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Design and Analysis of a Crank Shaft

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Abstract:
Crankshaft is one of the critical components for the effective and precise working of the internal combustion engine. In this paper a static simulation is conducted on a crankshaft from a single cylinder 4- stroke diesel engine. A three - dimension model of diesel engine crankshaft is created using Pro-E software. Finite element analysis (FEA) is performed to obtain the variation of stress magnitude at critical locations of crankshaft. Simulation inputs are taken from the engine specification chart. The static analysis is done using FEA Software ANSYS which resulted in the load spectrum ap lied to crank pin bearing. This load is applied to the FE model in ANSYS, and boundary conditions are applied according to the engine mounting conditions. The analysis is done for finding critical location in crankshaft. Stress variation over the engine cycle and the effect of torsion and bending load in the analysis are investigated. Von-mises stress is calculated using theoretical y and FEA software ANSYS. The relationship between n the frequency and the vibration modal is explained by the modal and harmonic analysis of crankshaft using FEA software ANSYS

I. INTRODUCTION

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. Heat engines are divided into two broad classes.

a) External combustion engines
b) Internal combustion engines.

In an external combustion engine the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle, as in the case of steam engine or a steam turbine plant where the heat of combustion is employed to generate steam which is used in the piston engine or turbine .Sterling engine is also an external combustion engine. In an internal combustion engine the product of the combustion are directly the motive fluids. Petrol, gas & diesel engines, Wankel engine, and open cycle gas turbine are example of internal combustion engine. Jet engines and rockets are also internal combustion engine. The main advantages of internal combustion engines over external combustion engines are greater mechanical simplicity, lower ratio of weight and bulk to output due to absence of auxiliary apparatus like boiler and condenser and hence lower first cost, higher overall efficiency, and lesser requirement of water for dissipation of energy through cooling system.

Internal Combustion Engines:

Historical development.

Huygens Gunpowder Engine:- The earliest internal combustion can be credited to famous Dutch physicist Christian Huygens (1629-1695) in the year 1680. Huygens engine employing gunpowder. Four Stroke Cycle: - All the engines developed until 1860 provided combustion of the charge at about atmospheric pressure. In 1862, Beau de Rocha's, a Frenchmen, wrote a paper describing the fundamental principles for efficient operation of piston combustion engine, which were demonstrated in a practical engine by Otto, a German engineer. This laid the foundation of four stroke cycle engine which is used till today in all four stroke spark-ignition engines. This method of operation was explained in the four operations as follows.

1st Stroke: - Induction of charge during the outward stroke of piston.
2nd Stroke: - Compression of the charge during inward stroke of the piston.
3rd Stroke: - Ignition of the air fuel mixture during inward dead centre, followed by Expansion during the next outward stroke of the piston.
4th Stroke: - Exhaust during the next inward stroke of the piston.

Crank:- Introduction to crank shaft:

It is a lever between connecting rod and crank shaft.
Material: 37C15 Alloy Steel.

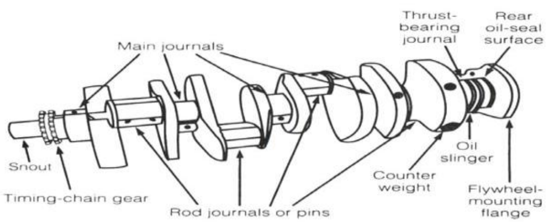

Figure .1.1 typical crankshaft with main journals that support the crankshaft in the engine block. Rod journals are offset from the crankshaft centerline.

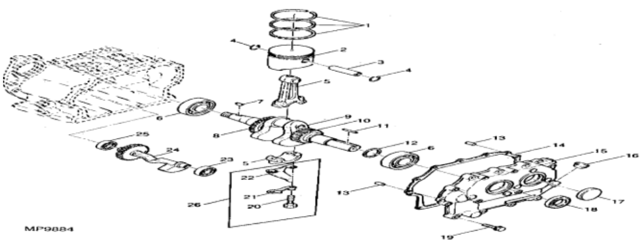

Figure.1.2 Exploded view of a single cylinder engine showing the crank shaft mounting in the engine.

II. LITERATURE REVIEW

Zissimos P. Mourelatos, A system model for analyzing the dynamic behaviour of an internal combustion engine crankshaft is described. The model couples the crankshaft structural dynamics, the main bearing hydrodynamic lubrication and the engine block stiffness using a system approach. A two-level dynamic sub structuring technique is used to predict the crankshaft dynamic response based on the finite-element method. The dynamic sub structuring uses a set of load-dependent Ritz vectors. The main bearing lubrication analysis is based on the solution of the Reynolds's equation. Comparison with experimental results demonstrates the accuracy of the model. Numerical results also show the capabilities and significance of the model in engine crankshaft design.

Y. Kang , G.-J. Sheen, M.-H. Tseng, S.-H. Tu, H.-W. Chiang, his study investigates the coupled modes, including coupled tensional–flexural vibration and coupled longitudinal–flexural vibration, for non-rotating crankshafts which are free–free suspended. The finite element models of those generally used are in two categories: beam elements and solid elements. By using these two models the natural frequencies and mode shapes of two crankshafts are determined by the finite element method (FEM) and compared with experimental data from modal testing. The accuracy and validity of the analytical approaches are verified. The results show that the solid element is more appropriate than the beam element in the modal analysis of crankshafts.

BA Peng;LYU Zhong-yang;CHEN Tao;ZHANG Yu-wei;College of Mechanical Engineering, Shenyang Ligong University; Crankshaft is the main part of the reciprocating air compressor, and the crankshaft is easy to produce torsional vibration, since it is subjected to complex alternating load in the process of operation. Therefore, torsional vibration analysis must be carried out on the six columns of the crankshaft. To high-power, high-speed development trend, the crankshaft system models with different structure are established using Pro/E, and using ANSYS for static and dynamic analysis of the crankshaft. The influence of the change of the crankshaft structure on the torsional vibration can be obtained by the comparison of the results. It also can provide theoretical support for the design of high speed crankshaft.

III.METALS AND ALLOYS

METALS:

A metal is a material that is typically hard, opaque, shiny, and has good electrical and thermal conductivity. Metals are generally malleable that is, they can be hammered or pressed permanently out of shape without breaking or cracking as well as fusible and ductile. Metals in general have high electrical conductivity, high thermal conductivity and high density. Mechanical properties of metals include ductility, i.e. their capacity for plastic deformation. Reversible elastic deformation in metals can be described by Hooke's Law for restoring forces, where the stress is linearly proportional to the strain. Forces larger than the elastic limit, or heat, may cause a permanent (irreversible) deformation of the object, known as plastic deformation or plasticity.

This irreversible change in atomic arrangement may occur as a result of:

- The action of an applied force (or work). An applied force may be tensile (pulling) force, compressive (pushing) force, shear, bending or torsion (twisting) forces.

ALLOYS:

An alloy is a mixture of two or more elements in which the main component is a metal. Most pure metals are either too soft, brittle or chemically reactive for practical use. Combining different ratios of metals as alloys modifies the properties of pure metals to produce desirable characteristics. The aim of making alloys is generally to make them less brittle, harder, resistant to corrosion, or have a more desirable color and luster of all the metallic alloys in use today, the alloys of iron make up the largest proportion both by quantity and commercial value. Iron alloyed with various proportions of carbon gives low, mid and high carbon steels, with increasing carbon levels reducing ductility and toughness. The addition of silicon will produce cast irons, while the addition of chromium, nickel and molybdenum to carbon steels results in stainless steels. other significant metallic alloys are those of aluminum, titanium, copper and magnesium. Copper alloys have been known since prehistory bronze gave the Bronze Age its name and have many applications today, most importantly in electrical wiring. The alloys of the other three metals have been developed relatively recently; due to their chemical reactivity they require electrolytic extraction processes. The alloys of aluminum, titanium and magnesium are valued for their high strength-to-weight ratios; magnesium can also provide electromagnetic shielding. These materials are ideal for situations where high strength to weight ratio is more important than material cost, such as in aerospace and some automotive applications. Alloys specially designed for highly demanding applications, such as jet engines, may contain more than ten elements.

Iron Alloys and Materials:

There are a number of different types of alloys containing iron. Some of the most important include carbon steels, alloy steels, stainless steels, tool steels, cast iron, and managing steel.

Carbon steels are steels in which the main alloying additive is carbon. Mild steel is the most common due to its low cost. It is neither brittle nor ductile, has relatively low tensile strength, and is malleable. Surface hardness can be increased through carburizing. High carbon steels have a higher carbon content which provides a much higher strength at the cost of ductility.

Alloy steels are steels (iron and carbon) alloyed with other metals to improve properties. The most common metals in low alloyed steels are molybdenum, chromium, and nickel to improve weld ability, formability, wear resistance, and corrosion resistance.

Stainless steels are steels that contain a minimum of 10% chromium. There are many grades of stainless steel, but the most common grade used for typical corrosion resistant applications is type 304, also known as 18-8. The term 18-8 refers to the amount of chromium (18%) and nickel (8%) combined with iron and other elements in smaller quantities. The metal's finish is depicted by a number, 3 to 8, with 3 being the roughest and 8 being a mirror-like finish. Other specifications to consider include textures and coatings.

Tool steels are particular steels designed for being made into tools. They are known for toughness, resistance to abrasion, ability to hold a cutting edge, and/or their resistance to deformation at high temperatures. The three types of tool steel available are cold work steels used in lower operating temperature environments, hot work steels used at elevated temperatures, and high speed steels able to withstand even higher temperatures giving them the ability to cut at higher speeds.

Cast iron is an iron alloy derived from pig iron, alloyed with carbon and silicon. Carbon is added to the base melt in amounts that exceed the solubility limits in iron and precipitates out as graphite particles. Silicon is added to the melt to nucleate the graphite which optimizes the properties of cast iron. Often dismissed as a cheap, dirty, brittle metal; cast iron is getting much more attention and use today because of its mach inability, light weight, strength, wear resistance, and damping properties.

Merging steels are carbon free iron-nickel alloys with additions of cobalt, molybdenum, titanium, and aluminum. The term managing is derived from the strengthening mechanism, which is transforming the alloy to marten site with subsequent age hardening. With yield strengths between 1400 and 2400 MPa, merging steels belong to the category of ultra-high-strength materials. The high strength is combined with excellent toughness properties and weld ability.

Materials usage for Crankshaft:
Camshafts can be made out of several different types of material. The materials used for the camshaft depends on the quality and type of engine being manufactured.

IV. EXISTING MATERIAL:

MILD STEEL

Mild steel also known as **plain-carbon steel**, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low-carbon steel contains approximately 0.05–0.15% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel.

Properties of Mild Steel:

Young's Modulus: 2.1e+005Mpa
Poisson's ratio : 0.3
Density : 7.85e-006 Kg/mm3
Tensile ultimate Strength: 841Mpa

Titanium alloy:
Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics.

Properties of Titanium Alloy:
Young's Modulus : 96000 Mpa
Poisson's ratio : 0.36
Density : 4.62e-006 Kg/mm3
Tensile ultimate Strength : 1070 Mpa

Chilled iron castings:

This is a good choice for high volume production. A chilled iron camshaft has a resistance against wear because the camshaft lobes have been chilled, generally making them harder. When making chilled iron castings, other elements are added to the iron before casting to make the material more suitable for its application. Chills can be made of many materials, including iron, copper, bronze, aluminum, graphite, and silicon carbide. Other sand materials with higher densities, thermal conductivity or thermal capacity can also be used as a chill. For example, chromate sand or zircon sand can be used when molding with silica sand.

Properties of Child Cast Iron:

Young's Modulus : 1.2e+005 Mpa
Poisson's ratio : 0.275
Density : 7.2e-006 Kg/mm3
Tensile ultimate Strength : 414 Mpa

Aluminum alloy:

A**luminum alloys** are alloys in which aluminum (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. Here are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminum is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminum alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminum alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminum alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Alloys composed mostly of aluminum have been very important in aerospace manufacturing since the introduction of metal-skinned aircraft. Aluminum-magnesium alloys are both lighter than other aluminum alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Properties of Aluminum Alloy:

Young's Modulus : 71000 Mpa
Poisson's ratio : 0.33
Density : 2.77e-006 Kg/mm3
Tensile ultimate Strength : 310 Mpa

V. INTRODUCTION TO PRO/E:

PRO/E is the industry's de facto standard 3D mechanical design suit. It is the world's leading **CAD/CAM /CAE** software, gives a broad range of integrated solutions to cover all aspects of product design and manufacturing. Much of its success can be attributed to its technology which spurs its customer's to more quickly and consistently innovate a new robust, parametric, feature based model. Because that ***PRO/E***

is unmatched in this field, in all processes, in all countries, in all kind of companies along the supply chains.***PRO/E*** is also the perfect solution for the manufacturing enterprise, with associative applications, robust responsiveness and web connectivity that make it the ideal flexible engineering solution to accelerate innovations. ***PRO/E*** provides easy to use solution tailored to the needs of small medium sized enterprises as well as large industrial corporations in all industries, consumer goods, fabrications and assembly. Electrical and electronics goods, automotive, aerospace, shipbuilding and plant design. It is user friendly solid and surface modeling can be done easily.

Advantages of *PRO/E:*

• It is much faster and more accurate.
• Once a design is completed. 2D and 3D views are readily obtainable.
• The ability to changes in late design process is possible.
• It provides a very accurate representation of model specifying all other dimensions hidden geometry etc.

- It is user friendly both solid and surface modeling can be done.
- It provides a greater flexibility for change. For example if we like to change the dimensions of our model, all the related dimensions in design assembly, manufacturing etc. will automatically change.

• It provides clear 3D models, which are easy to visualize and understand.

• ***PRO/E*** provides easy assembly of the individual parts or models created it also decreases the time required for the assembly to a large extent.

Modeling process of CAMSHAFT Parts:

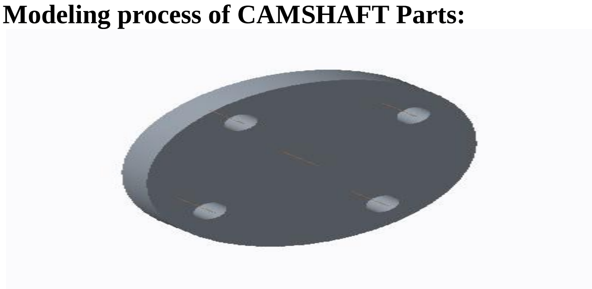

Figure.5.1FirstCrank shaft Preparation

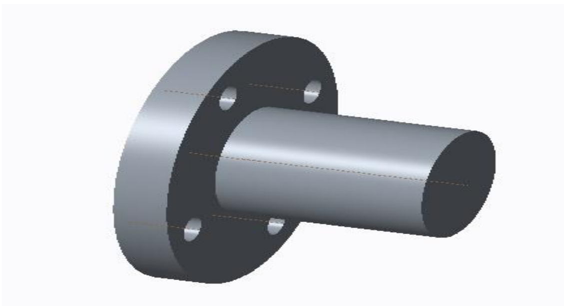

Figure.5.2 Second Crank shaft Preparation

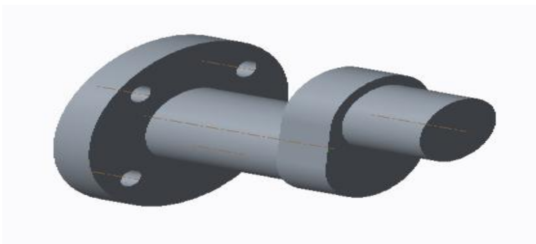

Figure.5.3first crank Preparation

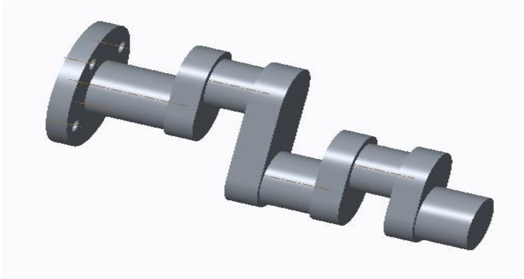

Figure.5.4fourth step Preparation

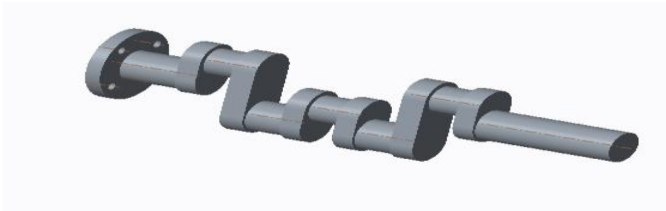

Figure.5.5Final Preparation of Crank shaft

Figure.5.6 An Exploded view of Crank shaft

FINITE ELEMENT METHOD / ANALYSIS (FEM/A) INTRODUCTION:

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 as an analysis tool, it is receiving much attention in almost every industry. In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problem rather than exact closed form solution. It is not possible to obtain analytical mathematical solutions for many engineering problems. The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It has been developed simultaneously with the increasing use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations. The basics in engineering field are must to idealize the given structure for the required behavior. The proven knowledge in the typical problem area, modeling techniques, data transfer and integration, computational aspects of the Finite Element Method is essential. In the Finite Element Method the solution region is considered as built up many small, interconnected sub regions called finite elements.

Geometrical definitions:

There are four different geometric entities in pre processor namely key points, lines, area and volumes. These entities can be used to obtain the geometric representation of the structure. All the entities are independent of other and have unique identification labels.
Model Generations:

Two different methods are used to generate a model:

- Direct generation.
- Solid modeling

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.

FINITE ELEMENT GENERATION:

The maximum amount of time in a finite element analysis is spent on generating elements and nodal data. Preprocessor 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 on one can plot, delete, or search nodes.

BOUNDARY CONDITIONS AND LOADING:

After completion of the finite element model it has to constrain and load has to be applied to the model. User can define constraints and loads in various ways. All constraints and loads are assigned set ID. This helps the user to keep track of load cases.

SOLUTION:

The solution phase deals with the solution of the problem according to the problem definitions. All the tedious work of formulating and assembling of matrices are done by the computer and finally displacements are stress values are given as output. Some of the capabilities of the ANSYS are linear static analysis, non linear static analysis, transient dynamic analysis, etc.

Post- Processor:
It is a powerful user- friendly post- processing program using interactive color graphics. It has extensive plotting features for displaying the results obtained from the finite element analysis. One picture of the analysis results (i.e. the results in a visual form) can often reveal in seconds what would take an engineer hour to assess from a numerical output, say in tabular form. The engineer may also see the important aspects of the results that could be easily missed in a stack of numerical data. Employing state of art image enhancement techniques, facilities viewing of Contours of stresses, displacements, temperatures, etc. The phases that are involved in the post processor

- Deform geometric plots
- Animated deformed shapes
- Time-history plots
- Solid sectioning
- Hidden line plot
- Light source shaded plot
- Boundary line plot etc.

The entire range of post processing options of different types of analysis can be accessed through the command/menu mode there by giving the user added flexibility and convenience.

THERMAL ANALYSIS:

A thermal analysis calculates the temperature distribution and related thermal quantities in brake disc. Typical thermal quantities are:
1. The temperature distribution
2. The amount of heat lost or gained
3. Thermal fluxes

STRUCTURAL ANALYSIS:

Structural analysis is the most common application of the finite element analysis. The term structural implies civil engineering structure such as bridge and building, but also naval, aeronautical and mechanical structure such as ship hulls, aircraft bodies and machine housing as well as mechanical components such as piston, machine parts and tools.
Modal Analysis
Harmonic Analysis
Transient Dynamic Analysis
Spectrum Analysis
Buckling Analysis
Explicit Dynamic Analysis

VI. PROCEDURE:

Importing the Model:

In this step the PRO/E model is to be imported into ANSYS workbench as follows:

In utility menu file option and selecting import external geometry and open file and click on generate. To enter into simulation module click on project tab and click on new simulation

Defining Material Properties:

To define material properties for the analysis, following steps are used the main menu is chosen select model and click on corresponding bodies in tree and then create new material enter the values again select simulation tab and select material

Defining Element Type:

To define type of element for the analysis, these steps are to be followed:

Chose the main menu select type of contacts and then click on mesh-right click-insert method
Method - Tetrahedrons
Algorithm - Patch Conforming
Element Mid side Nodes – Kept

Meshing the model

To perform the meshing of the model these steps are to be followed:

Chose the main menu click on mesh- right click- insert sizing and then select geometry enter element size and click on edge behavior curvy proximity refinement and then right click generate mesh.

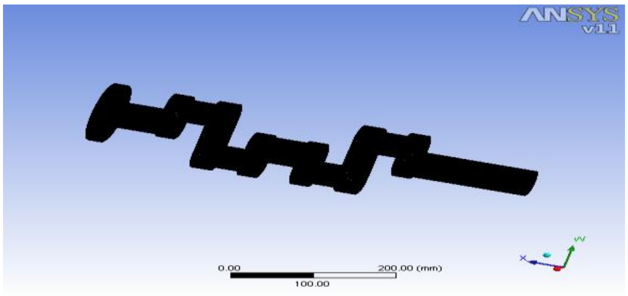

Figure.6.1 Mesh Generation of the Modal

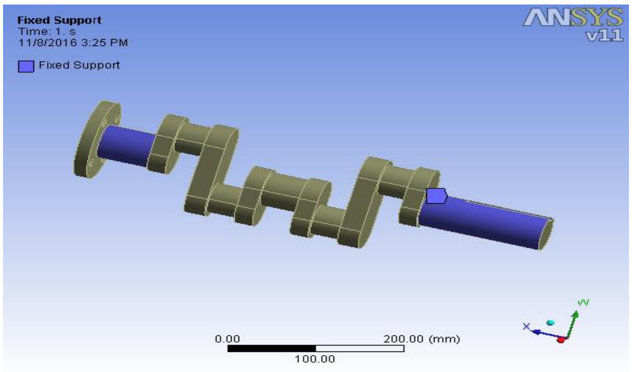

Figure.6.2Fixed support

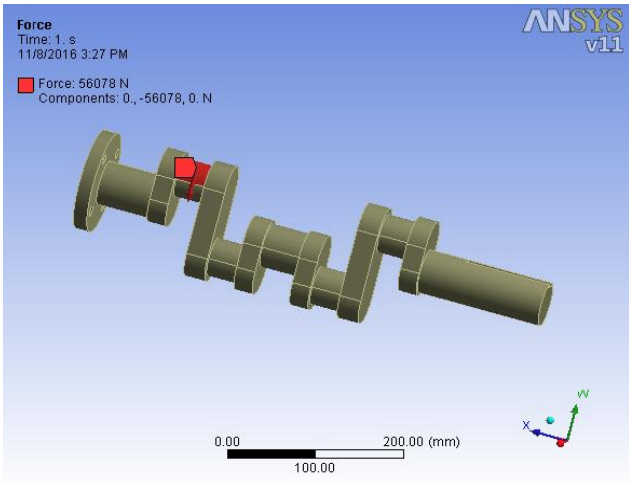

Figure. 6.3 First Force application

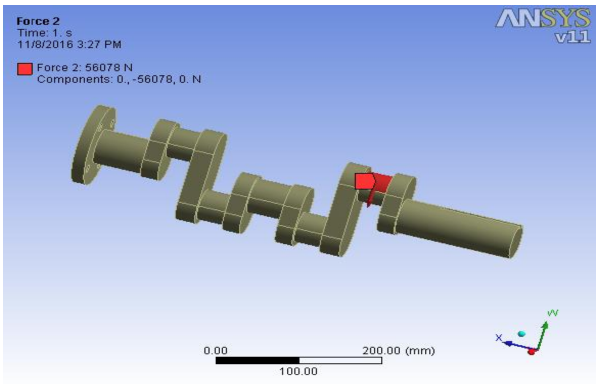

Figure. 6.4 Second Force application

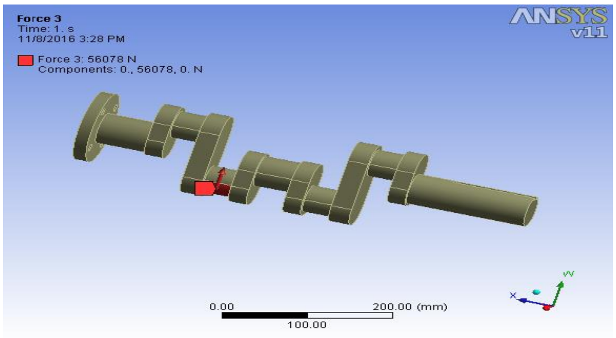

Figure. 6.5 Third Force application

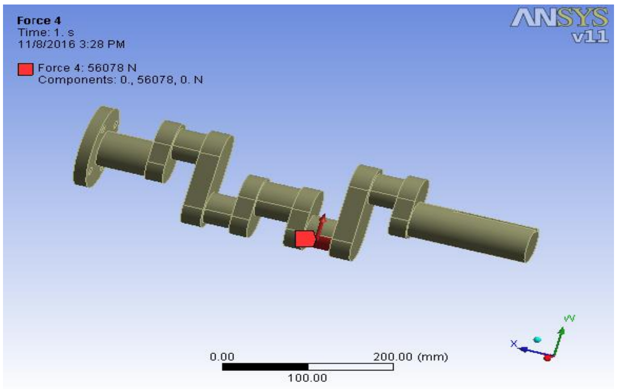

Figure. 6.6 Fourth Force application

TITANIUM ALLOY

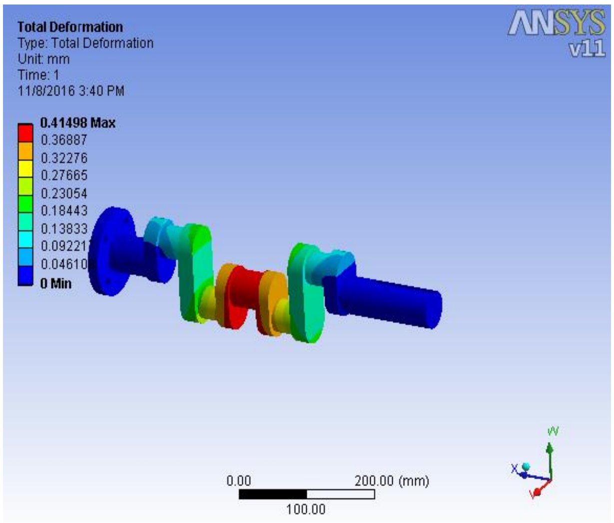

Figure. 6.7 Total deformation

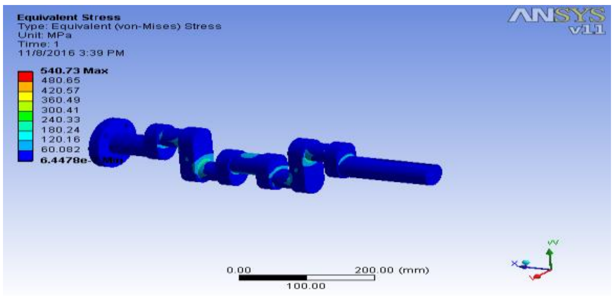

Figure. 6.8 Equivalents stress

CHILD CAST IRON

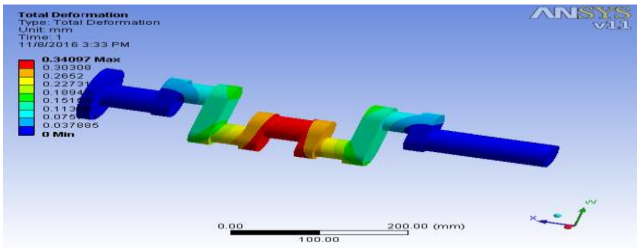

Figure. 6.9 Total deformation

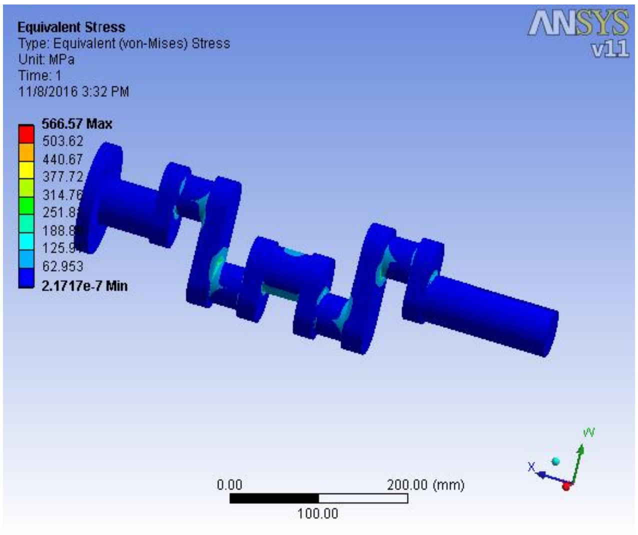

Figure. 6.10 Equivalents stress

CAST ALUMINUM ALLOY

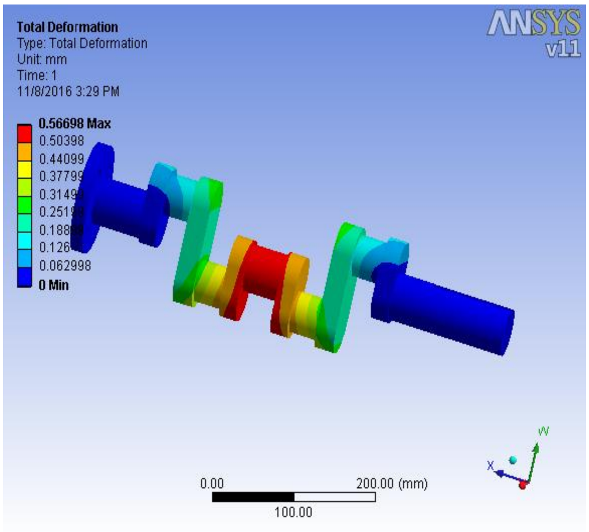

Figure.6.11 Total deformation

MILD STEEL

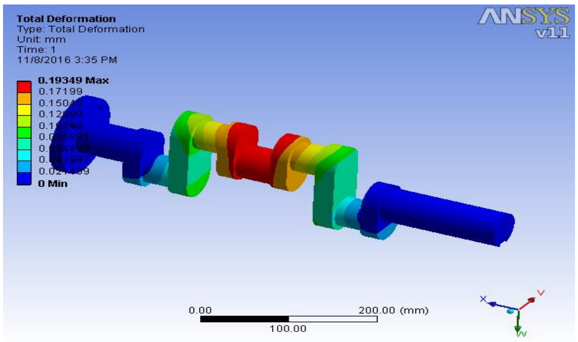

Figure. 6.12 Total deformation

VII. RESULTS AND CONCLUSION

In this Project, the crankshaft model was created by Pro/E software. Then, the model
created by Pro/E was imported to ANSYS software. The Value of Von-Misses Stresses that comes out from the analysis is far less than material yield stress so our design is safe and we should go for optimization to reduce the material and cost. After Performing Static Analysis I Performed the materials Titanium ally. Because the Titanium alloy's stress value is 540.73Mpa and the tensile ultimate strength is 1070Mpa. According to above discussion we concluded the Titanium Alloy is prepared one.

1. The maximum deformation appears at the center of crankpin neck surface.
2. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks and near the central point Journal.
3. The edge of main journal is high stress area.

Analysis Results. So we can Say that Dynamic FEA is a good tool to reduce Costly experimental work.

VIII. CONCLUSION

The crankshaft model is created by Pro/ENGINEER software. Then the model created by pro/Engineer was imported to ANSYS software. The maximum deformation appears at the centre of crankshaft surface. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks, and near the central point. Journal. The edge of main journal is high stress area. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So this area prones to appear the bending fatigue crack. Base on the results, we can forecast the possibility of mutual interference between the crankshaft and other parts. The resonance vibration of system can be avoided effectively by appropriate structure design. The results provide a theoretical basis to optimize the design and fatigue life calculation

- Dynamic loading analysis of the crankshaft results in more realistic stresses whereas static analysis provides overestimated 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.
- Considering torsional load in the overall dynamic loading conditions has no effect on von Mises stress at the critically stressed location. The effect of torsion on the stress range is also relatively small at other locations undergoing torsional load. Therefore, the crankshaft analysis could be simplified to applying only bending load.
- Superposition of FEM analysis results from two perpendicular loads is an efficient and simple method of achieving stresses for different loading conditions according to forces applied to the crankshaft from the dynamic analysis.

- Experimental stress and FEA results showed close agreement, within 7% difference. These 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.
- Critical (i.e. failure) locations on the crankshaft geometry are all located on the fillet areas because of high stress gradients in these locations, which result in high stress concentration factors.
- Using the rainflow cycle counting method on the critical stress history plot shows that in an entire cycle only one peak is important and can cause fatigue damage in the component.

As a result of geometry optimization from Stage II, the weight of the crankshaft was reduced by 26%. Crankshaft geometry changes in this optimization stage required changing the main bearings in the engine according to the optimized diameters and using thrust bearings to reduce the increase of axial displacement of the crankshaft.

TABLE.1. RESULT ANALYSIS

Material	**Total Deformation(mm)**		**Equivalent stress(Mpa)**	
	Mini	**Max**	**Mini**	**Max**
Titanium Alloy	0	0.41498	6.447e-7	540.73
Aluminum Alloy	0	0.56698	4.2275e-7	549.47
Child cast iron	0	0.34097	2.1717e-7	566.57
Mild Steel	0	0.19349	2.8979e-7	558.66

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