Finite Element Analysis of a Four-Cylinder Four Stroke Gasoline Engine Crankshaft

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Abstract. Stress analysis of a crankshaft using traditional method is complicated and needs modification by considering its stress concentration factors. To solve this problem, the crankshaft strength of a four-cylinder four stroke gasoline engine is modeled and analyzed using finite element method (FEM) in this paper. For this purpose, the crankshaft is modeled using CATIA software in detail. Then, the model is imported in ANSYS. In the recent software, the model is meshed into a number of finite elements. After defining the boundary and loading conditions, the stresses occur in the crankshaft are analyzed in order to identify critical locations on it.

1 Introduction

Engine crankshaft is an important component of an engine as it converts the reciprocating displacement of the piston to a rotary motion. The crankshaft effectively absorbs forces from the explosion, transmits energy to the engine flywheel, which transfers energy to a shaft connected to the driven machinery [1]. Since the crankshaft experiences a large number of load cycles during its service life, it is important to study and analyze the strength of this component in evaluating their performance and lifetime of the crankshaft.

In the traditional crankshaft stress calculation methods, such as the method of beam supported of both ends and the continuous beam method, the calculation process is complicated and needs to modify the crankshaft stress that calculated by stress concentration factor [2]. Finite element method (FEM) is a numerical calculation method based on variation principle for solving mathematical and physical problems [3]. Besides, it is a powerful tool to analyze various structural problems and provide theoretical basic for the design [4].

The objective of the paper is to model the four-cylinder four stroke gasoline engine crankshaft geometry using CATIA, and then analyze the stresses occur in it under loading conditions using ANSYS. Critical locations will be identified based on the results of finite element analysis given by the ANSYS software.

2 Finite Element Model

In this paper, the model of a four-cylinder four stroke gasoline engine crankshaft was developed using CATIA software. The model includes the parts of crankpin, journal, counterweight, main bearing

journal and flywheel mounting flange as shown in Figure 1. The dimensions of crankshaft parts are shown in Figure 2 and listed in Table 1.

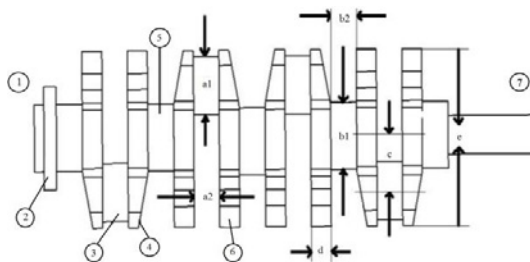**Figure 1.** Four-cylinder four stroke engine crankshaft.

Figure 2. Crankshaft dimension and parts: (1) power-off end, (2) flywheel mounting flange, (3) crankpin, (4) crank web, (5) journal, (6) counterweight and (7) crankshaft free end.

2.1 Engine crankshaft modeling

Several various reasonable simplifications were made in the finite element analysis. Petty details such as fillet, chamfering and so on were given up and only the relative importance features is left, such as done in Ref. [3]. These simplifications were necessary as to avoid the incomplete part when the model imported from CATIA software, see Figure 3, to the ANSYS software for the finite element analysis part as shown in Figure 4. It found that the mistakes frequently occurred for the incomplete part of the crankshaft in the grid analysis used in ANSYS software. Furthermore, the simplification made due to the of lack accurate geometric information for some parts of the crankshaft. Since the needed result from the analysis was the strength of the crankshaft, small errors could be occur by ignoring some chamfers and fillets. The position drawn of the crankshaft is in Top Dead Center (TDC) position.

Table 1. Basic dimension of crankshaft

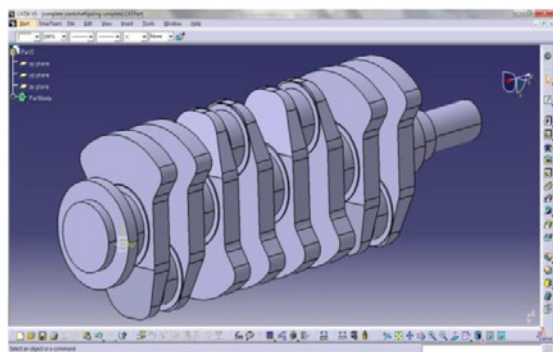|	Crankpin		Journal		c	d	e
	a1	a2	b1	b2			
Basic Dimension	48.0 mm	23.8 mm	55.0 mm	24.2mm	45.0 mm	18.6 mm	145.0 mm

Figure 3. Three-dimensional geometry model using CATIA.
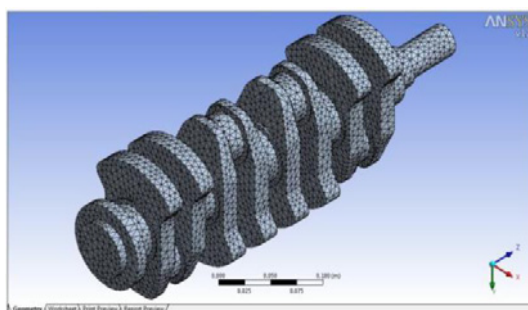

Figure 4. Meshing model in ANSYS.

2.2 Model meshing

Meshing is the procedure of cutting the structure into several elements. Then the connection between elements defined as nodes that hold elements together as if the nodes were pins or drops of glue. This process results in a set of simultaneous algebraic equations [1]. The mesh type selected for the model is tetrahedrons with 77442 elements number and 117685 nodes number as shown in the figure below. Greater the fineness of the model mesh, the better accuracy of the result. In order to analysis the strength of crankshaft, the material attribute of the model must be define. The material of the crankshaft is QT-800 (gray cast iron), where the mass density, Poisson's ratio, Young's modulus and the tensile strength are 7800 kg/m^3, 0.28, 210 GPa and 345 GPa, respectively.

3 Finite Element Analysis

3.1 Load constraints

According to the crankshaft actual working condition, the major force on the crankshaft is generated by interaction between the mixture of fuel and air combustion and the piston. Piston is connected to crankshaft by a connection rod at the crankpin. While the crankshaft is operated at high rotational motion, the bending load acts directly to the crankshaft through connecting road. The crankshaft analyzed in this project is one of the gasoline engine. Generally, it is also known as a spark-ignition (S.I) engine.
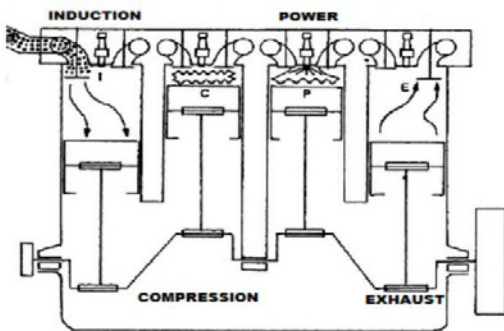

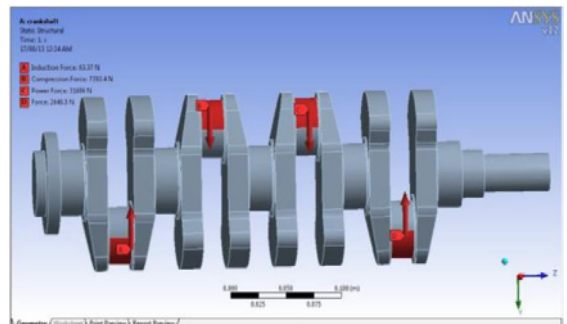**Figure 5.** Piston formation and top dead center (TDC) position.

Figure 6. Forces acting on the crankshaft.

In four stroke spark-ignition engine, four piston strokes required to complete one cycle [5]. The first strokes known as induction stroke where it created mixture of air and fuel as the piston moves away from cylinder head. The second stroke is compression stroke where it compressed the fuel and air mixture towards cylinder head. For the third stroke known as power stroke whose produced the highest force of the engine where the spark plug ignites the fuel and air mixture and pushed the piston downward. While the last stroke known as exhaust strokes works as to remove the exhaust gas of fuel and air combustion to the air. These formations of engine piston made the engine crankshaft at it top dead center (TDC) position which is studied in this paper as shown in Figure 5.

From the operation of the engine piston, it produced four different value pressures acting to the engine crankshaft. The maximum or the highest pressure produced by the power stroke is 60 bar, while induction stroke produced 0.12 bar, the compression stroke produced 14 bar and exhaust stroke produced 5 bar of pressure [4]. The force imposed to crankshaft calculated using mathematical equation of $P = F/A$ with the bore diameter of the engine cylinder is 82 mm. This force is assumed to be acting at the crankpin center point as shown in Figure 6.

3.2 Boundary conditions

The definition of boundary condition has a direct relationship to the type of the meshing model. Therefore, it must be carefully defined in order to be similar to the engine crankshaft actual working condition. Some simplified assumption has to be justified in order to establish the boundary condition in this paper: (1) The torque acting to the crankshaft is ignored. Only bending moment is considered in this analysis. Engine crankshaft mostly affected by the bending moment causing tensile and compressive stresses. (2) The mass force is included in the program itself. As the material defined in the program, it automatically provides the value of the mass based on the crankshaft density. Therefore, mass force boundary condition excluded.
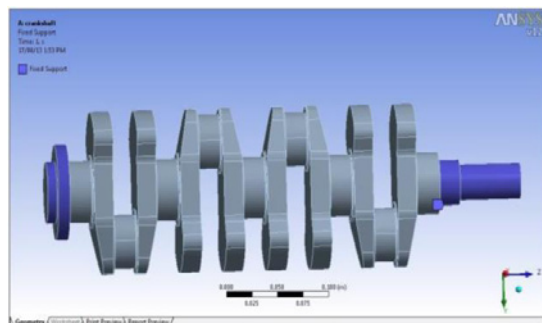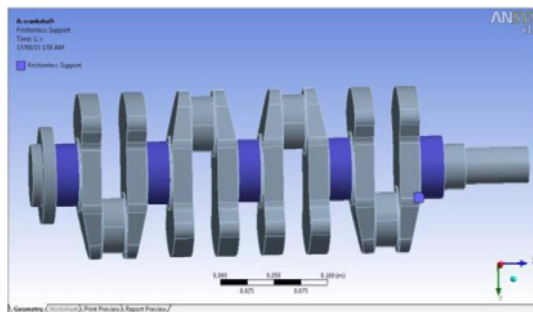
Figure 7. Fixed support on crankshaft.

Figure 8. Frictionless support on crankshaft.

The engine crankshaft is supported at both flywheel mounting flange and crank nose part. Therefore, it restricted the movement in x, y and z direction as shown in Figure 7. Based on Figure 8, the movement of the crankshaft journal is constrained in x and y direction as the bearing restricted the movement.
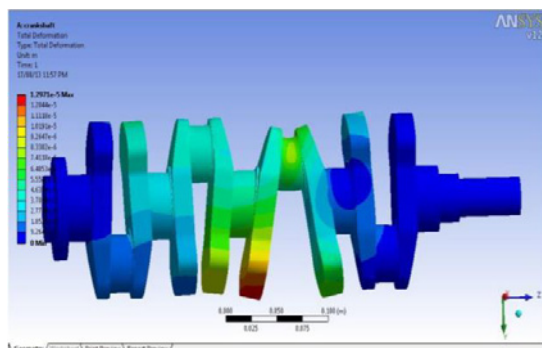
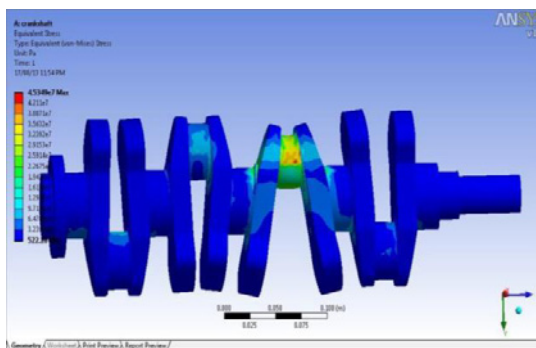**Figure 9.** Crankshaft deformation.

Figure 10. Crankshaft stress distribution.

4 Result and Discussion

After all the requirement data and steps fulfill in the program, the result calculated by the software. From Figure 9 and 10, it shows the deformation of engine crankshaft and stress concentration region resemble to actual working condition. Based from Figure 9, the maximum displacement value is 0.013 mm located at the counterweight part of crankshaft. Besides that, Figure 10 shows that the second crankpin from right became high stress concentration regions which suffered the largest stress and most easily broken. While according to Figure 11 shows the stress maximum point located at the edge of crankpin which value is 45.35 MPa. Furthermore, the shear stress maximum value calculated by the program is 22.17 MPa located opposite to the maximum stress point as shown in Figure 12. From the

value obtained by the software, it can be conclude that the crankpin parts of the engine crankshaft appeared to be the danger zone with high stress.
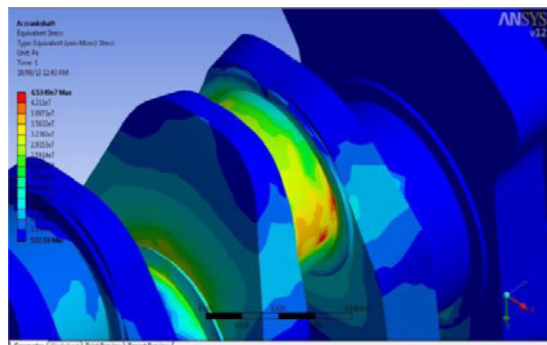

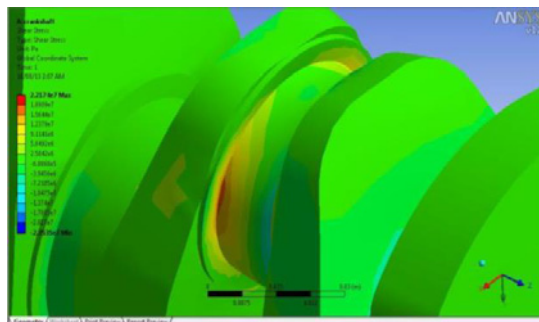**Figure 11.** Location of maximum stress at crankshaft.

Figure 12. Location of maximum shear stress at crankshaft.

5 Conclusion

Modeling the geometry and analysis the crankshaft using CATIA and ANSYS software has been done in this paper. The loads on the crankpin were modeled as surface forces. In the analysis, only bending loads were considered, while torsional loads were neglected.

Under 60 bars pressure, results indicate that the maximum stress on the crankshaft is 43.35 MPa and it occurs at the point located on the edge of crankpin. The value of maximum shear stress happening is 22.17 MPa and it takes place at the opposite side of the point with maximum stress.

Acknowledgement

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