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Design, Analysis and Optimization of a 6 cylinder Engine Crank shaft

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Abstract: *This paper deals with; the problem occurred in six cylinders four stroke engine crankshaft. It consist of static structural analysis of six cylinder engine crank shaft. It identifies and solves the problem by using the modelling and simulation techniques. The main work was to model the crankshaft with dimensions and then simulate the crankshaft for static structural analysis. The topic was chosen because of increasing interest in higher payloads, lower weight, higher efficiency and shorter load cycles in crankshaft. The modelling software used is Unigraphics-NX7.5 for modelling the crankshaft. The analysis software ANSYS is used for structural analysis of crankshaft. The objective involves modelling and analysis of crankshaft, so as to identify the effect of stresses on crankshaft, to compare various materials and to provide possible solution. Results obtained from the aforementioned analysis were then used in optimization of the crankshaft. The first step in the optimization process was weight reduction of the component considering static loading. This required the stress range under static loading not to exceed the magnitude of the stress range in the original crankshaft. Possible weight reduction options and their combinations were considered. The optimization process resulted in a weight reduction, increased strength and a reduced cost of the crankshaft.*

Keywords: *6 cylinder Engine Crankshaft, Unigraphics, Finite element analysis, Stress Analysis, optimization.*

I. Introduction

Crankshaft is one of the most important moving parts in internal combustion engine. 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. Crankshaft must be strong enough to take the downward force of the power stroke without excessive bending. So the reliability and life of the internal combustion engine depend on the strength of the crankshaft largely. And as the engine runs, the power impulses hit the crankshaft in one place and then another. This study is conduct on a six cylinder engine crank shaft. The modelling of six cylinder engine crankshaft is done by using Unigraphics-NX7.5 software. The finite element analysis has been performed on crankshaft in order to optimize the weight and manufacturing cost. The material for crankshaft is Cast Iron. Other alternate materials on which analysis has been done are, Forged steel, high carbon steel.

II. Literature Review

Solanki et al. [1] presented literature review on crankshaft design and optimization. The materials, manufacturing process, failure analysis, design consideration etc. were reviewed. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of the automobile specifications with cost and size effectiveness. They concluded that crack grows faster on the free surface while the central part of the crack front becomes straighter. Fatigue is the dominant mechanism of failure of the crankshaft. Residual imbalances along the length of the crankshafts are Crucial to performance.

Meng et al. [2] discussed the stress analysis and modal analysis of a 4 cylinder crankshaft. FEM software ANSYS was used to analyse the vibration modal and distortion and stress status of crank throw. The relationship between frequency and the vibration modal was explained by the modal analysis of crankshaft. This provides a valuable theoretical foundation for the optimization and improvement of engine design. Maximum deformation appears at the centre of the crankpin neck surface. The maximum stress appears at the fillet between the crankshaft journal and crank cheeks, and near the central point journal. The crankshaft deformation was mainly bending deformation was mainly bending deformation under the lower frequency. Maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So, the area prone to appear the bending fatigue crack.

Montazersadgh and Fatemi [3] choose forged steel and a cast iron crankshaft of a single cylinder four stroke engine. Both crankshafts were digitized using a CMM machine. Load analysis was performed and verification of results by ADAMS modelling of the engine. At the next step, geometry and manufacturing cost optimization was performed. Considering torsional load in the overall dynamic loading conditions has no effect on von mises stress at the critically stressed location. Experimental stress and FEA results showed close agreement, within 7% difference. Critical locations on the crankshaft are all located on the fillet areas because of high stress gradients in these locations. Geometry optimization results in 18% weight reduction of the forged steel. Fillet rolling induces compressive residual stress in the fillet areas, which results in 165% increase in fatigue strength of the crankshaft.

III. Design Calculation For Crankshaft

The specification of diesel engine for crankshaft is TABULATED below:

No of cylinders	6
Bore/Stroke	86 mm/ 68 mm
Compression Ratio	18 : 1
Max. Power	8.1 HP @ 3600rpm
Max. Torque	16.7 Nm@ 2200rpm
Maximum Gas pressure	25 Bar

Table 1: Specification of engine

Deign of crankshaft when the crank is at an angle of Maximum bending moment. At this position of the crank, the maximum gas pressure on the piston will transmit maximum force on the crankpin in the plane of the crank causing only bending of the shaft. The crankpin as well as ends of the crankshaft will be only subjected to bending moment. Thus, when the crank is at the dead center, the bending moment on the shaft is maximum and the twisting moment is zero.

Let, D = Piston diameter or cylinder bore in mm, p = Maximum intensity of pressure on the piston in N/mm2The thrust in the connecting rod will be equal to the gas load on the piston (Fp). We know that gas load on the piston,

Force on the piston:

Bore diameter (D) =86mm,

F_p= Area of the bore $\times P_{max}$

$F_p = \pi/4 \times D^2 \times P_{max} = 14.52$ KN

Distance between two bearings is given by,

$$b=2D=2\times86=172mm$$

$$\text{Therefore } b_1=b_2=b/2=86mm$$

Due to this piston gas load (F_P) acting horizontally, there will be two horizontal reactions H_1 and H_2 at bearings 1 and 2

Respectively, such that

$$H_1=H_2=F_p/2=7.26KN$$

Design of crank pin against loading

According to distortion energy theory, the Von-Misses stress induced in the crank-pin is,

$M_{ev}=\sqrt{} (K_b\times M_c)^2+3/4(K_t\times T_c)^2$

Where,

Kb = combined shock and fatigue factor for bending (Assume Kb=2)

Kt = combined shock and fatigue factor for torsion (Assume K t =1.5)

Putting the values in above equation we get

$M_{ev=}1568KN\text{-}mm$
Also we know that
$M_{ev}= \pi/32\times\sigma_v\times44^3$
$1568\times10^3= \pi/32\times\sigma_v\times44^3$
Von-Mises stress σ_v= 187.49 N/mm^2

IV. Modeling Of Crankshaft

The software used for Modelling of crankshaft is Unigraphics-NX7.5 and software it is developed by SIEMENS.
This is CAD/CAM/CAE software but we are using this for only 3-D part modelling (CAD).
This CAD includes.
1. Sketcher
2. Part modelling (part design)
3. Surface Design
4. Assembly Design
5. Drafting

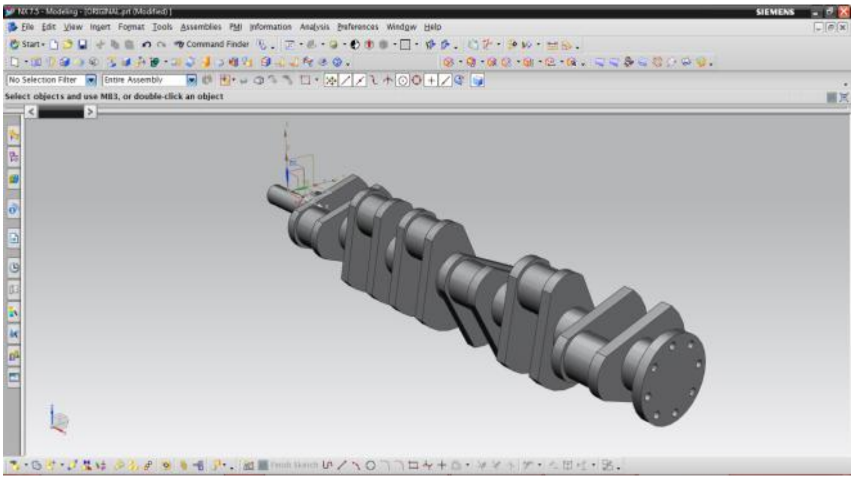

Figure 1: 3-D model of Crankshaft using Unigraphics-Design 1-Original

V. Meshing Of Crankshaft

The Figure.2 shows the meshed model of crankshaft. The Discretization (Mesh generation) is the first step of Finite Element Method. In this step the component or part is divided into number of small parts. In discretization the no of elements are 59971.The effect of force on each portion of the component is not same. The purpose of discretization is to perform the analysis on each small division separately.

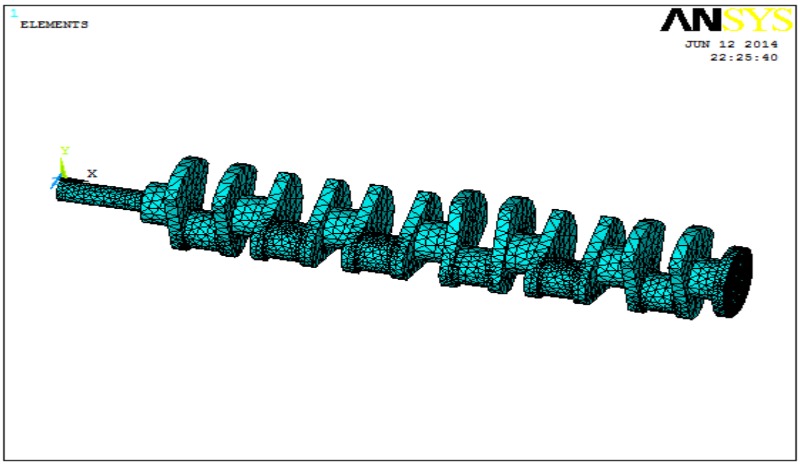

Figure 2: Meshed model of crankshaft

VI. Loading And Boundary Conditions

Crankshaft is a constraint with a ball bearing from one side and with a journal on the other side. The ball bearing is press fit to the crankshaft and does not allow the crankshaft to have any motion other than rotation about its main axis. Since only 180 degrees of the bearing surfaces facing the load direction constraint the motion of the crankshaft.

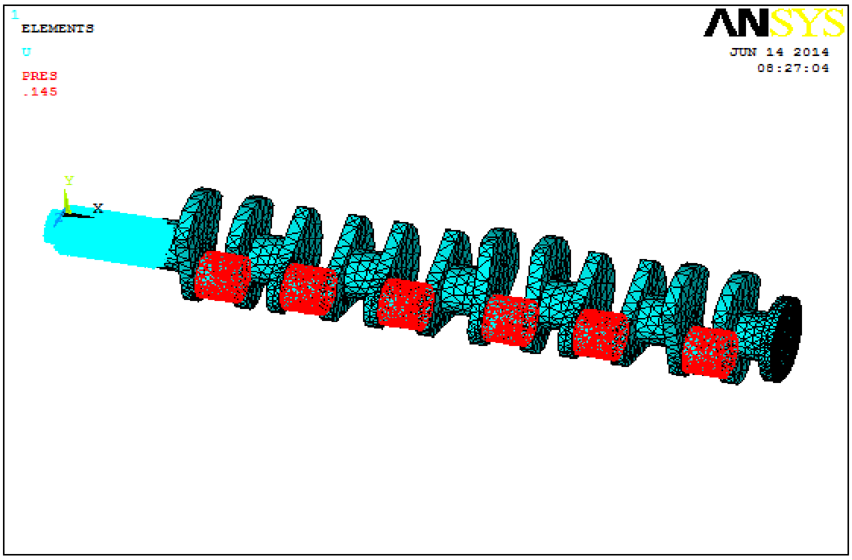

Figure 3: Load applied on crankshaft

This constraint is defined as a fixed semi-circular surface as wide as ball bearing width. The other side of the crankshaft is journal bearing. Therefore this side was modeled as a semi-circular edge facing the load at the bottom of the fillet radius fixed in a plane perpendicular to the central axis and free to move along central axis direction.

VII. Static Structural Analysis For Crankshaft Design 1-Original

After the application of boundary conditions and force, the next step is to perform the structural analysis of crankshaft. In this structural analysis, we are mainly concern with the total deformation and the stresses acting on the crankshaft (von-mises stresses). When the force is applied, the slight deformation and also the stresses take place in the crankshaft. The total deformation of crankshaft is shown in Figure.4. The deformation in the crankshaft is not same throughout. The portion in red colour shows that the deformation at that region is maximum and the portion in blue colour shows that the deformation is minimum in that region. The maximum displacement is 12.77 mm.

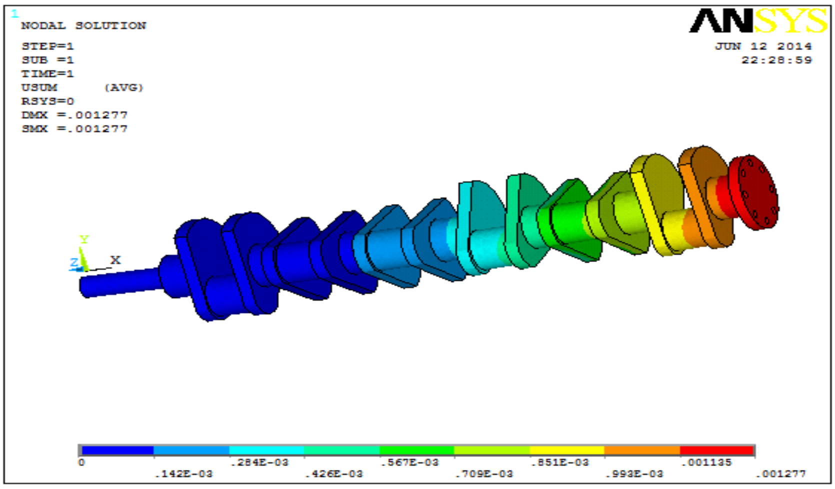

Figure: 4: Deformation of crankshaft

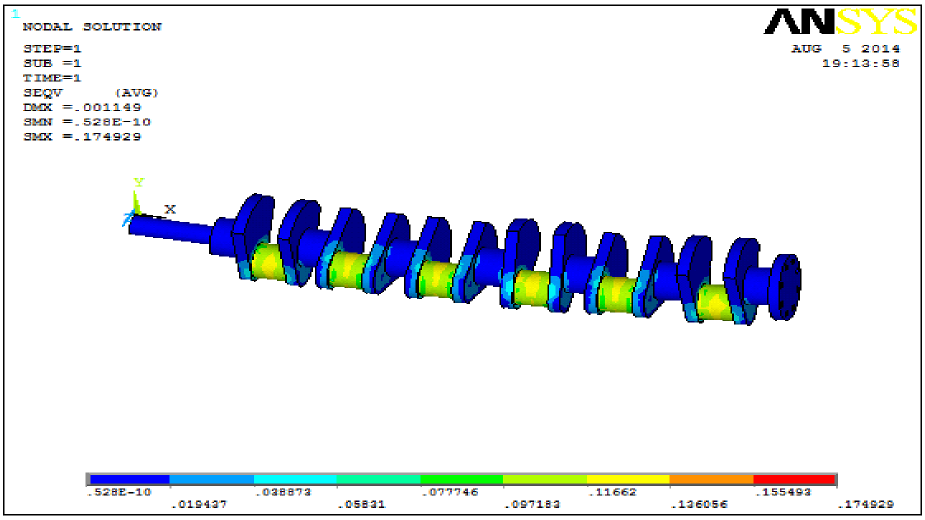

Figure5: Von Misses stress for Cast Iron 174.92MPa

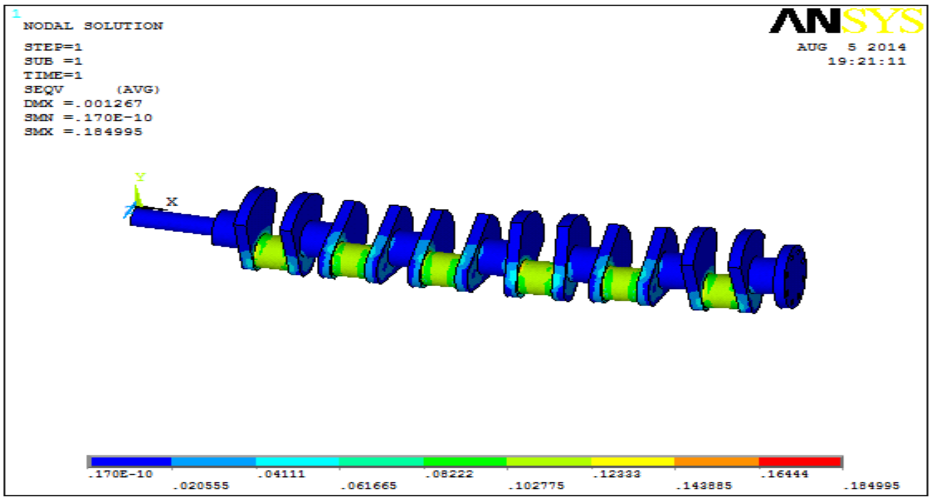

Figure6: Von Misses stress for Forged steel 184.99 MPa

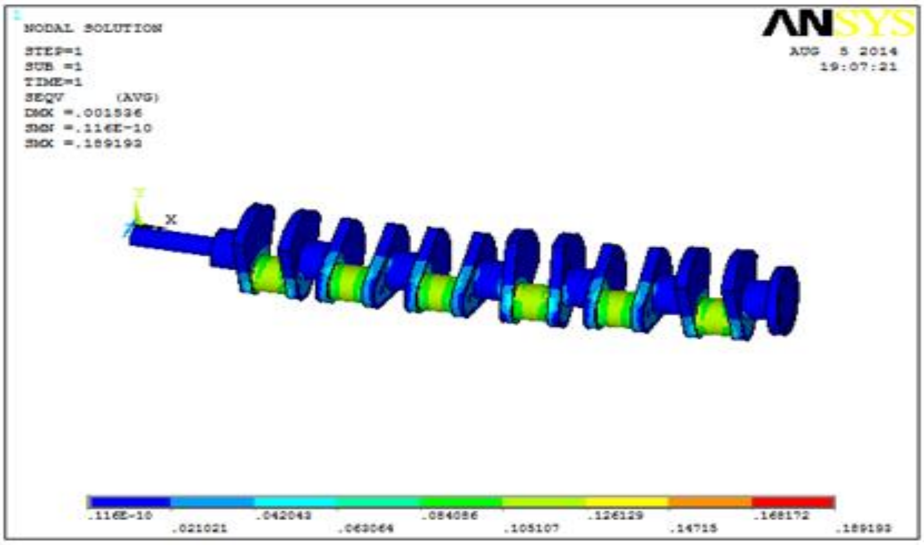

Figure: 7: Von Misses Stress for High Carbon Steel 189.19 MPa

The stress acting on the Design1Original crankshaft is shown in Figure.5, 6, and 7

VIII. Geometry Optimization

In order to achieve the objectives various changes in the initial design of the crankshaft were done and they were analysed among them two cases showed the most effective results. Design 1-Original is 4180032.9702 mm3 and the weight of the Design 1-Original is 33.23kg.In Design 2 Volume of the modified design after modification is 4051869.7021 mm3and the weight of the modified Design 2-Modified is 32.21kg. After designing, the load and boundary conditions were assigned to the new model. After applying the loading and boundary conditions, equivalent stress, equivalent strain, and total deformation diagrams are obtained. And then the various stress, strain and deformation of the different designs are then compared, analysed and the best results give the final optimized design.

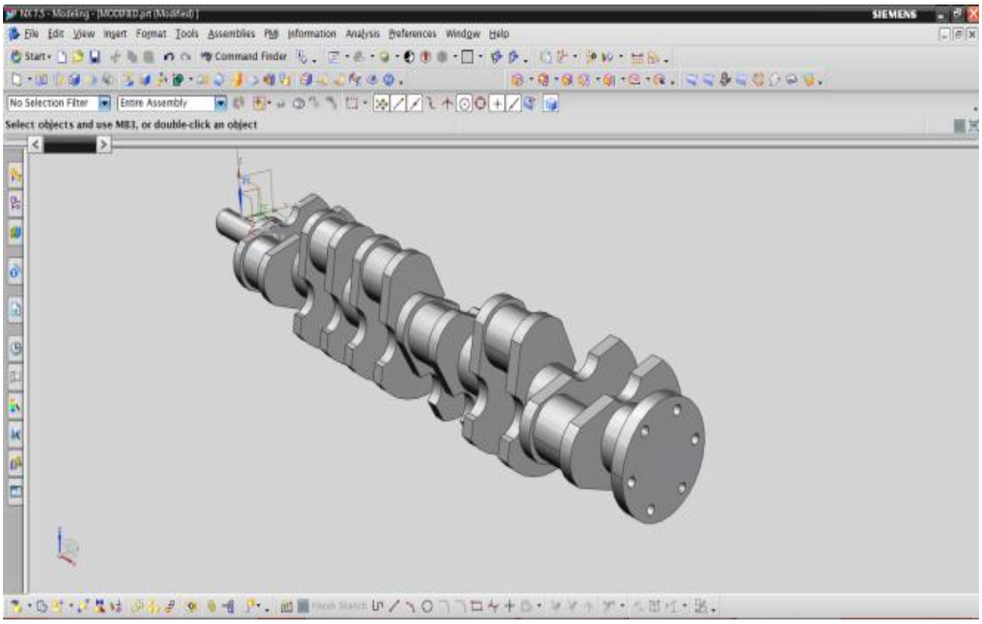

Figure 8: Modified 3-D model of Crankshaft using Unigraphics Design 2-Modified

IX. Static Structural Analysis For Crankshaft Design 2-Modified

The total deformation for a modified crankshaft is shown in Figure.9. The deformation in the crankshaft is not same throughout. The portion in red colour shows that the deformation at that region is maximum and the portion in blue colour shows that the deformation is minimum in that region. The maximum displacement is 11.57 mm.

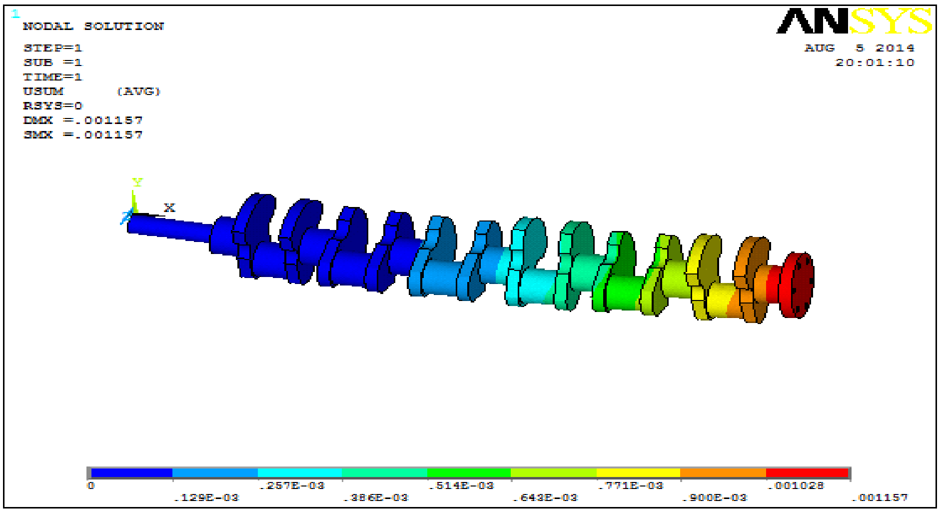

Figure: 9: Deformation of crankshaft

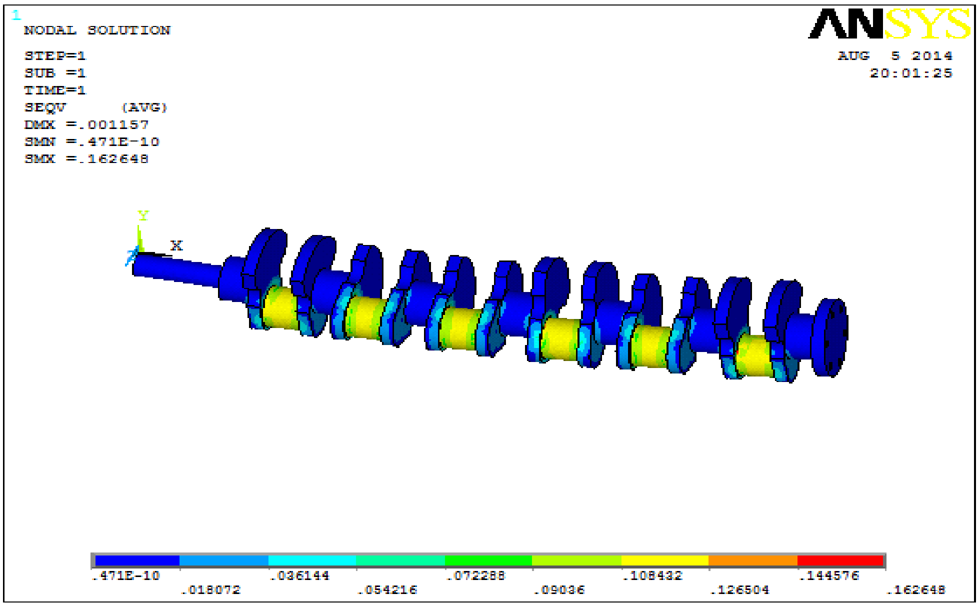

Figure10: Von Misses stress for Cast Iron 162.64MPa

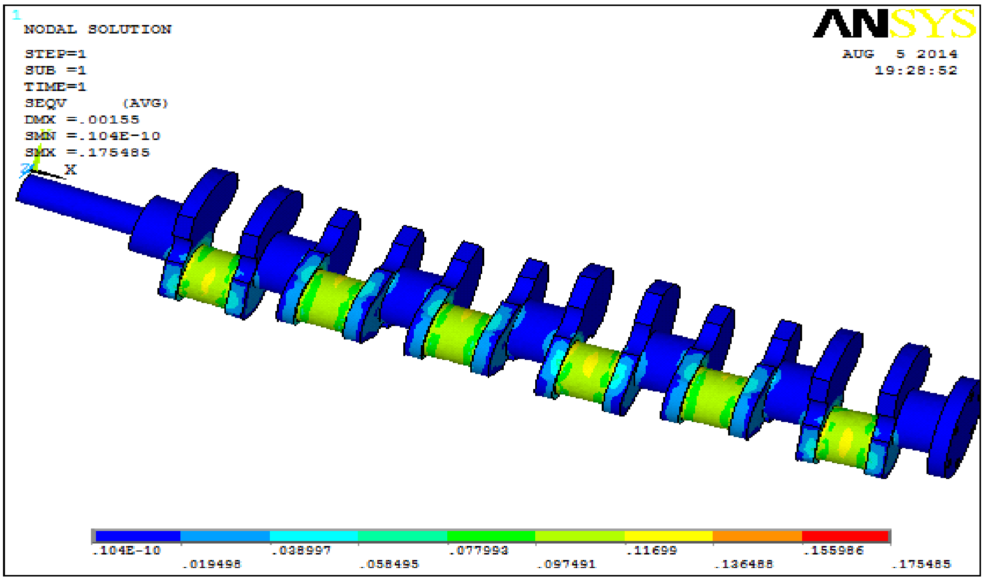

Figure: 12: Von Misses Stress for High Carbon Steel 175.48MPa

The stress acting on the Design 2-Modified crankshaft is shown in Figure.10, 11, 12

X. Comparison Of Results

After applying loading and boundary conditions results from ansys were obtained and compiled in table

Model	Design 1-Original		Design 2-Modified	
Material	**Von-Misses Stress (σ)MPa**	**Weight (kg)**	**Von-Misses Stress (σ)MPa**	**Weight (kg)**
Cast Iron	**174.92**	**33.23**	**162.64**	**32.21**
High Carbon Steel	**189.19**	**33.43**	**175.48**	**32.41**
Forged Steel	**184.99**	**35.168**	**171.64**	**34.04**

Table 2: Results obtained from ANSYS

XI. Conclusion

Finite Element analysis of the six cylinder crankshaft has been done using FEA tool ANSYS. From the results obtained from FE analysis, many discussions have been made.

1. Results show the improvement in the strength of the crankshaft as the maximum limits of stresses. The value of von-misses stresses that comes out from the analysis is far less than material yield stress so our design is safe.
2. The weight of the crankshaft is also reduced by 1133g (5% of weight Reduction) from Design 1-Original to Design 1-Modified. Thereby, reduces the inertia force.
3. As the weight of the crankshaft is decreased this will decrease the cost of the crankshaft and increase the engine performance
4. Above Results shows that FEA results conformal matches with the theoretical calculation so we can say that FEA is a good tool to reduce the time consuming theoretical work.
5.

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