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Deformation and stress analysis of crankshafts for single cylinder and four cylinder ic engine using ansys

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Abstract

The crankshaft is one of the most important loaded components in the engine, as it is experiencing cyclic loads in the form of a bending and torsion. In the study, crankshaft of the single-cylinder engine and crankshaft of the four-cylinder engine were designed in the SOLID WORKS software. Then these designs were transferred to ANSYS software with finite element method. Both crankshafts were compared in terms of stress and deformation. Critical areas had been identified as a result of stress and deformation. Comparative analysis of both shafts was not found in the literature. As a result, the values of stress and deformation increased as the speed increases in both shafts. Stress and deformation increased as the pressure increases associated with the speed applied on the crankpin journal. The stress in the crankshaft of the single cylinder engine was critically occurring on main journal, and the stress in the crankshaft of the four-cylinder engine was critically occurring on the crankpin journal. This much of the stress in the single cylinder engine crankshaft reduces the working life of the shaft. The shaft material should be selected considering the working conditions in crankshaft, or the material should be improved by coating the main journal and crankpin journal.

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1. Introduction

The crankshaft is a large component with a complex geometry in the engine that converts the displacement of the piston into a rotating movement with the coupling mechanism. The fatigue performance and durability of this component must be taken into account in the design process as the crankshaft operates at multiple loads over its operating life. A low-cost crankshaft is required with functional requirements such as minimum weight and suitable fatigue strength, higher fatigue life, stress, deformation, natural frequency [1,2]. Better fuel efficiency, higher power, lighter and smaller engines are achieved with such a crankshaft [2]. In addition, the crankshaft must be strong enough to receive downward force without excessive bending in the power stroke. Therefore, the reliability and lifetime of the internal combustion engine depends largely on the performance of the crankshaft [3].

The crankshaft consists of shaft parts rotating in the main bearings, crankpin and crank rings [4]. An overview of the crankshaft is given in Figure 1. During operation, power pulses cause the crankshaft to strike from one place to another. Torsional vibration occurs when a power stroke strikes the crank journal toward the front of the engine and the impact ends. If not checked, the crankshaft may break [5].

The strength of the crankshaft is a key factor in ensuring engine life. In the past studies, the beam and hollow frame model is used to calculate the stress of the crankshaft. The number of nodes is limited in mentioned models. Finite element method (FEM) has been used to calculate more crankshaft design and crankshaft stress with the development of the computer. Finite element analysis allows easy and inexpensive analysis of input parameters, including design parameters and process conditions to be investigated [6]. The design and analysis of the crankshaft effectively utilized process development, avoiding cost, time and limitations in practice. To date, many studies have been done on crankshaft modeling. In one study, the crankshaft designed in CATIA program is transferred to ANSYS software and static analysis is performed. The crankshaft of the single cylinder engine is used. It is emphasized that the stress range in the FE analysis should not exceed the magnitude of the stress range in the original crankshaft [7]. In another study, the stress analysis and modal analysis of a 4-cylinder crankshaft are discussed using the finite element method. The 480 diesel engine crankshaft and crankpin are designed using Pro /

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ENGINEER software. The vibration mode, distortion and stress state of the crankpin are analyzed with ANSYS. Maximum deformation, maximum stress point and hazardous areas are determined by stress analysis of the crankpin. The results provided a valuable theoretical basis for optimizing and improving crankshaft design [8]. In the study of Thriveni and Jayachandraiah, Von-misses stress and shear stress values are compared with the help of ANSYS and theoretical study of the crankshaft of single cylinder engine. The values obtained by both methods were found to be close to each other. This has enabled the ANSYS program [9]. Stress and dynamic analysis of the single cylinder engine shaft is performed by ABAQUS program at two different loads. As a result of the analysis, the crankshaft is optimized [10]. The crankshaft of the four cylinder diesel engine is designed in CATIA V5 R15 program and this shaft analyzed in ANSYS software. Stress analysis, deformation, maximum stress areas and dangerous areas of crankshaft for different materials are determined in this study. The crankshaft is modified to reduce stress [11]. The crankshaft of a single cylinder diesel engine is designed using SOLID WORKS software and then transferred to ANSYS software. Von-mises stress, maximum shear stress and deformation analysis are performed. It is emphasized that the analysis is close to the values obtained from the theoretical model [12]. To date, the crankshaft has been evaluated for stress and deformation using many ANSYS programs. Crankshafts in different materials have identified critical regions in the analysis [13-18].

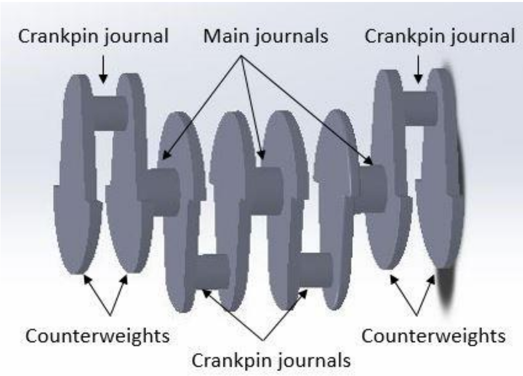


Figure 1. Main parts of a crank shaft.

In general, many studies have been made on the crankshaft in the literature. Most of the analyzes are related to stress and deformation. As a result of the analysis, critical areas are determined in the shaft and some studies have been optimized. In this present study, crankshafts of single and four cylinder engines were compared in terms of stress and deformation. Comparative analysis of both shafts had not been found in the literature. Here, both shafts were designed in SOLID WORKS software and then transferred to ANSYS software. In the analysis, the critical regions of both shafts were determined as a result of stress and deformation.

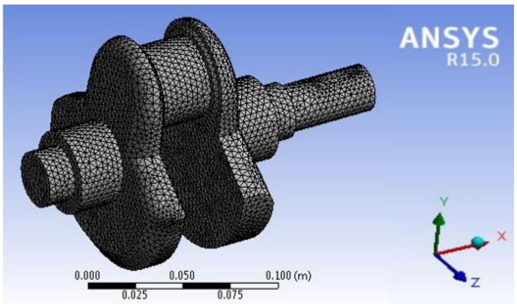
2. Numerical Modelling of The Crankshaft

Crankshafts of single piston and four piston engines were analyzed numerically. Crankshafts were modelled by using SOLIDWORKS software, and static analysis was done by using ANSYS Workbench software in attempt to evaluate the von-misses stress and nodal deformations. Mesh properties of the shafts were presented in Table 1, and their mesh geometries as well as boundary conditions were illustrated in Figure 2 and Figure 3.

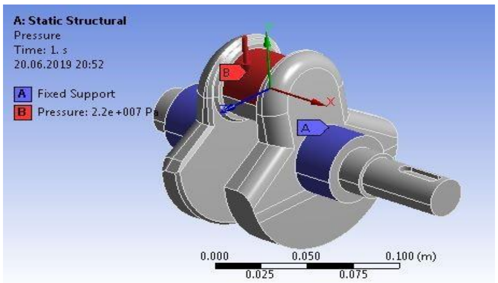
In Figure 3, the analysis of the crankshaft of the four-cylinder engine was performed in two phases, since two of the crankpin journals were in one direction and the other two were in another direction. These were called as Case 1 and Case 2.

Table 1. Mesh properties of shafts

Terms	Single- piston shaft	Four- piston shaft
Element type	Tetrahedrons	Tetrahedrons
Number of nodes	145779	26184
Number of elements	100147	13608



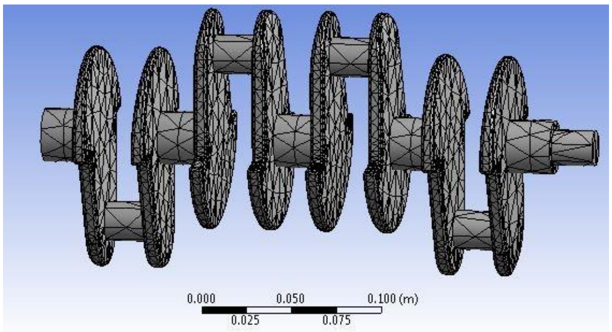
a)



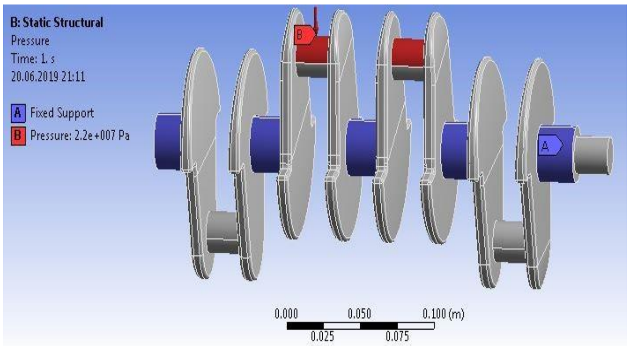
b)

Figure 2. 1-piston crank shaft. (a) Mesh geometry, (b) boundary conditions

In the modeling made for the shafts, different pressures were applied to the journal at different engine speeds. The operating conditions were given in Table 2. The pressures to the main journal and crankpin at different speeds under the in-cylinder maximum pressure of 10.1 MPa were numerically calculated in the Table 2. The load applied to the crankshaft, Factor of Safety (FOS) for the different parts of the crankshaft and the specific pressures in the main journal and crankpin were calculated by using the procedure given in the reference [19, 20]. The reason for choosing engine speeds of 2000, 2300, 2360 and 2750 rpm, pressures on the main journal and crankpin at these speeds in the literature were used in this study. The pressures on the journals were calculated by Finite Element Analysis (FEA) method.



a)



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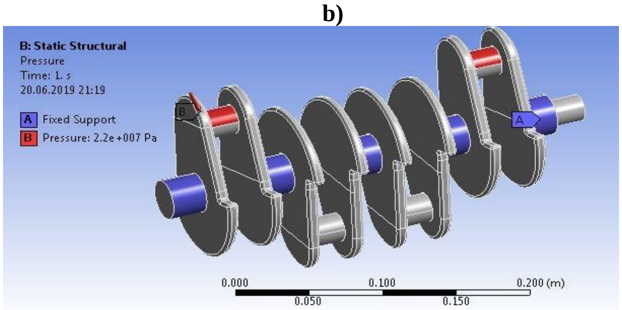


c)

Figure 3. 4-piston crank shaft. (a) mesh geometry, (b) boundary conditions for case 1, (c) boundary conditions for case 2

Cast iron was generally used as crankshaft material due to its durability and lifetime. Cast iron was used as shaft material in both models. The operating conditions of the analysis were given in Table 3. The operating temperature of the shaft was generally in the range of 80-110^{0}C [21]. The operating temperature of both models was taken to 90^{0}C.

Table 2. Average pressure to the main journal and crankpin at different engine speed [20].

Engine speed (rpm)	Specific Pressure (MPa)	
	Main journal	Crankpin
	Average	Average
2000	11.7	10.8
2300	13.5	13.5
2360	15.7	14.1
2750	22	18.5

Table 3. Cast iron properties [22].

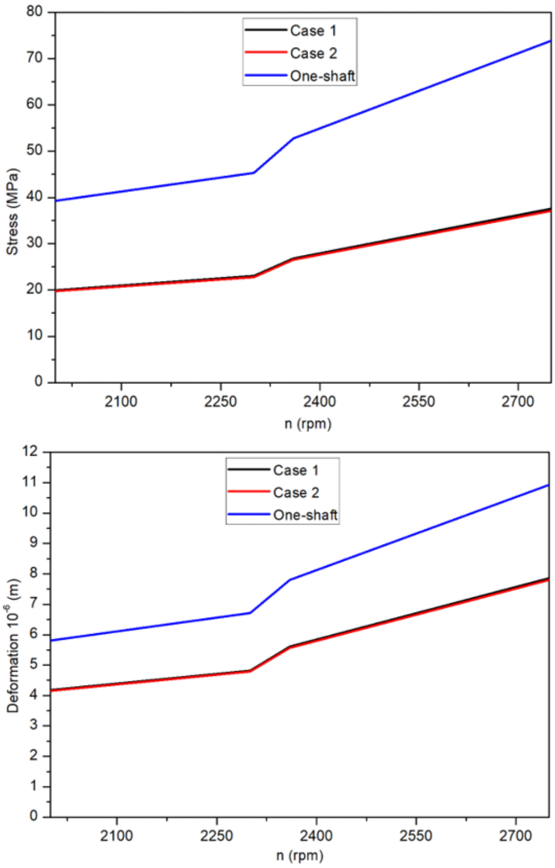
Stuructural	
Young's Modulus	1.78e+005 MPa
Poisson's Ratio	0.3
Density	7.197e-006 kg/mm^3

3. Results

In the study, crankshaft of the single-cylinder engine and crankshaft of the four-cylinder engine were designed in the SOLID WORKS software. Afterwards, shafts were transferred to the ANSYS software. The main journals were kept constant and pressure was applied to the crankpin journal at different speeds. The most widely used cast iron in the market was selected as the crankshaft material. As mentioned previously, the comparative stress and deformation analysis of the crankshaft of the single cylinder engine and the crankshaft of the four cylinder engine had not been found in the literature. The stress analysis of the crankshaft of the single cylinder engine and the crankshaft of the four cylinder engine were compared in Figure 4. As mentioned earlier, the analysis of the crankshaft of the four-cylinder engine was performed in two phases, since two of the crankpin journals were in one direction and the other two were in another direction. These were called as Case 1 and Case 2.

The stress of the single-cylinder engine crankshaft was greater than that of the four-cylinder engine's crankshaft (Figure 4). The stress occurred on the main journal in the One-shaft, and the stress was formed on the crankpin journal in the Case 1 and Case 2. This much of the stress in the single cylinder engine crankshaft reduces the working life of the component. Therefore, the thermal conductivity coefficient of this one-shaft material should be chosen higher than the four-cylinder engine's crankshaft. In addition, the physical, mechanical and thermal properties of the material should be better in this shaft (One-shaft). On the other hand, the stress and deformation results of Case 1 and Case 2 were almost the same as expected. The results of stress and deformation analysis of shafts were given in Table 4 and Table 5 at different speeds.

The deformations were maximized in the crankpin journal of both shafts (Table 4 and Table 5). The forces that come on the crankpin journal cause the shaft to deform at different loads and speeds. Because of deformation, the crankpin journal undergoes deformations by various external forces.
The crankpin journal is one of the most important parts of the shaft. Material selection should be made considering the working conditions. It should be produced by coating on the crankpin journal or with a material that is better than the physical properties of the shaft. The same pressure had been applied to the crankpin journal of both shafts. In Figure 4 shows that the single cylinder engine crankshaft was more deformed. Shaft material must be selected according to critical value and operating conditions in stress and deformation. The crankshaft of the single cylinder engine was seen to have more stress and deformation compared to the crankshaft of the four-cylinder engine.

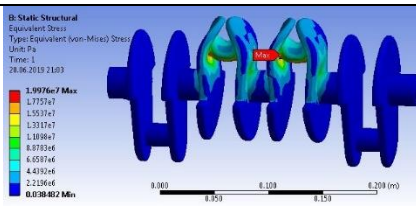
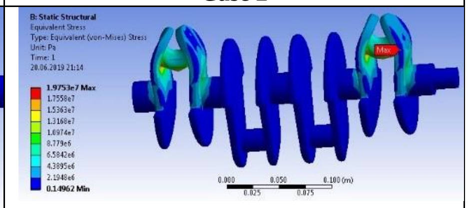
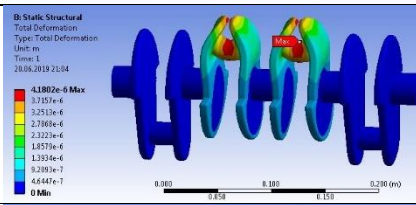
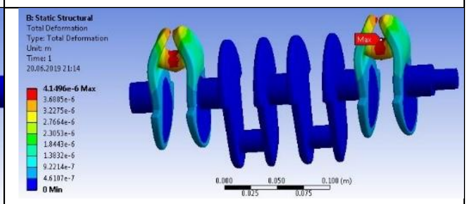
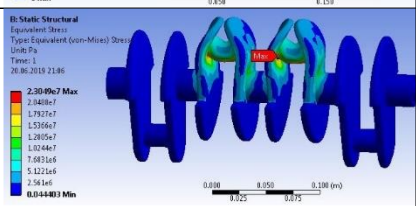
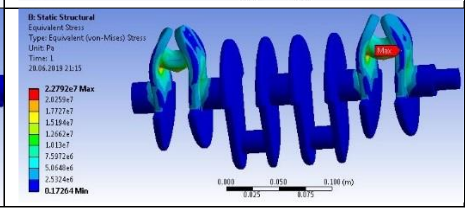


a)

b)

Figure 4. Comparison of stress (a) and deformation (b) of both shafts.

Table 4. Stress and deformation analysis of the crankshaft of a four-cylinder engine.

Terms	n (rpm)	Crankshaft of four cylinder engine	
		Case 1	Case 2
Stress	2000		
Deformation	2000		
Stress	2300		

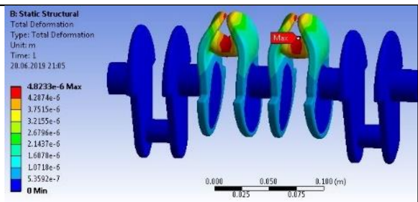
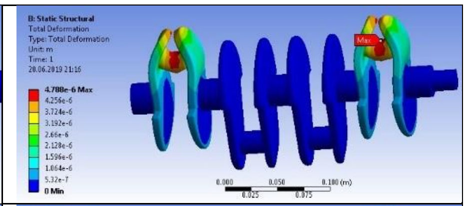
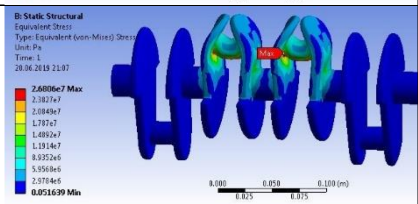
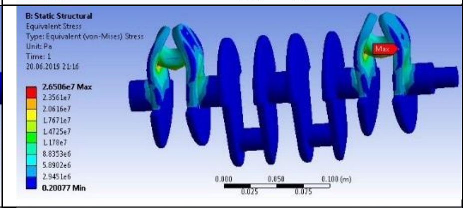
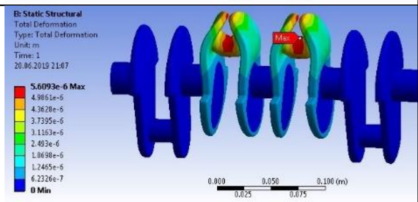
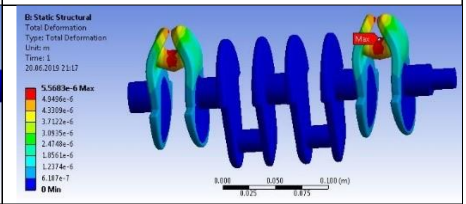
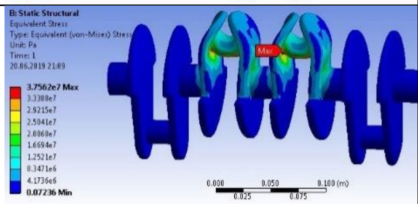
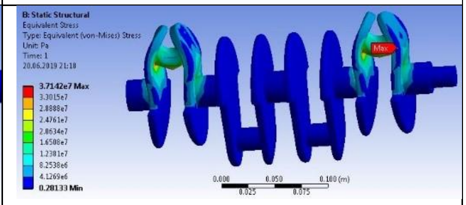
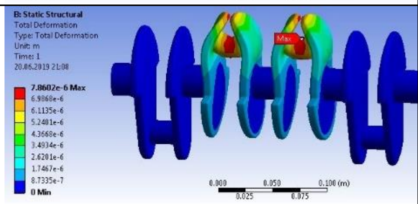
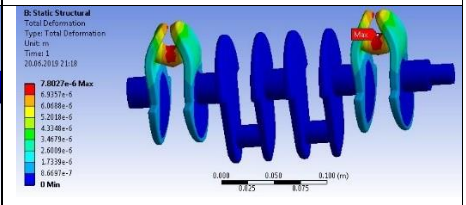
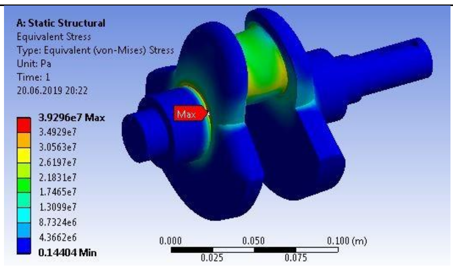
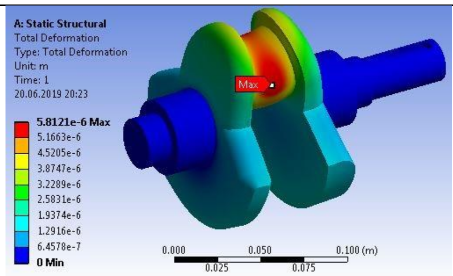
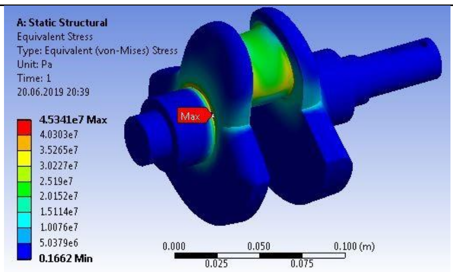
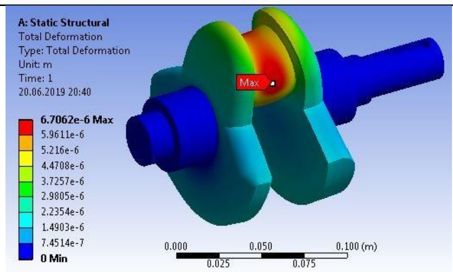
Deformation	2300		
Stress	2360		
Deformation	2360		
Stress	2750		
Deformation	2750		

Table 5. Stress and deformation analysis of the crankshaft of a single-cylinder engine.

	Crankshaft of single cylinder engine	
n (rpm)	**Stress**	**Deformation**
2000		
2300		

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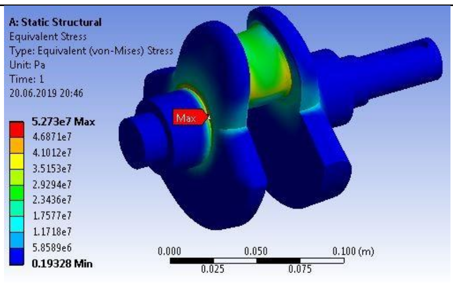
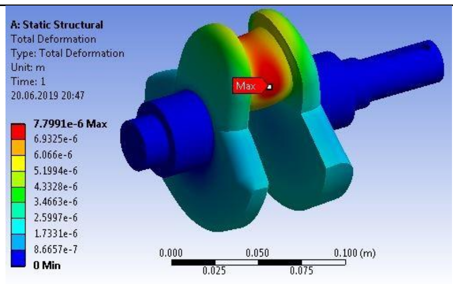
<tr><td>2360</td><td>
</td><td>
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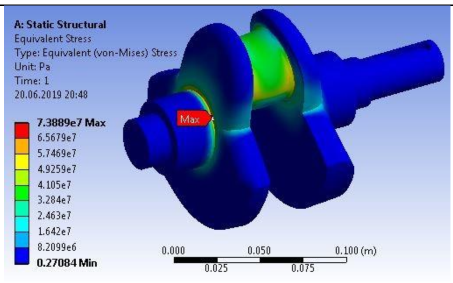
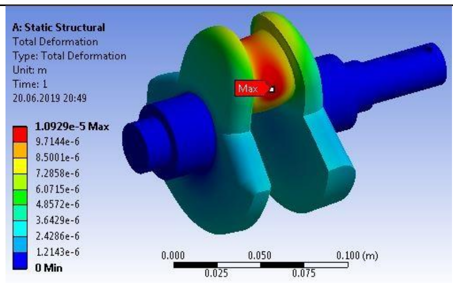
<tr><td>2750</td><td>
</td><td>
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4. Conclusion

In the study, crankshaft of the single-cylinder engine and crankshaft of the four-cylinder engine were designed in the SOLID WORKS software. Afterwards, shafts were transferred to the ANSYS software. In ANSYS program, pressure was applied to the crankpin journal in different spindle speeds. The stress and deformation of both shafts were compared in the analysis. In this regard, a study does not take place in the literature. As a result, the values of stress and deformation increased as the speed increases in both shafts. Stress and deformation increased as the pressure increases associated with the speed applied on the crankpin journal. Stress is critically formed in the main journal in the crankshaft of the single cylinder engine. In the crankshaft of the four-cylinder engine, the stress was formed in the critical area crankpin journal. The stress of the single-cylinder engine crankshaft is greater than that of the four-cylinder engine crankshaft. This much of the stress in the single cylinder engine crankshaft reduces the working life of the component. The crankshaft of the single cylinder engine had been deformed more than the other crankshaft. Therefore, the thermal conductivity coefficient of the shaft material should be selected higher. In addition, the physical, mechanical and thermal properties of the material should be better in this shaft.

5. Nomenclature

CA : Crank Angle

FEA : Finite Element Analysis

FEM : Finite element method

n : Shaft speed

TDC : Top Dead Center

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