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Failure Analysis of a Diesel Engine Crankshaft based on Finite Element Modeling

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Abstract: The crankshaft is one of the essential components of an internal combustion engine that converts the piston's linear motion into the crank's rotary motion. This research has been carried out to study the failure analysis of diesel engine crankshafts, and forged steel material is selected. A crankshaft's geometry is relatively complex compared to other parts; its working conditions are critical, and the stress concentration areas are very complicated. While considering all these phenomena, it is significant that a crankshaft's fatigue strength, stiffness, durability, and wear resistance should be checked and analyzed properly. Firstly, a 3D model of the crankshaft is designed using SolidWorks 2022 software. After that, the Model is imported to ANSYS software 2022 R2 student version. However, using ANSYS (finite element method) is carried out on the crankshaft's Model. This research aims to obtain the variation in stress magnitude at critical locations of the crankshaft by applying variable loads and boundary conditions. Simulation techniques were conducted for both static and dynamic analysis. The total deformation observed at the critical area of the crank pin is 1.3488e-8. The corresponding equivalent stress is 318.37, and the crankshaft's safety factor is 15.

Keywords: Failure analysis; Crankshaft; ANSYS; Finite element method

1. Introduction

The engine's crankshaft is one of the core parts that withstand all the force exerted by the piston and then convert it into torque; it also transmits the pressure acting on the top of the piston to the output power [1]. In a diesel engine, the crankshaft is the primary link between the piston and the crankshaft

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[2]. It turns the piston's linear motion into the crankshaft's rotating motion. It conveys the pressure acting on the piston's top to the crankshaft, resulting in output power [3]. The driving source of the crankshaft is the combination of continuous changes in the gas pressure and the rotating and reciprocating masses alongside their bending and torsional moments [4]. During work, the crankshaft experiences torsional and bending deformation, so the conditions of employment are highly demanding [5]. The likelihood of bending fatigue and torsion failure, particularly in the transition area of the fillet connection between the crank and the journal, is relatively significant, which leads to irreversible crankshaft fracture [6]. If the crankshaft isn't designed correctly, stress concentration or insufficient local strength or rigidity can readily occur during use, leading to crankshaft failure [7]. Another research work reported that the major cause of engine failure is the dysfunctionality of the crankshaft [8].

So as so, the operating conditions of the crankshaft are quite complex as it is constantly subjected to variable loading conditions. However, due to changes in gas pressure, the inertial force of reciprocating and rotating masses, and their torsional and bending moments [9]. Recently, several types of research have been carried out to improve the Model and design of the crankshaft [10]. It has been observed that under dynamic loading conditions, the crankshaft is subjected to multi-axial load referred to as the bending moment and torsional moment [11]. Fatigue failure occurs typically due to this cyclic loading and thus causes the crankshaft to fail as a sudden catastrophic failure [12]. This type of failure occurs mainly in the critical areas of the crankshaft, where the stress concentration is higher [13]. The complex locations of crankshafts are usually oil holes, keyways, and other irregulars shaped areas like Sharpe corners and interior cracks due to manufacturing defects [14]. However, there is a mechanical concept or fatigue observed that a material can fail due to the application of repetitive loading. Each time crankshafts rotate, the loads reverse, causing a slight shaft flexing. However, in this research work, the shaft flexing and premature failure are analyzed using FEM.

2. Problem Statement

The crankshaft is the core element, determines the overall efficiency and performance of the engine. Due to its complex geometry and critical working conditions, premature failures tend to occur, so it is important to check the ability of a crankshaft to withstand the loads before putting it under working conditions.

3. Methodology

The methods for design and techniques used for analysis are one by mentioned are used to conduct this research:

3.1 3D Model of the crankshaft

SolidWorks version of 2022 is employed to design a 3D model of the diesel engine crankshaft. Firstly, forged steel was selected as the working material, and then all the dimensional parameters were given to create the geometry of the crankshaft. The 3D Model of the crankshaft created in SolidWorks is shown in Fig. 1. SolidWorks is solid modeling software that utilizes the parameters such as length, size, shape, and geometry to analyze the complete structure [15].

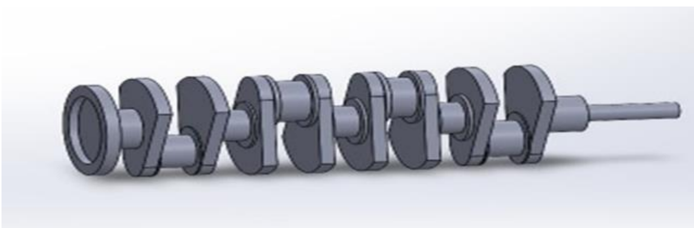

Fig. 1 - 3D model of the crankshaft

3.2 Finite Element Analysis (FEA)

The finite element method is a numerical technique that calculates the approximate solution to problems involving complex geometry using computational analysis [16]. Using this method, all the problems' complications, like irregular variations of shapes, boundary conditions, and loads, are kept as they are, and approximate solutions are obtained [14]. The finite element procedure eliminates or reduces these unknown values to a finite number by dividing the regions of the geometry into small parts called elements [17]. Initially, the Model was developed using SolidWorks and then imported to ANSYS, where suitable material was assigned that functioned practically like an actual crankshaft [18]. Forged steel is selected as the material for this research work due to its remarkable mechanical properties. It is made of carbon and iron alloy forged under high pressure and possesses high ductility and fatigue strength [19].

Table.1 Material's properties

Sr. no	Material Properties	Specifications
1	Material	Micro alloy steel
2	Manufacturing process	Forging
3	Young's modulus	$2.00*10^5$ MPa
4	Poisson's ratio	0.3
5	Density	7830 kg/m^3
6	Ultimate tensile strength	1100 MPa
7	Yield strength	650 MPa

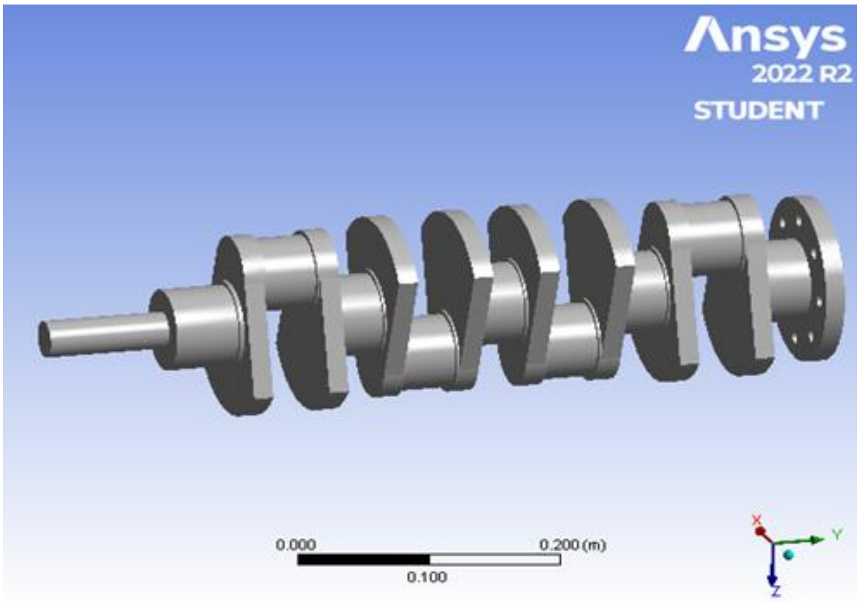

Fig. 2 - Pictorial view of forged steel crankshaft in ANSYS

3.3 Loading and Boundary Condition

The material properties values are taken from Table 1, and then some boundary conditions have been assigned to the crankshaft. This study applied only one loading condition to the crankshaft: bending load. The magnitude of this load depends on the size, shape, geometry, and radius of the crankshaft.

3.4 The meshing of the crankshaft

After applying boundary conditions, the meshing of the crankshaft is done on ANSYS, as shown in Figure 3. Five mesh were used in this study, which resulted in the relationship between stress and strain being plotted.

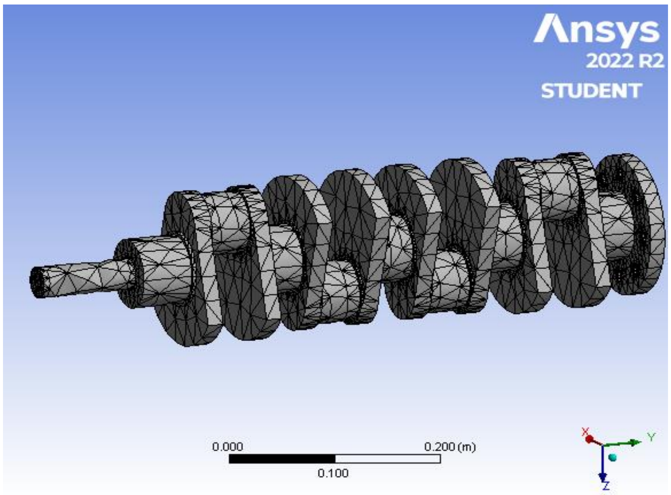

Fig. 3 - Meshing of the crankshaft

4. Results and Discussion

The final stage of the analysis is referred to as result visualization and is also called post-processing. At this point distribution of loads and stress are determined, and the deformed geometry is examined. From the analysis, the generated results state that the fillet area is the most critical location with the maximum high-stress concentration. The location where maximum deformation occurs is the main focus of our research. The numerical results are shown as:

4.1 Transient Structural Result

The transient analysis of a structure is also referred to as dynamic analysis, and it is used for calculating forces and loads applied to any structure. It evaluated the behavior of the structure under the application of time-dependent loads [20]. However, the results of the maximum and minimum values of stress, total deformation, and factor of safety are given in Table 2.

Table.2 Transient structure result

Sr. No	Term	Maximum	Minimum
1	Total deformation	0.0021132	0
2	Equivalent stress	7.312e7Mpa	14304Mpa
3	Shear stress	40801e7Mpa	8166.1Mpa
4	Alternating stress	1.4077e6Mpa	873.58Mpa

4.1 Static Structural Results

Static structural results are referred to as the analysis done on any structure in equilibrium condition while the structure ignores all the damping force and effect of inertia. Table.3 shows the results obtained when the crankshaft is in equilibrium condition. The total deformation on the crankpin's critical area is 1.3488e-8. The corresponding equivalent stress is 318.37, whereas the safety factor for the crankshaft is given as 15.

Table.3 Static structural result

Sr. No	**Term**	**Maximum**	**Minimum**
1	Total deformation	1.3488e-8	0
2	Equivalent stress	318.37Mpa	1.2892Mpa
3	Factor of safety	15	0

4.3 Equivalent stresses (von-misses)

Figure 4 indicates that the maximum equivalent stresses are acting on the crankpin. Therefore, these stresses represent a material's status for its ductile nature. The max stress is 7.312e7 MPa, as given below in Fig. 4.

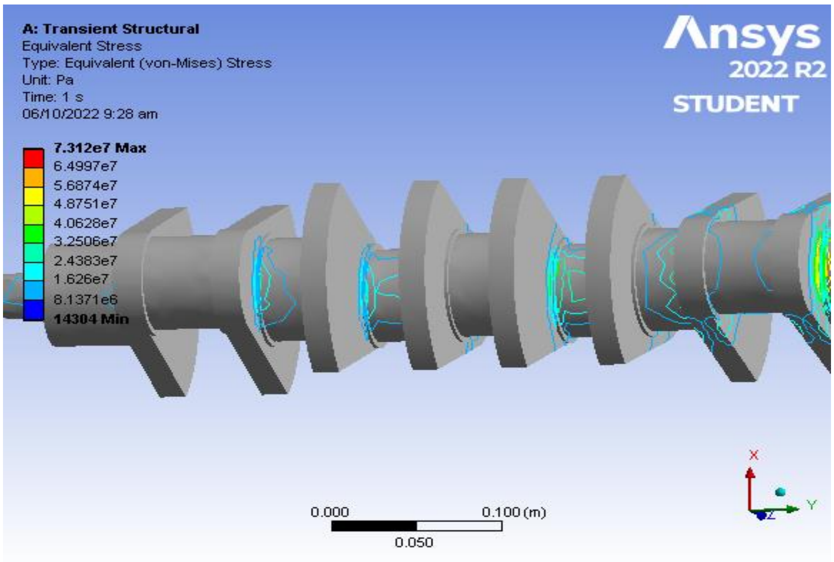

Fig. 4 - Equivalent stresses on the crankshaft

4.4 Total Deformation

The total deformation of any model explains the number of forces acting on the different point of location and their maximum effect in all three coordinates (X, Y, and Z). The cracks propagate at the fillet area due to the application of bending load, which eventually causes the crankshaft to fail. The maximum deformation is calculated as 0.0021132, and the minimum deformation is 0, as given in Fig. 5.

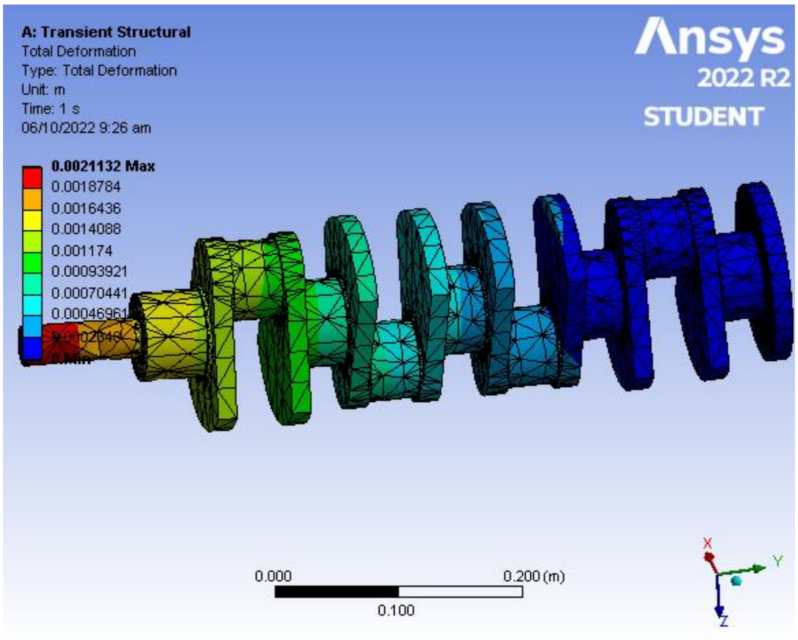

Fig. 5 - Total deformation

4.5 Factors of Safety

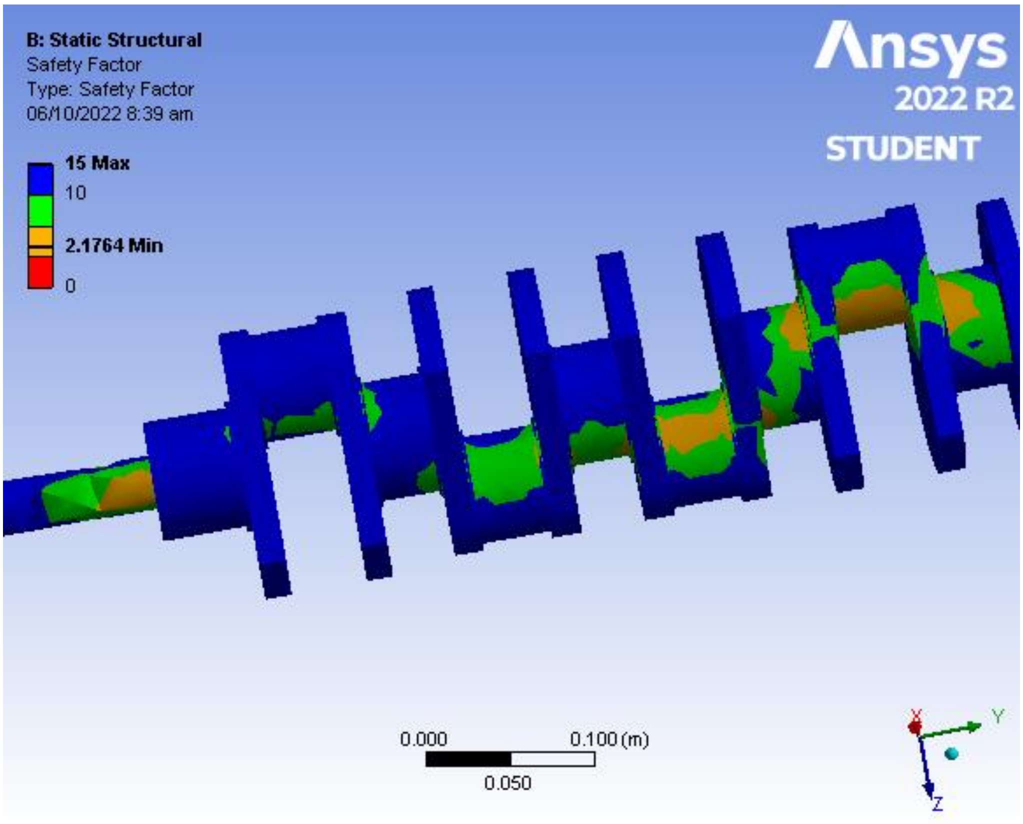

Fig. 6 - Factors of safety

The factor of safety is the extent to which the system or structure carries the load [21]. The maximum value of the safety factor calculated for this crankshaft is 15.

4.6 Stress-Strain Graph

The stress-strain curve is a graphical representation of the behavior of any structure, system, or Model under the application of operating loads. Fig. 7 shows the amount of stress acting on this crankshaft model in working conditions and the corresponding strain produced by this stress.

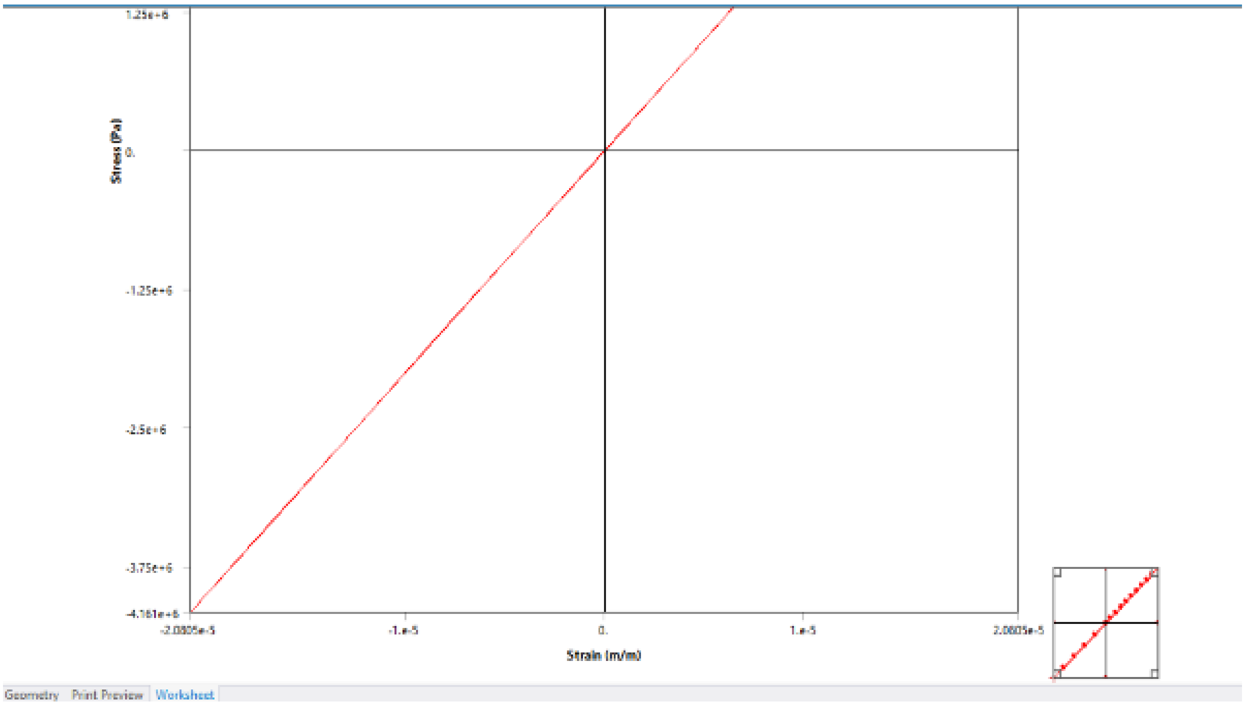

Fig. 7 - Stress-strain curve

5. Conclusion and Future Recommendations

In this research, we analyzed the location of the stresses developed in the critical areas of the crankshaft subjected to static and dynamic loading conditions. The static and dynamic simulation was conducted on the crankshaft, and FEM was implemented to obtain the stress magnitude at critical parts of geometry. Boundary conditions are applied by using the stress-strain curve. Furthermore, the results observed from the simulation concluded that the crankshaft design is safe when the equivalent (von-misses) forces are under the limit, but when the limits were exceeded, failure occurred. The deformation of the crankshaft was mainly because of the bending load. The fillets between the crankshaft journal and cranks cheeks are subjected to maximum stress; also, near the central point journal and the edge of the main journal, a high-stress area is located. There is always room for development, no matter how much research has been conducted and how many studies have been done. The same goes for the study of crankshaft analysis. Advanced materials with higher ductility, fatigue strength, and enhanced mechanical properties are required. New fillet hardening processes and advanced high-quality lubrication are essential for the engine's smooth working. Lastly, the size and the weight of the crankshaft is needed to be reduced for effective performance.

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