero (2009),” The recovery of design intent in reverse engineering problems”, Computers & Industrial Engineering 56 (2009) 1265–1275.
[8] Giovanna Sansoni, Franco Docchio (2004),” Three-dimensional optical measurements and reverse engineering for automotive applications”, Robotics and Computer-Integrated Manufacturing 20 (2004) 359–367.
[9] Liang-Chia Chen, Grier C.I. Lin (2000),”Reverse engineering in the design of turbine blades a case studying applying the MAMDP”,Robotics and Computer Integrated Manufacturing 16 (2000) 161}167.
[10] Farzin H. Montazersadgh andAli Fatemi (2008),”Optimization of a Forged Steel Crankshaft Subject to Dynamic Loading”,SAE International paper,2008(01-0432).
[11] A.Gaska, J. Sładek, K. Ostrowska, R. Kupiec, M. Krawczyk, W. Harmatys,P.GaskaM. Gruzaa, D. Owczarek, R. Knapik, A. Kmita (2015),”Analysis of changes in coordinate measuring machines accuracymade by different nodes density in geometrical errors correction matrix”,Measurement 68 (2015) 155–163.
[12] DatengZheng,Chengtao Du, Yonggang Hu (2012),”Research on optimal measurement area of flexible coordinatemeasuringmachines”,Measurement 45 (2012) 250–254.
[13] Eun-Young Heo, Dong-Won Kim, Jong-Yeong Lee, Kyoung-Yun Kim (2008),”Computer-aided measurement plan for an impeller on a coordinatemeasurement machine with a rotating and tilting probe”,Robotics and Computer-Integrated Manufacturing 24 (2008) 788–795.
[14] C.M.Balamurugan, R.Krishnaraj, Dr.M.Sakthivel, K.Kanthavel, DeepanMarudachalamM.G ,R.Palani (2011),”Computer Aided Modeling and Optimization of Crankshaft”,International Journal of Scientific & Engineering Research Volume 2, Issue 8, August-2011.
[15] Shih-Wen HsiaoandJiun-Chau Chuang (2003),”A reverse engineering based approachfor product form design”,Design Studies24(2003) 155–171.
[16] B.Vijaya Ramnath M. Jaivignesh, R. Harikrishnan, S. Dwarakesh, Jayanth Narahari, and Dr.C.Elanchzhian “Application of Reverse Engineering in the design of land tiller machinery", International Review of Mechanical Engineering (IREME). Vol. 6 n. 7, 2012, pp. 1379-1387

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