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OPTIMAL SINGLE CYLINDER ENGINE CRANKSHAFT SUBJECTED TO DYNAMIC LOADING

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ABSTRACT

Single cylinder crankshaft is basic for other internal combustion engine crankshaft since it has one crankpin, two crank web and journals at both ends. The large size crankshaft needs more energy than that of small size. So, optimization takes place by varying geometry of selected parameters. The main objective of this study was to investigate possibility of weight and cost reductions of a typical crankshaft without scarifying the desired performances under dynamic loading condition. For a successful completion of this research, the dynamic load analysis of a crankshaft rotating in internal combustion engine was evaluated. Using this loads as input for finite element method (FEM) determine the stress distribution by ANSYS software and compare with analytical result. On the other hand the percentage weight of crankshaft reduced in this research work is 4.16%.

Key words: Crankshaft, Finite Element Analysis (FEA), Optimization.

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1. INTRODUCTION

The assembly of a piston, cylinder, connecting-rod and crankshaft is the classic form of the slider-crank mechanism. In general a slider crank transmits motion generated by the linear displacement of the piston by a working fluid to rotational motion of a shaft. There are many applications of slider cranks and among the most common are engines. The use of these mechanisms for power generation began with the steam engine in the late 18th century and has developed into possibly its most recognizable form as the current day internal combustion engine.

One of the things that made the original Pratt & Whitney "Wasp" so successful in 1926 when it first passed its type test was the ability to make its power at a higher RPM and a lighter weight than its competitors. Key to this accomplishment was the use of a one-piece master rod and two-piece crankshaft. Though two piece crankshafts had been built before, George Mead and Andy Willgoos chose a new construction consisting of a split crankpin splined to its mating crankpin, the whole assembly being held together with a bolt through the center of the crankpin.

George E. Meloy was heavily involved in R-2800 crankshaft development almost from the start. One of his first jobs at Pratt & Whitney was to write a report on the history of R-2800 development, which included many details on the successes and failures of the crankshaft. Meloy was later responsible for sorting out problems with the "C" engine crankshaft and getting it into successful production in the Kansas City, Missouri plant.

A detailed procedure of obtaining stresses in the fillet area of a crankshaft was introduced by Henry et al. [1], in which FEM and BEM (Boundary Element Method) were used. Obtained stresses were verified by experimental results on a 1.9 liter turbocharged diesel engine with Ricardo type combustion chamber configuration. The crankshaft durability assessment tool used in this study was developed by RENAULT. The software used took into account torsional vibrations and internal centrifugal loads. Fatigue life predictions were made using the multiaxial Dang Van criterion. The procedure developed is such it that could be used for conceptual design and geometry optimization of crankshaft.

A review of Crankshaft Lightweight Design and Evaluation based on Simulation Technology is presented by Sheng Su, et al [2]. In order to reduce fuel consumption and emission and improve efficiency, it is essential to take lightweight design into consideration in concept design phase and layout design phase. Crankshaft is one of the most important components in gasoline engine, and it is related to durability, torsional vibration, bearing design and friction loss, therefore lightweight crankshaft must meet the needs to see to it that the final design is satisfactory

An analysis of the stress distribution inside a crankshaft crank was studied by Borges et al [3]. The stress analysis was done to evaluate the overall structural efficiency of the crank, concerned with the homogeneity and magnitude of stresses as well as the amount and localization of stress concentration points. Due to memory limitations in the computers available, the crank model had to be simplified by mostly restricting it according to symmetry planes. In order to evaluate results from the finite element analysis a 3D photo elasticity test was conducted.

Zoroufi and Fatemi [4] in this research a comprehensive comparison of manufacturing processes with respect to mechanical properties, manufacturing aspects, and finished cost for crankshafts was studied. Finally they proposes the major crankshaft material competitors currently used in industry are forged steel, and cast iron. So Comparison of the performance of these materials with respect to static, cyclic, and impact loading are of great interest to the automotive industry.

Nallicheri et al [5].also performed on material alternatives for the automotive crankshaft based on manufacturing economics. They considered steel forging, nodular cast iron, micro-alloy forging, and au-tempered ductile iron casting as manufacturing options to evaluate the cost effectiveness of using these alternatives for crankshafts.

Steve Smith [6]. Other person provided a simple method to understand how well a crankshaft can cope with power delivery by monitoring crankcase deflection during powered dyno runs. The data made available supports engineering decisions to improve the crankshaft design and balance conditions; this reduces main bearing loads, which lead to reduced friction and fatigue, releasing power, performance and reliability. As the power and speed of engines increase, crankshaft stiffness is critical and Utilize crankcase deflection analysis to improve crankshaft design and engine performance.

Terry M. Shaw et al [7]. Studies an analytical tool for the efficient analysis of crankshaft design. Finite element models are generated from a limited number of key dimensions which describe a family of crankshafts. These models have been verified by stress and deflection measurements on several crankshaft throws.

Farzin H. Montazersadgh et al. [8] investigated first dynamic load analysis of the crankshaft. Results from the FE model are then presented which includes identification of the critically stressed location, variation of stresses over an entire cycle, and a discussion of the effects of engine speed as well as torsion load on stresses.

Shenoy and Fatemi [9] 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.

Humberto Aguayo Téllez et al. [10] is described for determining the design unbalance of crankshafts and also the recommended procedure for a balanced design strategy on Computer aided innovation of crankshafts using Genetic Algorithms. The use of a search tool for solutions is suggested based on Genetic Algorithms (GA). GAs have been used in different applications, one of them is the optimization of geometric shapes, a relatively recent area with high research potential. The interest towards this field is growing, and it is anticipated that in the future mechanical engineering will be an area where many applications of shape optimization will be widely applied. In addition systematic cost estimation of crankshafts is provided in the work of Nallicheri et al [4]. Dividing the cost of crankshafts into variable and fixed cost, they evaluate and compare the production cost of crankshafts made of nodular cast iron, austempered ductile iron, forged steel, and micro alloyed forged steel. The common variable cost elements are named as the costs of material, direct labor, and energy. The common elements of fixed cost are named as the costs of main machine, auxiliary equipment, tooling, building, overhead labor, and maintenance.

2. METHODS AND CONDITIONS

2.1. Material

Generally, crankshafts materials should be readily shaped, machined and heat-treated, and have adequate strength, toughness, hardness, and high fatigue strength. The crankshaft used in this study is AISI1045 forged steel mostly used in agricultural machines that have single cylinder diesel engine.

Table 2.1 Material property of Crankshaft

Material Type	AISI1045steel	Unit
Density	7.85	g/cm^3
Young's modulus	221	GPa
Poisson's ratio	0.3	-
Yield stress	370	MPa
tensile strength	235	MPa

Table 2.2 Dimension of single cylinder engine crankshaft

S. No	Parameters	Symbol	Values(mm)
1	Diameter of the Crank Pin	d_c	39
2	Length of the Crank Pin	l_c	32
3	Crankpin oil hole diameter	c_{oh}	18
4	Diameter of the shaft/journal	d_s	35
5	Web Thickness (Both Left and Right Hand)	w_t	20.5
6	Web Width (Both Left and Right Hand)	w_w	65
7	Length of the Crank shaft	L	341
8	Crankpin fillet radius	R_h	3

Table 2.3 Parameters used in crankshaft geometry optimization

S. No.	Parameters	crankshaft
1	Crankpin inner hole diameter	18mm Original
2	Crank web thickness	20.5mm
3	Drilled hole diameter and Length	4mm dia. and 34mm

3. CRANKSHAFT MODEL

The model of crankshaft is created by solidwork2014 software. The dimension used to draw a model was taken from engine specification chart. The figure 3.1 below shows the original single cylinder crankshaft model before modification.

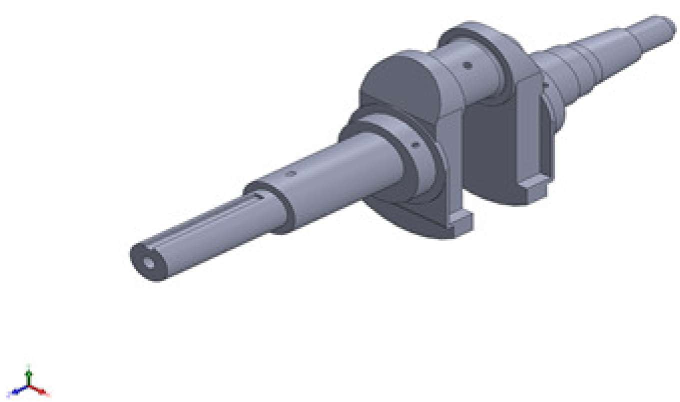

Fig 3.1 Model of Single Cylinder Crankshaft Drawn by Solidwork

3.1. Finite Element Analysis of Single Cylinder Crankshaft

For complex geometry of a given part it is difficult to analyze the finite element analysis manually. Hence, for this research work ANSYS Workbench was used. The CAD model of a single cylinder crankshaft created by solidwork and was imported to ANSYS Workbench to start the simulation step by step.

3.2. Meshed model of crankshaft

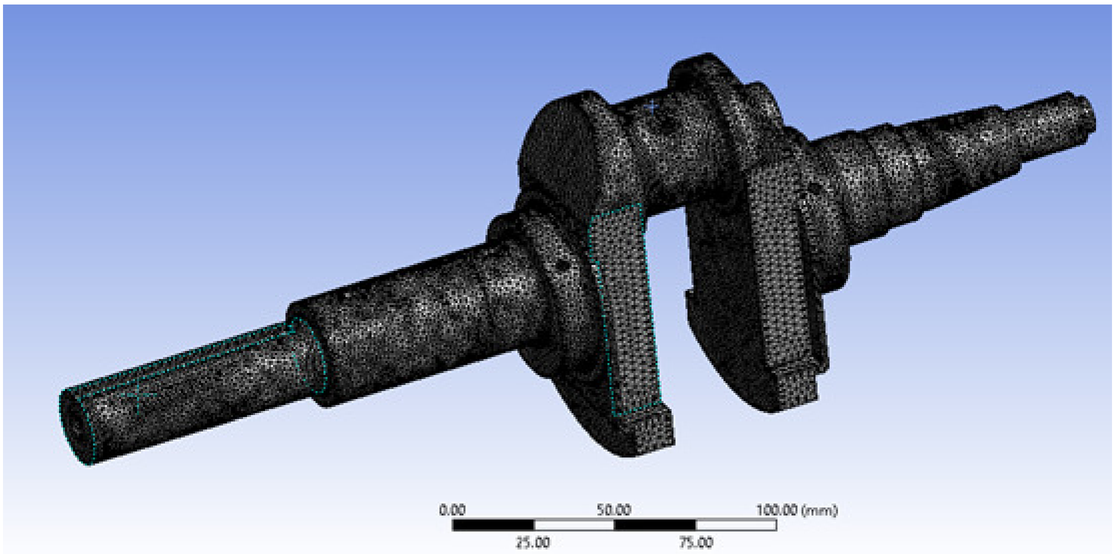

Fig 3.2 Meshed model of Crankshaft

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 to allow a localized element size (Elements). As number of element increases (or element size decreases) the stress values predicted by FEM approach to exact value.

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. In this research, static structure analysis is used. The type of element used is tetrahedron and no of elements are 75196 when element size is 1.2mm.

3.3. Loading and Boundary Conditions

Boundary Conditions

Crankshaft is a constrained with a ball bearing from one side and with a journal bearing on the other side. The ball bearing is press fitted 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, this constraint is defined as a fixed semicircular surface equal to ball bearing's width. The other side of the crankshaft is constrained with a journal bearing. Therefore, this side was modeled as a semicircular 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. The distribution of load over the connecting rod bearing is uniform pressure on 120 degree of contact area. Since the crankshaft is in interaction with the connecting rod, the same loading distribution will be transmitted to the crankshaft.

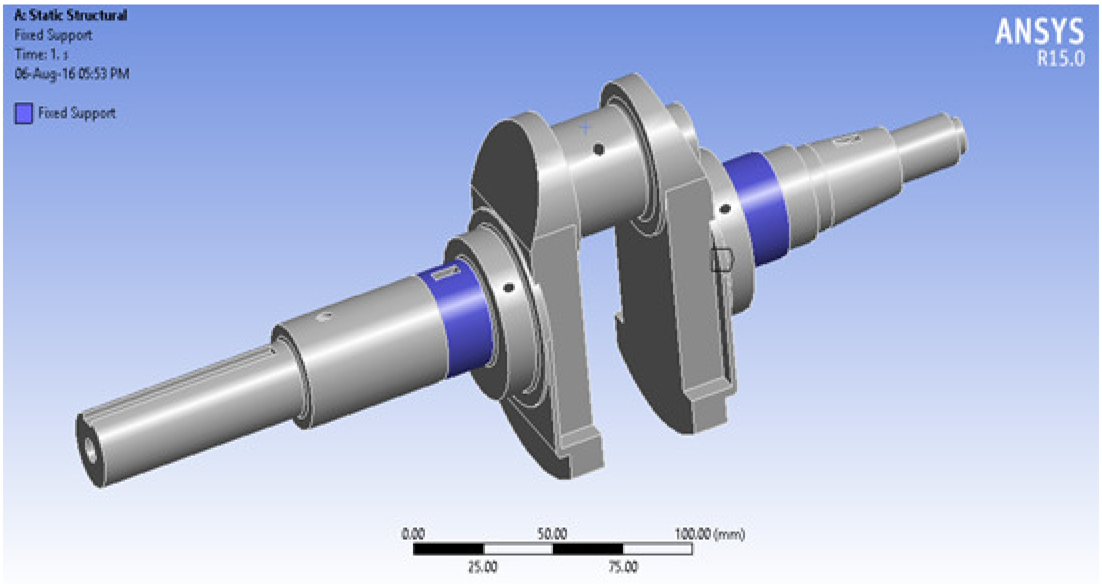

Fig 3.3 Boundary conditions of Crankshaft

In both sides crankshaft is supported at equidistance on its journals. On the other hand, crankshaft is fixed in the engine at both ends to control vibration and alignment.

Loading

In combustion chamber maximum load is applied to crankshaft when a piston is at top dead center. It must be strong enough to take the downward force during power stroke without excessive bending. So the reliability and life of internal combustion engine depend on the strength of the crankshaft largely. In ANSYS the load is applied perpendicular to the surface of crankpin to represent a piston load at top dead center.

In this study a pressure of 2.5 MPa is applied on the crankpin at top dead center position of the piston. From the figure below red color arrow on crankpin is assumed to be maximum load acting on the crankshaft at top dead center.

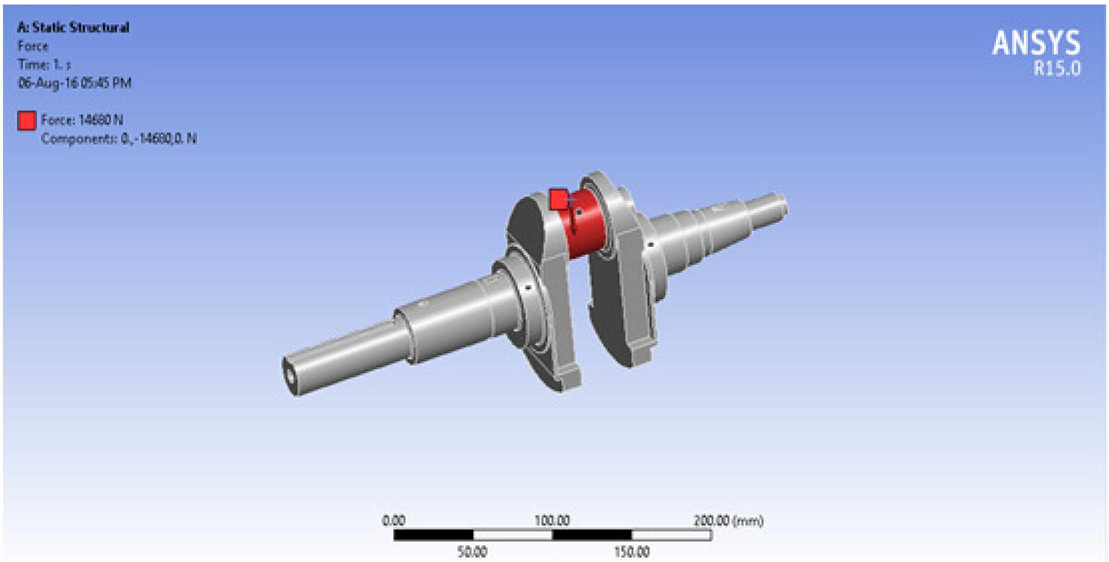

Fig 3.4 Load applied on Crankpin of Shaft

On crankpin a 14680N force, which crankshaft through connecting rod, is used as an input to perform the analysis.

3.4. Stress Analysis at Variable Crankweb Thickness

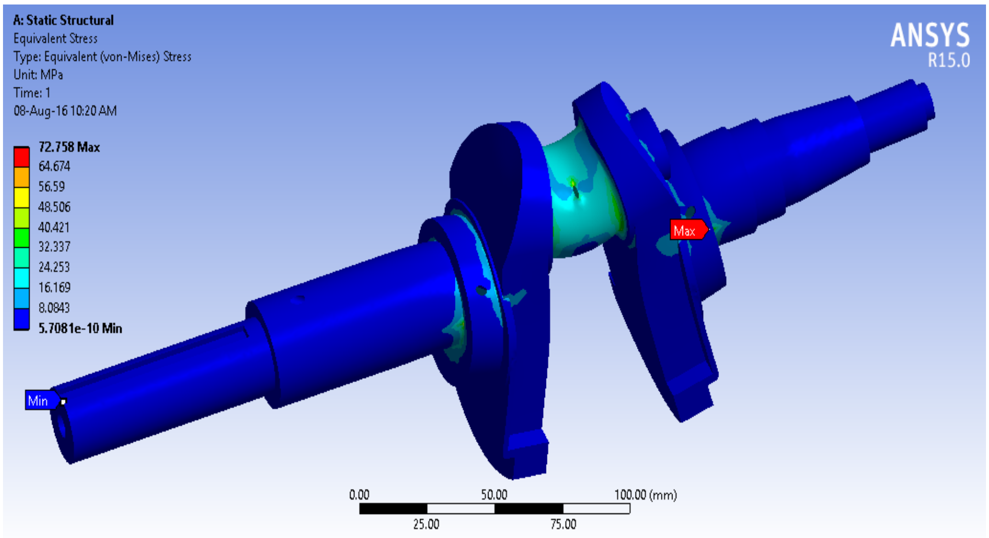

Fig 3.5 Von-mises stress at cranweb thickness 20.5mm

As shown in the figure 3.5 red color indicates maximum bending stress of 72.158MPa and the blue color indicates the minimum bending stress.

4. RESULT AND DISCUSSION

In this present work, the single cylinder engine crankshaft model was created by Solid work software. Then, the model created by solid work was imported to ANSYS software for analysis.

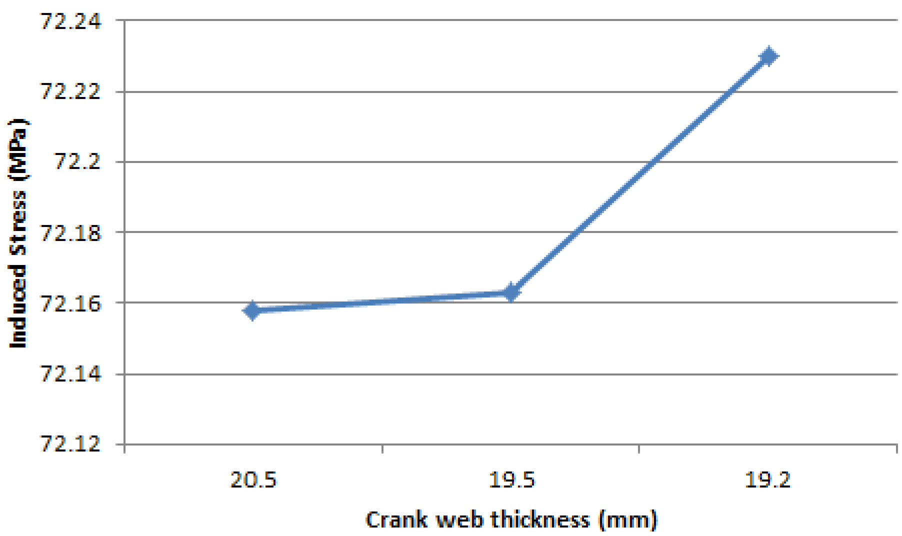

Fig 4.1 Induced stress with crank web thickness

Fig 4.1 shows ANSYS result of bending stress of variable crankweb thickness. As crankweb thickness reduces bending stress increases because of reduction in thickness. ANSYS simulation induced that the stress is 72.23Mpa which is less than allowable stress. So, since the induced stress become less than allowable stress, the design is safe. As a result of geometry changes on the crankweb the weight of crankshaft is reduced to 3.5842Kg.

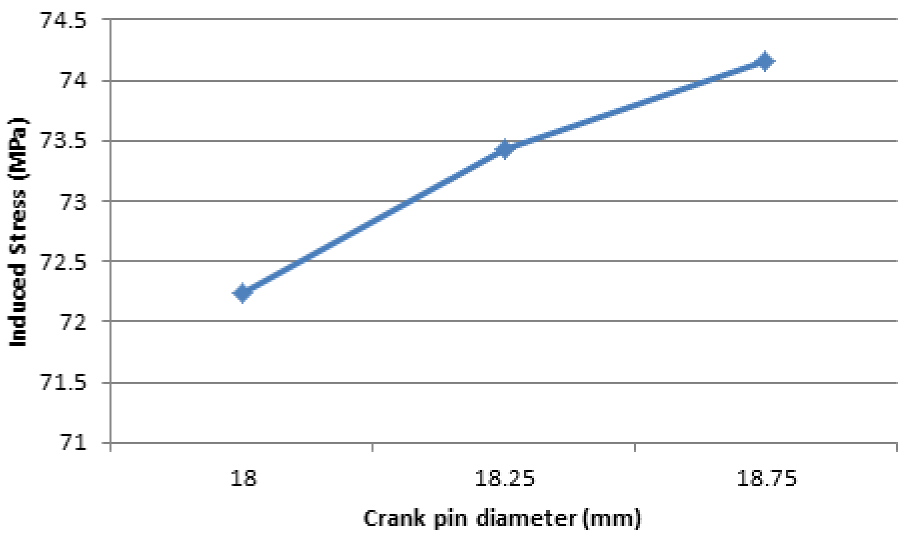

Fig 4.2 Induced stress with Crank pin diameter

Fig 4.2 shows the calculated and ANSYS results of shear stresses of variable inner diameter of crankpin. As the inner diameter of crankpin increases shear stress also increases because of reduction in thickness. For ANSYS the induced stress is 40.97MPa which is less than allowable shear stress 51.9 Mpa, and design is safe.

5. CONCLUSION AND FUTURE WORK

Conclusion

In this paper, the crankshaft model was created by Solid works 2014 software. Then, the model created by Solid works was imported to ANSYS WORKBENCH simulation software. This project focused on the stress analysis and weight optimization of single cylinder engine crankshaft subjected to dynamic loading. Crankshaft material is AISI 1045 Steel which was selected to utilize for flexibility of the forging process and the cost benefits of using steel. The geometry changes on desired parameters can reduce the total weight of crankshaft. The weight reductions achieved by individual component, i.e., crankweb, journal and crankpin are 3.64%, 0.22% and 0.3% respectively. Overall weight of the crankshaft was reduced by this research is 4.15%. The stress on all iteration increases, but it doesn't exceeded allowable stress of material. On the other hand, results show that the deformation of optimized crankshaft is less than original one because of the reduction in inertia. According to the outputs of the ANSYS simulations and analytical calculation, the goals defined by the optimization are realizable, without affecting the performance of whole assembly.

Future Work

By considering the aspects presented in this study other optimization can also be done in the same area. The considerations for future work are as follows,

- Optimization can be done by changing other parameters such as right side journal and web.
- The value of Von-Misses stresses that indicated from the analysis is less than the material yield stress so our design is safe and we should go for optimization to save the material and cost.
- Crankshaft has to be dynamically balanced, optimization process fulfill removing or adding material in the crank web and at the right side of journal.

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