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Material Selection for Computer Aided Design Software for Crankshaft Design

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Abstract- A crankshaft contains two or more centrally-located coaxial cylindrical ("main") journals and one or more offset cylindrical crankpin ("rod") journals. The design of the Crankshaft considers the dynamic loading and the optimization an lead to a shaft diameter satisfying the requirements of Automobile's specifications with cost and size effectiveness.

Microsoft visual studio package was used in the development of this software, which is capable of designing the shaft with reference to its easy interface, being an open system and its ease of file formats acceptability. It was used during the entire cycle of this software development (analysis phase, design phase and implementation phase).

The developed Software was able to design the crankshaft taken into consideration the dimensions and the materials used; it will automatically generate the shape after the input of the expected configuration. The Software was able to select the materials to be used in the Crankshaft design with its properties and loading conditions incorporated.

Consequently, the problems encountered in manually shaft design which is majorly design error, repetitive drawing and, or iteration when changes are to be made, can be overcome if the various advantages, utilities and flexibilities which modern high – speed micro – computers offer are put into good use in the design of shafts.

Index Terms- CAD, Crankshaft, Material Selection, Software

I. Introduction

Generally automobile crankshafts were forged in past to have all the desirable properties. However, with the evolution of the nodular cast irons and improvements in foundry techniques, cast crankshafts are now preferred for moderate loads. Only for heavy duty applications forged shafts are favoured. The selection of crankshaft materials and heat treatments for various applications are essential.

Crankshafts materials should be readily shaped, machined and heat-treated, and have adequate strength, toughness, hardness, and high fatigue strength. The crankshafts are manufactured from steel either by forging or casting.

The usefulness of computers in product design ranges from data management, drawing, analysis, and simulation to numerous other applications. Computers are programmed to do what humans intend and are capable of performing far beyond the abilities of the most skilled designer. In the world of mechanical design, software tools are used for a large number of applications, from modeling and optimization tasks to simulating the performance of a product. This allows the engineering designer to concentrate on activities related to software analysis, prototype testing, creativity and innovation. Computer-aided innovation uses software tools to provide extended support for the creative part of the design process. With this support, the designer can improve the performance of his or her concepts, letting computers take part not only in generating variants, but also in making judgments, by simulation, of these variants. Thus, a designer can explore numerous creative solutions to problems (overcoming 'design fixation' or the limitations of conventional wisdom) by generating alternative solutions. Software tools can use knowledge from designers to generate new solutions based on many separate ideas and suggest entirely new design concepts. Methods for structural and topological optimization, based on evolutionary algorithms, are used to obtain optimal geometric solutions. They evolve into configurations that minimize the cost of trial and error.

The case study is selected in view of the importance of motor crankshafts in the automotive industry and the increased performance requirements for engines, which have increased the production of forged steel crankshafts worldwide. Imbalance, one of the quality parameters of crankshafts, has a significant impact on the life of the entire system. In the forging process, given the variations of material composition, temperature, etc., the imbalance dispersion increases compared to casting crankshafts. It is of particular importance to reduce this variation right from the conceptual design of the crankshaft.

Computer Aided Design (CAD) is the use of computer system to assist in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, and improves communication through documentation and to create a database for manufacturing. Computer – aided design is used in many fields. It's used in electrical design known as Electronic Design Automation, or EDA. In mechanical design, it is also known as computer aided drafting (CAD) or computer aided design and drafting (CADD), which describe the process of creating a technical drawing with the use of computer software.

CAD software for mechanical design uses either vector based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions. (Narayan, 2008)

Crankshaft bearings can wear out due to:

- Excessive heat (if the oil doesn't provide sufficient cooling)
- Pressure
- Etching or corrosion due to exposure to chemicals or acid in contaminated oil
- Exposure to dirt or debris in the oil, which will scratch the bearings (in turn scratching the engine parts they contact)
- Drying out due to oil leakage, blockage or otherwise poor circulation (also sometimes caused by incorrectly sized or fitted bearings)
- Metal-on-metal contact (as a result of drying out from poor oil flow)

These are all common conditions in a car's engine and are sometimes signs of other problems. There aren't many external indicators of crankshaft bearing problems, but if one suspect the oil supply might be compromised, there's a good chance there might be premature wear inside. If one's crankshaft is losing oil from a faulty seal, there will be a puddle in the parking spot; when the car's running and the smell oil burning as it drips on the hot manifold would be felt.

II. CRANKSHAFT

The crankshaft exits as long as the four-stroke engine. The atmospheric gas engine as the precursor did not have a crankshaft, however, the steam engine had, even if most often just for one cylinder or with integrated flywheel. The first crankshaft in the car four-stroke engine managed a revolution of less than 2001/min, its bearings were lubricated by small oil tanks from which one can be recognized at the big-end bearing in the side outline. The counterbalances are quite noteworthy.
Crankshafts are highly demanded. Hammer-forged blanks from quenched and tempered steel were used in the beginning of the last century. The substantially less expensive, cast crankshaft asserted itself only in the second half of the century. Highly demanded crankshafts were first hammer forged, and afterwards pressed with very high pressures with which already the final form was approached.

The appearance and the manufacturing of crankshafts have changed. A bigger number of main bearings and more counterbalances reflect the crankshaft production of in-line engines. New cylinder designs developed like the W-12 which cause considerable demands for the production. Producing millions of pieces, only fully automated manufacturing process, which imply pouring and pressing, can do the trick. A good example is the twisting. This process implies that e.g. the crankshaft of in-line six-cylinder engines are first manufactured with all their headers in one level, and subsequently some rank pins are twisted by machine to receive the right ignition interval. The firmness of such shafts is rather higher due to the uninterrupted fibre course. (Huppertz, 2008)

A crankshaft is a device which contains two or more centrally-located coaxial cylindrical ("main") journals and one or more offset cylindrical crankpin ("rod") journals. Plane V8 crankshaft has five main journals and four rod journals, each spaced 90° from its neighbors.

The crankshaft main journals rotate in a set of supporting bearings ("main bearings"), causing the offset rod journals to rotate in a circular path around the main journal centers, the diameter of which is twice the offset of the rod journals. The diameter of that path is the engine "stroke": the distance the piston moves up and down in its cylinder. (Jack, 2012)

The main function of crank shaft is conversion of reciprocating motion into rotary motion. The piston reciprocates due to heat developed inside the engine, this motion is turned into rotary by crank shaft, it transmit the power developed in the engine that is indicated power to the flywheel, the flywheel serves as a energy reservoir, the end of crank shaft will be connected to cam shaft that is push rod and rocker arm to operate the opening and closing of inlet and exhaust valves. (Jaspal, 2012)

III. CRANKSHAFT MATERIALS

Crankshaft materials should be readily shaped, machined, and heat treaded, and have adequate strength, toughness, hardness, and high fatigue strength. The crankshafts are manufactured from steel either by forging or casting. Forged crankshafts are stronger than the forged crankshafts, but they are more expensive.

With the evolution of the nodular cast irons and improvements in foundry techniques, cast crankshafts are now preferred for moderate loads. Only for heavy duty applications is forged crankshaft meaningful. The selection of crankshaft materials and heat treatments for various applications are as follows:
i. Manganese – molybdenum steel.
ii. 1% - Chromium – molybdenum steel.
iii. 2.5% - Nickel – chromium – molybdenum steel.
iv. 3% - Chromium – molybdenum or 1.5% - Chromium – aluminum – molybdenum steel.
v. Nodular Cast Irons.

IV. CRANKSHAFT MANUFACTURING PROCESS

Many high performance crankshafts are formed by the forging process, in which a billet of suitable size is heated to the appropriate forging temperature, typically in the range of 1950 - 2250°F, and then successively pounded or pressed into the desired shape by squeezing the billet between pairs of dies under very high pressure. These die sets have the concave negative form of the desired external shape. Complex shapes and / or extreme deformations often require more than one set of dies to accomplish the shaping.

Crankshafts at the upper end of the motorsport spectrum are manufactured from billet. Billet crankshafts are fully machined from a round bar ("billet") of the selected material. This method of manufacture provides extreme flexibility of design and allows rapid alterations to a design in search of optimal performance characteristics.

V. TYPES OF CRANKSHAFT

There are two major types of crankshaft which are:

i. **Cross Plane Crankshaft:** Is a crankshaft design for V8 engines with a 90^0 angle between the cylinder banks. The cross-plane crankshaft is the configuration used in most V8 road cars. It has four crankpins each offset at 90^0 from the adjacent crankpins. The first and last of the four crank pins are at 180^0 with respect to each other as are the second and third, with each pair at 90^0 to the other, so that viewed from the end the crankshaft forms a cross. The crankpins are therefore in two planes crossed at 90^0; hence the name cross-plane crank may have up to five main bearing and usually does, as well as large balancing weights.

i. Same Plane Crankshaft: With all crank-pins in the same plane and the only offset 180^0. Early V8 engines, modern racing engines and some others used or use the flat-plane crankshaft, which is similar to that used in a straight four or flat-four engine. Flat-plane V8 engines may use any angle between the cylinder banks, with 60^0 and 90^0 the most common. They lack the V8 burble and the superior mechanical balance of the cross-plane design, but do not require the large crankshaft balancing weights.

VI. MANUFACTURING METHOD OF CRANKSHAFT

i. The manufacturing of crankshaft is not a straightforward matter; many pitfalls await the adventurous novice attempting to make his own crankshaft, and there are reasons why there are so few reputable race crankshaft manufacturers.

ii. Greater care needs to be taken in the manufacturing of crankshaft, especially heat treatment, if serious distortion is to be avoided. Manufacturing stresses, with surface commonly stressed in tension by the shearing action of machining, mean that distortion is likely in heat treatment where these are excessive.

iii. Modern machining method have improved the accuracy of manufacture and reduced the amount of manual dressing of features. Features that previously required careful manual processing were the edges of bevels on the webs between crankpins and main bearings, as well as the edges of oil holes, both types of feature are commonly finished now by CNC machining methods, and the surface of crank-bevel features are no longer restricted to swept surfaces defined by eccentric machining on a lathe.

iv. Modern crankshaft manufacture has given us shorter manufacturing times, lower levels of machining stress and the opportunity to design a light, stiff, fatigue-resistant part. (Jack, 2012)

VII. FAILURE IN CRANKSHAFT

i. An investigation of a damaged crankshaft from a horizontal, six-cylinder, in –line diesel engine of a public bus was conducted after several failure cases were reported by the bus company. All crankshafts were made from forged and nitrided steel.

Each crankshaft was sent for grinding, after a life of approximately 300,000 km of service, as requested by the engine manufacturer. After grinding and assembling in the engine, some crankshafts lasted barely 15,000 km before serious fractures took place. Few other crankshafts demonstrated higher lives. Several vital components were damaged as a result of crankshaft failures. It was then decided to send the crankshaft for laboratory investigation to determine the cause of failure. The depth of the nitrided layer near fracture locations in the crankshaft, particularly at the fillet region where cracks were initiated, was determined by scanning electron microscope (SEM) equipped with electron-dispersive X-ray analysis (EDAX). Microhardness gradient through the nitrided layer close to fracture, surface hardness, and macrohardness at the journals were all measured. Fractographic analysis indicated that fatigue was the dominant mechanism of failure of the crankshaft. (Wayne, 2007)

VIII. SOFTWARE

Software is a set of machine-readable instruction that directs a computer's processor to perform specific operations. The term is used to constant with computer hardware, the physical objects which are the processor and related devices that carry out the instructions. Hardware and software require each other; neither has any value without the other.

Software is a general term. It can refer to all computer instructions in general or to any specific set of computer instructions. It is inclusive of both machine instructions (the *binary code* that the processor understands) and source code (more human-understandable instructions that must be rendered into machine code by *compilers* or *interpreters* before being executed). (Princeton University, 2007)

IX. MATERIALS AND MANUFACTURING PROCESSES

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 Zoroufi and Fatemi (2005)

X. DYNAMIC LOAD ANALYSIS

Dynamic loading analysis by Montazersadgh and Fatemi (2007) of the crankshaft results in more realistic stresses whereas static analysis provided an overestimate results. Accurate stresses are critical input to fatigue analysis and optimization of the crankshaft. There are two different load sources in an engine; inertia and combustion. These two load source cause both bending and torsional load on the crankshaft. The maximum load occurs at the crank angle of 355 degrees for this specific engine. At this angle only bending load is applied to the crankshaft. Superposition of FEM analysis results from two perpendicular loads is an efficient and simple method of achieving stresses at different loading conditions according to forces applied to the crankshaft in dynamic analysis. Experimental and FEA results showed close agreement, within 7% difference. The results indicate non-symmetric bending stresses on the crankpin bearing, whereas using analytical method predicts bending stresses to be symmetric at this location. The lack of symmetry is a geometry deformation effect, indicating the need for FEA modeling due to the relatively complex geometry of the crankshaft.

Shenoy and Fatemi (2006) conducted dynamic analysis of loads and stresses in the connecting rod component, which is in contact with the crankshaft. Dynamic analysis of the connecting rod is similar to dynamics of the crankshaft, since these components form a slide-crank mechanism and the connecting rod motion applies dynamic load on the crank-pin bearing. Their analysis was compared with commonly used static FEA and considerable differences were obtained between the two sets of analysis.

XI. DEVELOPMENT OF SOFTWARE

Software is usually designed and created (coded/written/programmed) in integrated development environments (IDE) like Eclipse, Emacs and Microsoft Visual Studio that can simplify the process and compile the program, as noted in different section, software is usually created on top of existing software and the application programming interface (API) that the underlying software provides like GTK+, JavaBeans or Swing. Libraries (APIs) are categorized for different purposes. For instance, JavaBeans library is used for designing enterprise applications, Windows Forms library is used for designing graphical user interface (GUI) applications like Microsoft Word, and Windows Communication Foundation is used for designing web services. Underlying computer programming concepts like quicksort, hash table, array, and binary tree can be useful to creating software. When a program is designed, it relies on the API. For instance, if a user is designing a Microsoft Windows desktop application, he/she might use the NET Windows Forms library to design the desktop application and call its APIs like Form1.Close() and Form1.Show() to close or open the application and write the additional operations him/herself that it need to have. Without these APIs, the programmer needs to write these APIs him/herself. Companies like Sun Microsystems, Novell, and Microsoft provide their own APIs so that many applications are written using their software libraries that usually have numerous APIs in them. (Hally and Mike, 2005)

Computer Aided Design

Computer-Aided Design (CAD) involves creating computer models defined by geometrical parameters. These models typically appear on a computer monitor as a three-dimensional representation of a part or a system of parts, which can be readily altered by changing relevant parameters. CAD systems enable designers to view objects under a wide variety of representations and to test these objects by simulating real-world conditions.

The increasing power of CAD has had a significant impact on the product development process, allowing improved quality, reduced cost, and aids products to get to market faster. CAD software is rapidly evolving into what might be better described as product development, or perhaps virtual prototyping software. (Adekunle and Adejuyigbe 2012).

CAD had its origins in three separate sources, which also serve to highlight the basic operations that CAD systems provide. The first source of CAD resulted from attempts to automate the drafting process. These developments were pioneered by the General Motors Research Laboratories in the early 1960s. One of the important time-saving advantages of computer modeling over traditional drafting methods is that the former can be quickly corrected or manipulated by changing a model's parameters. The second source of CAD was in the testing of designs by simulation. The use of computer modeling to test products was pioneered by high-tech industries like aerospace and semiconductors. The third source of CAD development resulted from efforts to facilitate the flow from the design process to the manufacturing process using numerical control (NC) technologies, which enjoyed widespread use in many applications by the mid-1960s. It was this source that resulted in the linkage between CAD and CAM. One of the most important trends in CAD/CAM technologies is the ever-tighter integration between the design and manufacturing stages of CAD/CAM-based production processes.

The development of CAD and CAM and particularly the linkage between the two overcame traditional NC shortcomings in expense, ease of use, and speed by enabling the design and manufacture of a part to be undertaken using the same system of encoding geometrical data. This innovation greatly shortened the period between design and manufacture and greatly expanded the scope of production processes for which automated machinery could be economically used. Just as important, CAD/CAM gave the designer much more direct control over the production process, creating the possibility of completely integrated design and manufacturing processes.

The rapid growth in the use of CAD/CAM technologies after the early 1970s was made possible by the development of mass-produced silicon chips and the microprocessor, resulting in more readily affordable computers. As the price of computers continued to decline and their processing power improved, the use of CAD/CAM broadened from large firms using large-scale mass production techniques to firms of all sizes. The scope of operations to which CAD/CAM was applied broadened as well. In addition to parts-shaping by traditional machine tool processes such as stamping, drilling, milling, and grinding, CAD/CAM has come to be used by firms involved in producing consumer electronics, electronic components, molded plastics, and a host of other products. Computers are also used to control a number of manufacturing processes (such as chemical processing) that are not strictly defined as CAM because the control data are not based on geometrical parameters.

Using CAD, it is possible to simulate in three dimensions the movement of a part through a production process. This process can simulate feed rates, angles and speeds of machine tools, the position of part-holding clamps, as well as range and other constraints limiting the operations of a machine. The continuing development of the simulation of various manufacturing processes is one of the key means by which CAD and CAM systems are becoming increasingly integrated. CAD/CAM systems also facilitate communication among those involved in design, manufacturing, and other processes. This is of particular importance when one firm contracts another to either design or produce a component. (Christman, 2005)

XII. CAD APPLICATION

Computer-Aided Design is a data that can facilitate design and to assist manufacturing process. Due to the complexity of product design nowadays, there is an increasing need to integrate computer simulation and designer intelligence for maximum benefits from expediting advanced design. Computer simulation has played an important role in the design stage. It is a system, which assumes or characteristic of the object under study. (Mohd, 2008).

XIII. NECESSITY OF CAD

The reasons for implementing a computer aided design system are to:

i. increase the productivity of the designer by:

1. Helping designer to conceptualize the product
2. Reducing time required to design and analyze.

ii. To improve the quality of the design by allowing the engineer to do a more complete engineering analysis and to consider a variety of design alternatives, therefore increasing quality. (Grewe and Kessener 2007)

XIV. METHODOLOGY

Microsoft visual studio package was used in the development of this software due to its easy interface, being an open system and its ease of file formats acceptability. It was used during the entire cycle of this software development (analysis phase, design phase and implementation phase).

Programming the computer to handle a design work involves the development of a set of instructions (program) in line with the design procedures, coding the instruction set with a high level programming language and using a compiler, which serves as an interface between the computer and user, to enable user supply various inputs or parameters of the design. The compiler translates the written program (high – level language) to a machine – readable program (low – level language) (Adekunle *et al* 2012).

XV. MICROSOFT VISUAL STUDIO

This is an Integrated Development Environment (IDE) from Microsoft. It will be used to develop console and graphical user interface application along with window forms application, website, web applications and web services in both native code together with managed code for all platforms supported by Microsoft windows, windows mobile, windows CE, NET compact framework and Microsoft silver light.

Visual studio comprises of a code editor supporting intelligence as well as code refractory. The integrated debugger works both as a source lead debugger and a machine level debugger. Other built in tools include a forms of designer for building GUI applications, web designer, class designer and data base schemer designer. It accepts plug in that enhance the functionality at almost every level including adding support for source control systems(like sub version and visual source safe)and adding new tool sets like editors and visuals designers for domain. Specific languages or tool sets for other aspect of the development life cycle (like the foundation server client: team explorer)

It also supports different programming languages by means of language services, which allow the code editor and debugger to support (to varying degrees) nearly any programming language. Built in languages include C/C++ (via visual C++), VB.NET (via visual basic.NET), C# (visual C#) and F# (as of visual studio). It supports for programming languages is added by using specific visual studio package called a language service. A language service defines various interfaces which the visual studio package implementation can implement to add support for various functionalities. The programming language used in the development of this software will be Microsoft C#. (Lextrait, 2010)

Visual studio includes a host of visual designers which was incorporated in the development of this software. These tools include:

1. Windows forms designer

This will be used to build GUI application using window forms. Layout will be controlled by housing the controls inside other containers or locking them to the side of the form.

2. WPF designer

This will be introduced with visual studio. Like the windows forms designer, it supports the drag and drop metaphor. It will be used to author user interfaces targeting windows presentation foundation.

3. Data designing

It will be used to graphically edit data base schemas including typed tables, primary and foreign key and constraints. It will also be used to design queries from the graphical view.

4. **Class designer**

It will be used to generate C# code outlines for the classes and methods .it will also be used to generate class diagrams from hand written classes. (Charles, 2012)

XVI. RESULTS AND DISCUSSIONS

The Software was used to select materials for the crankshaft design, and it was used to get the materials properties as well. The software was able to determine the size of the designed crankshaft and the subsequent crankshaft' segment's variation was established by the software. The following shows sequence of design consideration:

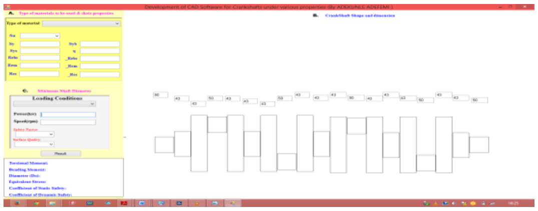

Fig. 1: The interface shows the navigation interface divided into three sections for the shaft design

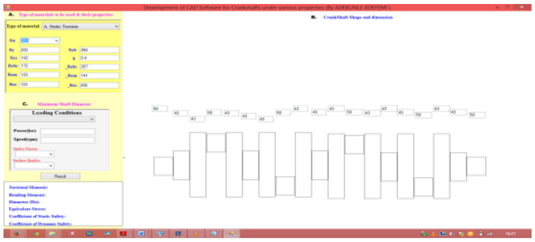

Fig. 2; Section A which is meant for material selection has the type of materials to be selected and their properties

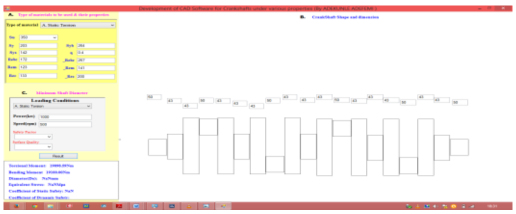

Fig. 3: Static Torsion selected as property for the crankshaft design.

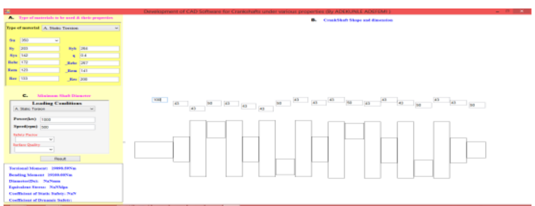

Fig. 4: Minimum shaft diameter calculated by the Software, The input for the first segment was 100mm and it protruded forward

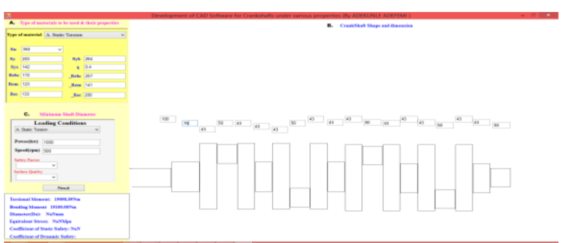

Fig. 5: 80mm was input for the second segment

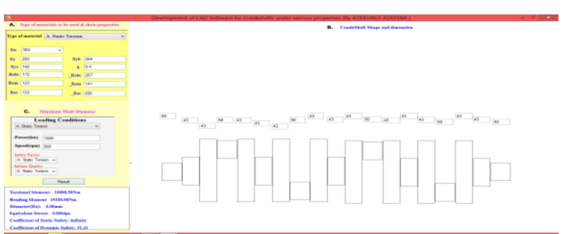

Fig. 6: This interface shows the computed result by the software

XVII. CONCLUSION

The Computer Aided Design Software was able to design the crankshaft, and at the same time calculate the result of Bending Moment, Coefficient of static safety and the likes.
We were able to use the software to select the material to be used for the Crankshaft design, and its properties included.

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