Design, Static and Modal Analysis Of Crankshaft

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***Abstract**:* crankshaft is the part of an engine that translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

It typically connects to a flywheel to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional damper at the opposite end, to reduce the torsional vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal.

In this project Static and Modal Analysis was done on crankshafts of single cylinder four stroke engines by using Steel En36 and Cast iron Alloy. Static element analysis was performed on Crankshaft to obtain the Deformation and Stress at critical locations. Modal Analysis was done on the Crankshaft to obtain Mode Shapes and Natural Frequency of the crankshaft.
Finally Fatigue Analysis is done for best material to estimate life time of crankshaft.

***Index Terms* – crank pins, crank shaft, connecting rod, cylinder.**

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.

FUNCTION OF CRANKSHAFTS IN IC ENGINES

The crankshaft, connecting rod, and piston constitute a four bar 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 n 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.

SERVICE LOADS AND FAILURES EXPERIENCED BY CRANKSHAFTS

Crankshaft experiences large forces from gas combustion. This force is applied to the top of the piston and since the connecting rod connects the piston to the crankshaft, the force will be transmitted to the crankshaft. The magnitude of the force depends on many factors which consists of crank radius, connecting rod dimensions, weight of the connecting rod, piston, piston rings, and pin. Combustion and inertia forces acting on the crankshaft cause two types of loading on the crankshaft structure; torsional load and bending load.

II. LITERATURE REVIEW

An extensive literature review on crankshafts was performed by Zoroufi and Fatemi (2005). Their study 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.

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 by Zoroufi and Fatemi (2005).

FORGING PROCESS AND THE INFLUENCING PARAMETERS

Forging is the term for shaping metal by plastic deformation. Cold forging is done at 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 work piece is heated to a temperature significantly below the typical hot forging temperature, ranging from 500º C to 750º C.

LUBRICATION

In hot forging, in addition to lubrication effects, the effects of die chilling or heat transfer from the host material to the colder dies must be considered. Therefore, values of the friction factor, or coefficient of friction, obtained under certain forging conditions may not be applicable under other conditions. For example, for a given lubricant, friction data obtained in hydraulic press forging cannot be useful in mechanical press or hammer forging, even if the die and billet temperatures are comparable (Altan et al., 1983).

SHAPE COMPLEXITY IN FORGING

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.

HEAT TREATMENT

All hot forged parts receive a certain amount of heat treatment in the process of being forged and, thereafter, may be used without additional heat treatment. For maximum usefulness, however, many forgings are heat treated one or more times before being put into service. For instance, bearing sections and fillet areas on crankshafts are heat treated in order to improve fatigue and wear properties of the material at these certain locations.

Usually forgings are heat treated before and after their machining. The purpose of the initial treatment is to secure uniform structure of the metal and contribute to ease of machining of the forged part. The final treatment makes it possible to use the finished forgings for the service intended. For example, forged tools must be hard and tough, consequently, they must receive final hardening and tempering treatments.

STRAIGHTENING AND COINING

When the flash is trimmed from the drop forging, the shape may become distorted, which common in forged crankshafts because of geometry section changes and non-uniform is cooling during forging process. Correction of this condition may be necessary. Correction to a certain degree may be accomplished by hammering the distorted forging in a special re-striking die. The correction is made while the forging cools. Other re-striking operations, called coining, are conducted on powerful and accurate presses after the forgings have cooled to room temperature. The forgings are brought to the correct size and shape in these presses, and final machining operations ordinarily performed are either entirely or partially eliminated

CASTING PROCESS AND THE INFLUENCING 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).

GREEN SAND

Green sand refers to the fact that water is added to activate the clay binder. Green sand-mold casting involves mixing sand with a suitable clay binder (usually a bentonite clay) and other additives, and packing the sand mixture tightly around a pattern that is constructed from the part design, but the pattern is not an exact replica of the part since various dimensional allowances must be made to accommodate certain physical effects. For most metals and most sizes and shapes of casting, green sand molding is the most economical of all the molding processes.

DRY SAND MOLDS

Dry sand molding is a sand casting process using a mold made of greensand which is dried in an oven to remove the moisture and increase its strength. The absence of moisture eliminates the formation of water vapor and reduces the type of casting defects that are due to gas formation.

OPERATING CONDITIONS AND FAILURE OF CRANKSHAFTS

Crankshaft is one of the largest components in the internal combustion engine that has a complex geometry consisting of cylinders as bearings and plates as the crank webs. Geometry section changes in the crankshaft cause stress concentration at fillet areas where bearings are connected to the crank webs. In addition, this component experiences both torsional and bending load during its service life. Therefore, fillet areas are locations that experience the most critical stresses during the service life of the crankshaft. As a result, these locations are main sections of fatigue failure of the component. The size of a crankshaft depends on the number of cylinders and horsepower output of the engine. The size of the crankshaft could range from 3.2 kg for a single cylinder engine with the output power of 12 hp, to 300 tons for a fourteen cylinder diesel engine with the output power of 108,920 hp.

DYNAMIC LOAD DETERMINATION AND ANALYSIS

Jenson (1970) 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. The critical sections are shown on the V8 crankshaft in Figure 2.7. In order to measure the bending and torsion loads applied to each section of the crankshaft, bending and torsion strain gage bridges were mounted in pairs. Figure 2.8 shows the details of strain gage bridges mounted on section No. 4 in Figure 2.7. After mounting the strain gages, the crankshaft was carefully assembled in the engine and then the engine was completely assembled and installed on a dynamometer stand.

MATERIAL AND COST OPTIMIZATION

An extensive study was performed by Nallicheri et al. (1991) 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. Technical cost modeling method was used in their study to estimate the manufacturing costs of various material alternatives

Fig.1 Four cylinder forged crankshaft

III. MODELING SOFTWARE

CatiaV5 R19 is an interactive Computer- Aided Design and Computer Aided Manufacturing system. The CAD functions automate the normal engineering, design and drafting capabilities found in today's manufacturing companies. The CAM functions provide NC programming for modern machine tools using the CatiaV5 R19 design model to describe the finished part. CatiaV5 R19 functions are divided into "applications" of common capabilities. These applications are supported by a prerequisite application called "CatiaV5 R19 Gateway". CatiaV5R19 is fully three dimensional, double precision system that allows to accurately describing almost any geometric shape. By combining these shapes, one can design, analyze, and create drawings of products.

IV. CREATION OF SOLID BODIES

We can create solid bodies by sweeping sketch and non-sketch geometry to create associative features or Creating primitives for the basic building blocks, then adding more specific features (for example, holes and slots). Sweeping sketch and non-sketch geometry lets us to create a solid body with complex geometry. This method also gives us total control over the editing of the body. Editing is done by changing the swept creation parameters or by changing the sketch. Editing the sketch causes the swept feature to update to match the sketch. Creating a solid body using primitive's results in a simple geometry solid body. Making changes to primitives is more difficult, because primitives cannot always be parametrically edited. We can use primitives when we do not need to be concerned with editing the model. Generally, however, it is to our advantage to create the model from a sketch.

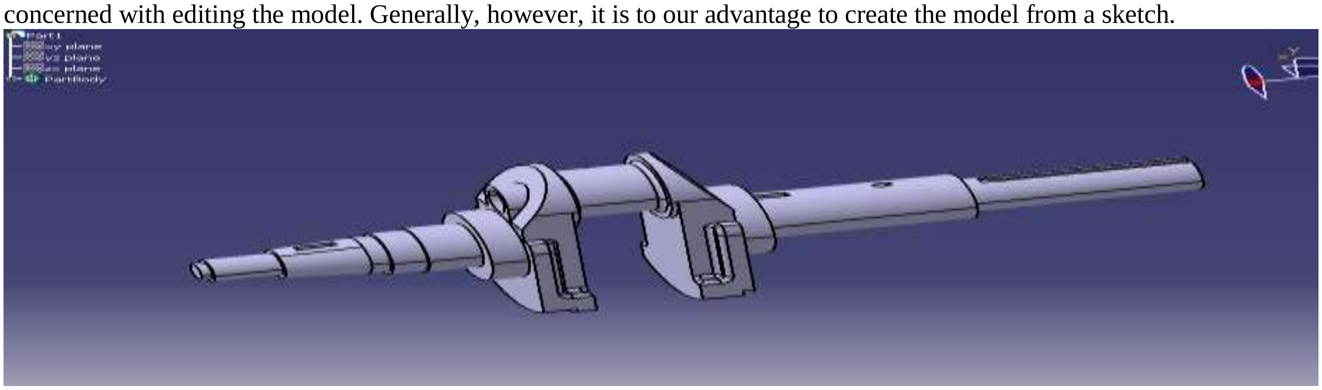


Fig.2 Four cylinder forged solid body crankshaft

V. FINITE ELEMENT METHODS

It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provides approximate, but acceptable solutions.The fundamental areas that have to be learned for working capability of finite element method include: Matrix algebra, Solid mechanics. Variation methods, Computer skills.

TERMS COMMONLY USED IN FINITE ELEMENT METHOD:

Descritization: The process of selecting only a certain number of discrete points in the body can be termed as Descritization.
Continuum: The continuum is the physical body, structure or solid being analyzed.
Node: The finite elements, which are interconnected at joints, are called nodes or nodal points.
Element: Small geometrical regular figures are called elements.
Displace Models: The nodal displacements, rotations and strains necessary to specify completely deformation of finite element.
Degree of freedom: The nodal displacements, rotations and strains necessary to specify completely deformation of finite element.

VI. INTRODUCTION TO ANSYS

Dr. John Swanson founded ANSYS. Inc in 1970 with a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEA). ANSYS inc. supports the ongoing development of innovative technology and delivers flexible, enterprise wide engineering systems that enable companies to solve the full range of analysis problem, maximizing their existing investments in software and hardware. ANSYS Inc. continues its role as a technical innovator. It also supports a process-centric approach to design and manufacturing, allowing the users to avoid expensive and time-consuming “built and break” cycles. ANSYS analysis and simulation tools give customers ease-of-use, data compatibility, multi platform support and coupled field multi-physics capabilities

VII. MESH GENERATION:

In the finite element analysis the basic concept is to analyze the structure, which is an assemblage of discrete pieces called elements, which are connected, together at a finite number of points called Nodes. Loading boundary conditions are then applied to these elements and nodes. A network of these elements is known as Mesh.

VIII. FINITE ELEMENT GENERATION:

The maximum amount of time in a finite element analysis is spent on generating elements and nodal data. Pre processor allows the user to generate nodes and elements automatically at the same time allowing control over size and number of elements. There are various types of elements that can be mapped or generated on various geometric entities.

The elements developed by various automatic element generation capabilities of pre processor can be checked element characteristics that may need to be verified before the finite element analysis for connectivity, distortion-index, etc.

Generally, automatic mesh generating capabilities of pre processor are used rather than defining the nodes individually. If required, nodes can be defined easily by defining the allocations or by translating the existing nodes. Also one can plot, delete, or search nodes.

Fig.3 Mesh model of crankshaft

BOUNDARY CONDITIONS

Fig.4 Boundary conditions of Crank shaft

IX. RESULTS & DISCUSSIONS

STATIC ANALYSIS OF CRANKSHAFT

A) STRUCTURAL ANALYSIS OF CRANKSHAFT WITH EN 36 STEEL

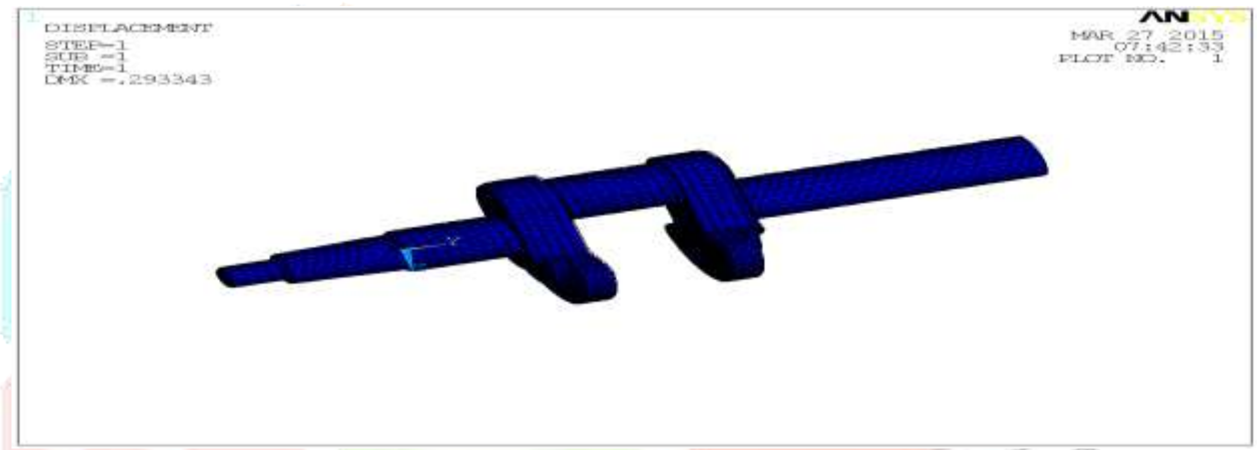


Fig.5 Deformation of crankshaft

The above diagram shows deformation of the crank shaft At 2000 RPM, maximum deformation is 0.293343 mm

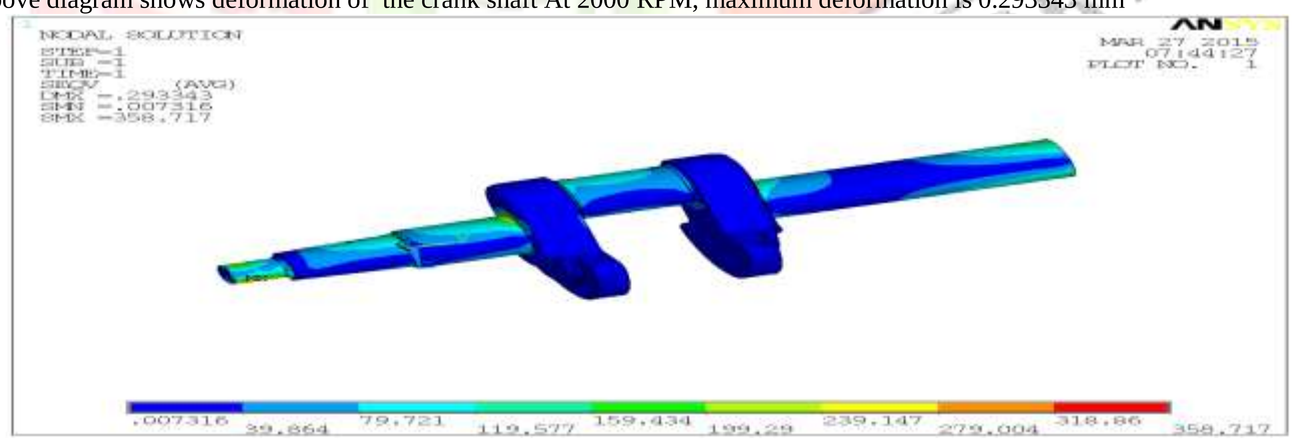


Fig.6 vonmises stress of crankshaft

B)STRUCTURAL ANALYSIS OF CRANKSHAFT WITH CAST IRON ALLOY

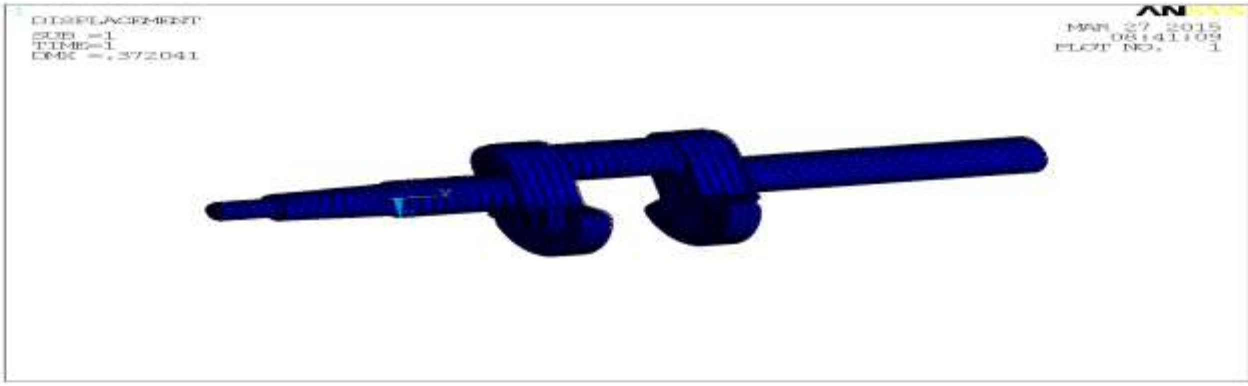


Fig.7 Deformation of crankshaft

The above diagram shows deformation of the crank shaft At 2000 RPM, maximum deformation is 0.372041 mm

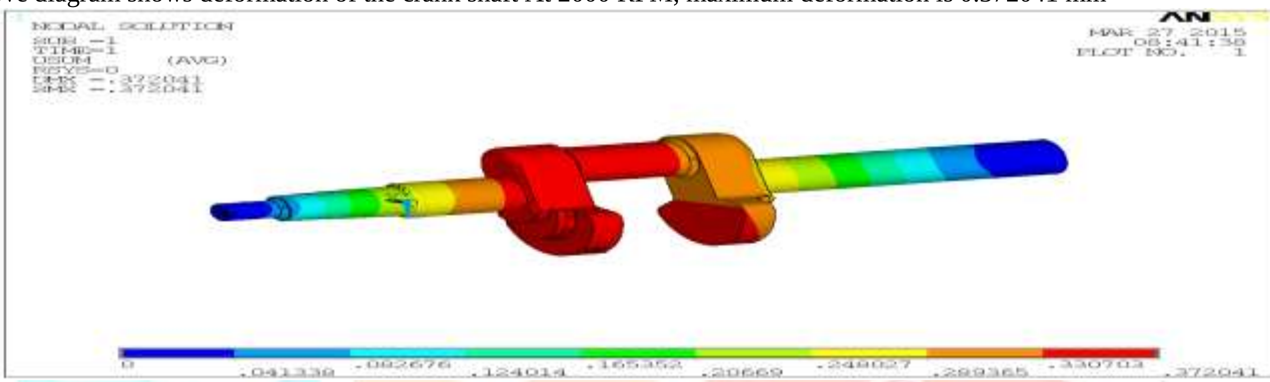


Fig.8 Vector sum of displacement of crankshaft.

X. MODAL ANALYSIS OF EN36 STEEL.

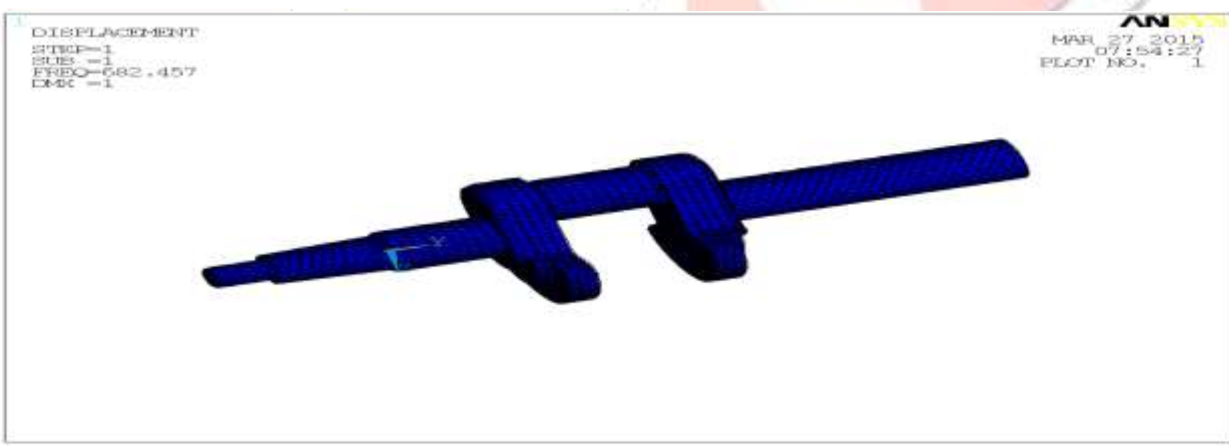


Fig. 9 1st Mode Shape of crankshaft

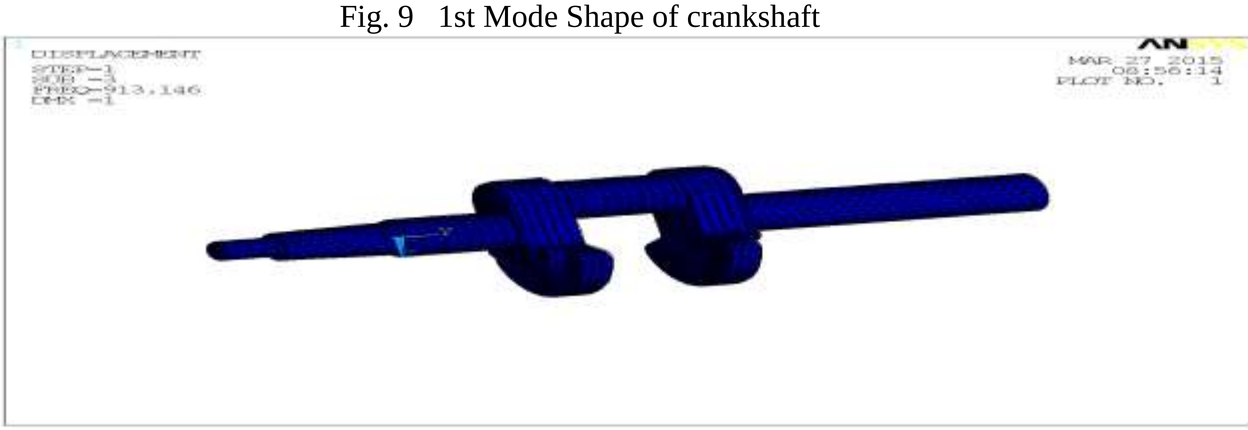
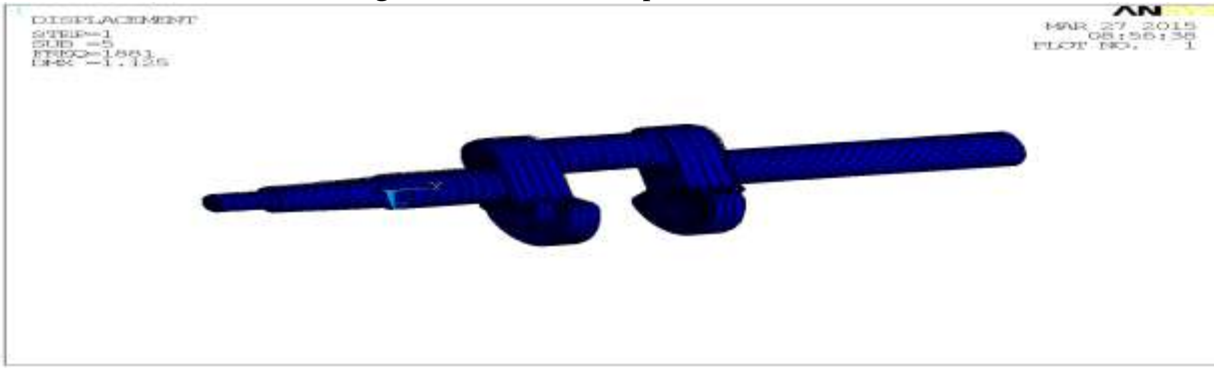


Fig. 10 3rd Mode Shape of crankshaft



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g.11 5th Mode Shape of crankshaft

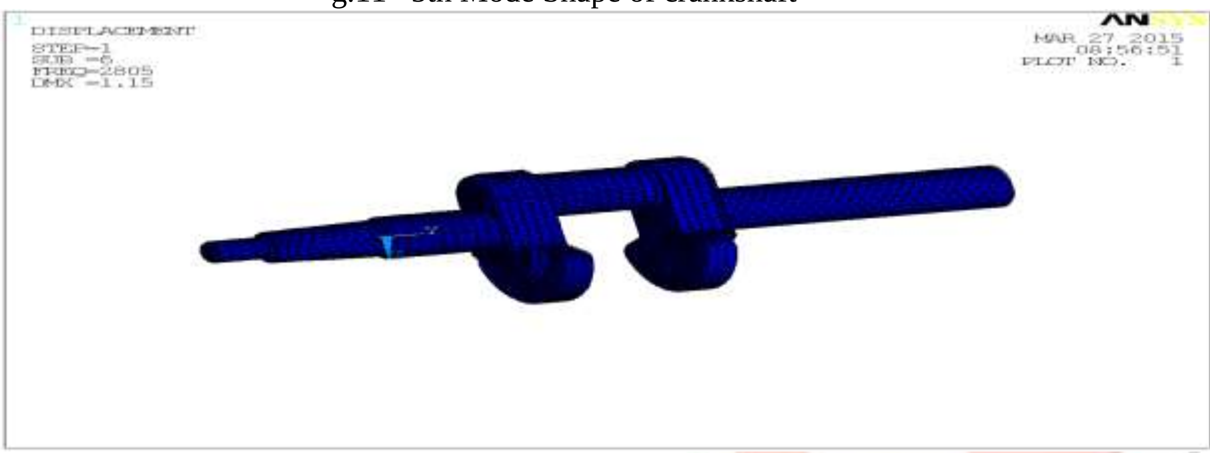


Fig.11 6th Mode Shape of crankshaft

RESULTS OF MODAL ANALYSIS IN HZ

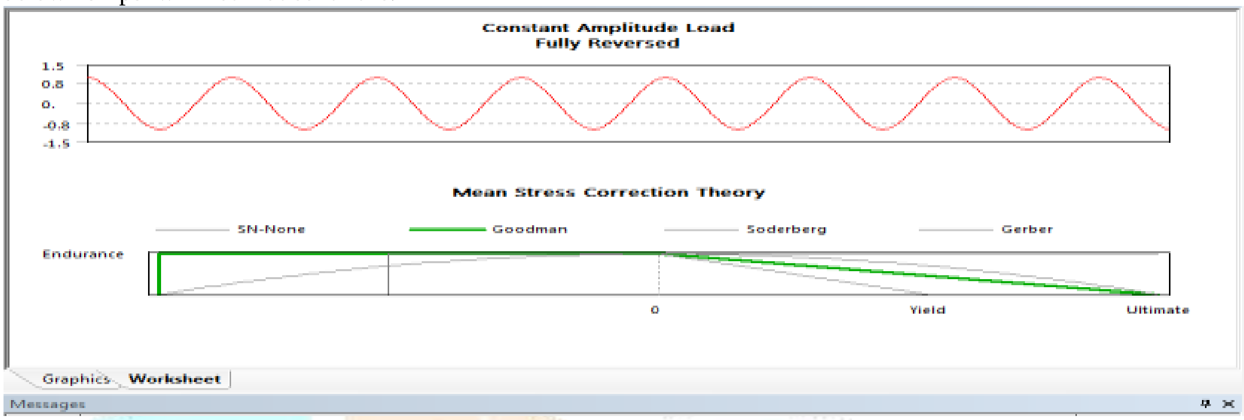
Mode Shapes	SteelEn36 Frequency(Hz)	CastIron Alloy Frequency(Hz)
1 Mode	682.457	616.823
2 Mode	739.232	668.944
3 Mode	1018	913.146
4 Mode	1882	1694
5 Mode	2079	1881
6 Mode	3112	2805

RESULTS OF STATIC ANALYSIS

S. No	Material	Deformation,mm	Vonmises stresses, MPa
1	Steel En36	0.293343	358.717
2	Cast Iron Alloy	0.372041	370.215

S-N CURVE

The discussion above touched on the relationship between applied stress and expected life. For the designer, it is critical that this relationship be characterized so that fatigue life can be predicted. One of the early methods for characterizing this relationship is the S-N curve. 'S' stands for the cyclic stress range while 'N' represents the number of cycles to failure. To develop the curve, a series of samples is tested to failure at various stress ranges. The resulting lives are plotted versus the corresponding stress range. The S-N curve is the locus of these data points. In more thorough testing, multiple samples are tested at each stress range. Common practice is to plot the S-N curve through the mean value at each stress range. An example is shown in Figure 1. Note that in this case, a fatigue stress below 49 kpsi will not induce failure.



LIFE CYCLE TIME=1E6 CYCLES, DESIGN LIFE =1E9 CYCLES

CONCLUSION

Steel En36 and Cast iron crankshaft were chosen for this Project, both of which belong to similar single cylinder four stroke air cooled gasoline engines. Static analysis and Modal analysis was performed based on of the slider crank mechanism consisting of the crankshaft.

The following conclusions can be drawn from the analysis :

Static analysis of the crankshaft results in more realistic stresses where as all Stress are within the limits .

From the results it is observed that Steel En36 is safer than cast iron Alloy .

But both materials are within the elastic limits. From the Modal Analysis results we observe that Steel En36 is Stable than cast iron Alloy .

FUTURE SCOPE OF THE WORK

In the present investigation of static and Modal analysis is done on Crankshaft by using ANSYS package.

Accurate stresses are critical input to optimization of the crankshaft.

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