Estimation of Fatigue Strength of Crank Shaft with and Without Flywheel

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***Abstract:** Evaluation of life and performance of complex engineering structures subjected to inherent randomness in loading, material properties and geometric parameters is becoming increasingly important in the design of structures. Fatigue analysis provides a means to quantify the reliability of complex systems and estimate the life by quantifying the cycles to failure. Crankshaft design is a complex task as engine runs at wide range of operating conditions. Loads are produced both by pressure (released by internal combustion) and inertia. It is designed to withstand high cyclic loads for 10 to 10 cycles. Crankshaft operates under high loads requiring high strength in tension and compression as well as fatigue strength. In this paper we describe the Computer aided fatigue analysis of crankshaft, a critical component in the functioning of an automotive. 3-D solid part of the crankshaft is modeled using CATIA V5 R15 and meshed using HYPERMESH 7.0. Boundary conditions and loading conditions are given in ABAQUS 6.5 and fatigue analysis is carried out using FE-SAFE software. Crack initiation location is also determined using FE-SAFE software.*

***Index Terms:** Carbon nanotubes, Spark plasma sintering, Wear behavior, Corrosion resistance crankshaft, Fatigue life, White curve, Gas pressure.*

I. INTRODUCTION

A. Crankshaft

Crankshaft is a very important part of IC engine, together with the connecting rod, converts the reciprocating motion of the piston into rotary motion needed to power the driveline of the vehicle. The crankshaft revolves in bearings called “main” bearings. These bearings are housed in the main bearing bores of the engine block and are manufactured under very close tolerances to withstand extreme loads. The main functions of crankshaft is to convert reciprocating motion of piston assembly into rotary motion, to transmit torque from engine connecting rod to flywheel and to balance engine cylinders forces and hence minimizing the vibrations developed in its operation.

The very early cranks had only six counterbalance weights on them, as opposed to eight found on later production crankshaft. The crankshaft can be classified based on the type of crank used, number of crank used and process of manufacturing.

The crankshaft usually a one piece forging. It is made of heat treated alloy steel of considerable mechanical strength. It is machined in special lathes, hardened and finished by grinding to provide suitable journals for the connecting rod and main bearings.

B. Flywheel

Flywheel is a heavy wheel fastened to the flange, which is keyed to the rear end of the crankshaft. The main purpose of the flywheel is to store energy during power strokes and to release it during idle strokes. The inertia of the flywheel keeps the fluctuation of speed during a cycle of operations within the permissible limits. The size of the flywheel varies with the number of cylinder and the general construction of the engine.

II. MODELING AND ANALYSIS

A. Modeling

The Early CAD systems uses geometry construction and editing techniques to create the model. These techniques created the models of wire frame and surfaces that could be edited by a geometric editing, however, these systems had no capabilities to understand the relations between the geometry.

Later parametric modeling systems were introduced, which could be used to build relationships between geometric entities. These techniques relied on constraints and parametric expressions defined by the user to build the model. These approaches built a more intelligent model, but could become restrictive; the constraints would sometimes stop a user from carrying out a modification, which had not been originally foreseen. Parametric systems also relied heavily on bodies created from swept sketches, and did not have a wide variety of construction and editing techniques. Modeling of the Crankshaft is done using CATIA.

CATIA is powerful modeling software package which is one of the most effective parametric modeling and surface feature based modeling software. Solid modeling is done in CATIA which has a rich set of features to create and modify the designs.

In this paper 3-D solid crankshaft is considered for the analysis. The procedure followed in CATIA for modeling of the solid bar is, first getting the 2-D sketch which is the profile of the web, then the web profile is projected by using “project 3D element” option and then tr “rotate” option is used to rotate the projected profile. Care should be taken to convert the projected profile into construction lines.

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After modeling the crankshaft, it is saved as CATIA file and IGES file format for meshing purpose. IGES means Initial Graphic Exchange Specification, this file can be easily imported to any software package. The CATIA part file can also be saved as STEP file.

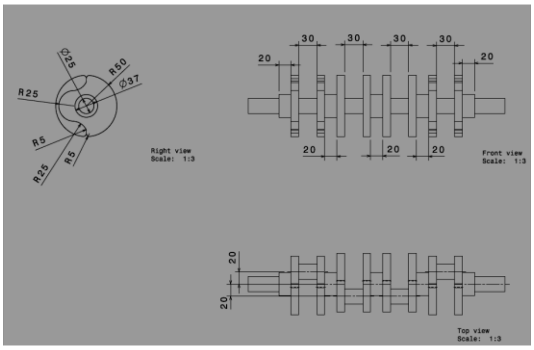

Figure 1. 2D drawing of crankshaft

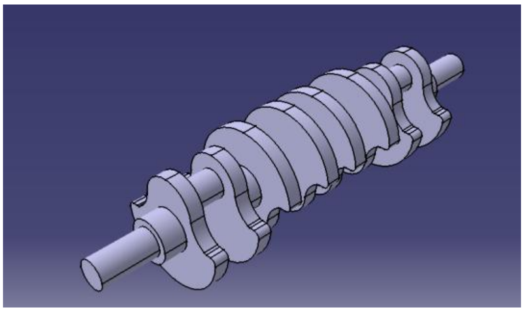

Figure 2. Crankshaft modeled in CATIA

B. Meshing

Meshing is a process of converting infinite number of degrees of freedom into finite number of degrees of freedom for analysis. The meshing of the stabilizer bar is carried out using the commercially available software - HYPERMESH. Hypermesh is a very effective tool of meshing which can deal with both shell and solid models where quality characteristics of mesh as required for different types of analysis can be maintained and controlled. For meshing of surfaces Hypermesh has many options and capabilities including meshing across multiple surface boundaries and choosing between quad or triangle-dominated meshes. Model editing features include combining, detaching, and translating elements. Hypermesh can check meshes for duplicate elements, facet warpage, aspect ratio, skewness, and can display and modify element normals.

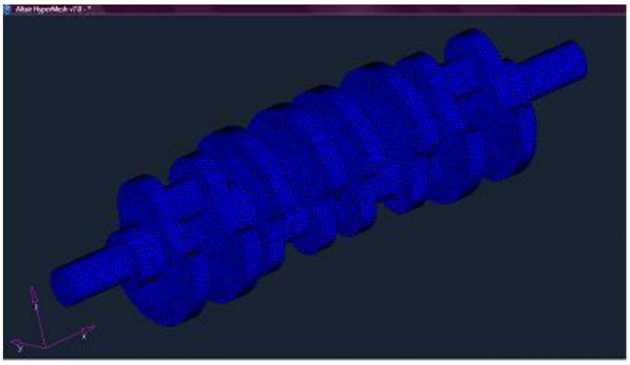

Figure 3. Crankshaft meshed in HYPERMESH

In this work, tetramesh is done for the crankshaft. Firstly, a collector is created named as “shell” and the surfaces of the component are meshed using triangular elements. Then, another collector is created and the “Tetramesh” option is used to produce tetramesh for the whole component. The element used in this work is the first order tetrahedral element. HYPERMESH is a very effective package to maintain various mesh qualities like warpage angle, jacobian, minimum and maximum angle, minimum and maximum length

C. Boundary and Loading Conditions.

In commercial vehicle engine, the Crankshaft revolves in the bearing called the “main” bearing. These bearings are housed in the main bearing bores of the engine block. The bearing locations are considered as simply supported. As the shaft and crankpins are cylindrical in shape, a new polar co-ordinate system is created for the purpose of creating a boundary conditions for journal bearing. The boundary conditions are given with respect to the newly created polar co-ordinate system. These boundary conditions are given in ABAQUS using Boundary Condition option which constrains all degrees of freedom except in radial direction (theta constraint). The rotations are constrained as the solid model does not have the rotational degrees of freedom.

The crankshaft is connected to the connecting rod which is connected to the piston. Firing takes place when the piston is at the TDC (top dead centre). Due to this, the gas pressure acts on the piston which causes a pulling effect on the crankpin. Hence, the gas pressure is applied on the upper half of the crankpin where the connecting rod pulls the crankpin. Minimum pressure acts on bottom half of the crankpin when the piston is in BDC (bottom dead centre). There are four cylinders in this model and due to firing order the two cylinders are fired while the other two cylinders will be either in suction stroke or exhaust. Therefore, maximum pressure is given on the top halves of the crankpins which are connected to the firing pistons and minimum pressure is given to the bottom halves of the crankpins which are connected to the pistons which are at BDC.

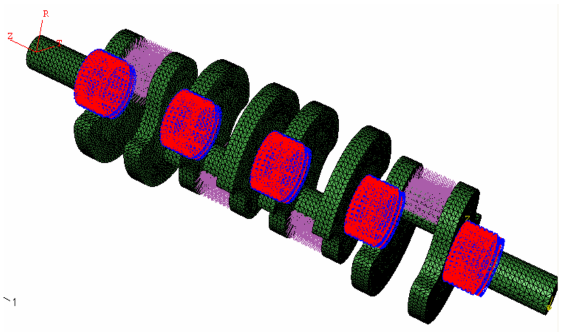

Figure 4. Simply supported at bearing locations and pressure applied on appropriate surfaces

D. Stress Analysis

Crankshaft is modeled in CATIA and meshed in HYPERMEH. Stress analysis is carried out in ABAQUS.

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Boundary and Loading conditions are given in ABAQUS. The Hyper meshed model (.INP) is imported to ABAQUS and material properties of the Crankshaft is given. The elastic properties are given in the Table1.0

Table 1. Elastic Property of the Crankshaft

Part	Material	Young's Modulus (E)	Poisons Ratio
Crankshaft	C45- Steel	210 GPa	0.31

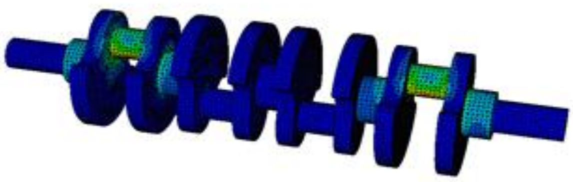

Figure 4. Final simulation

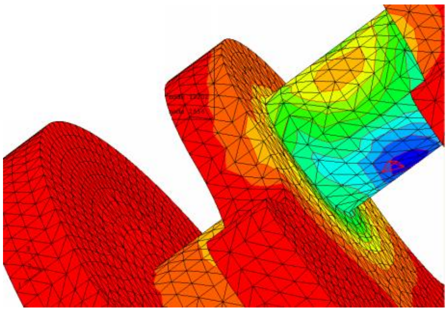

Figure 5. Location of maximum Von mises stress Fatigue Analysis without flywheel

E. Fatigue Analysis without flywheel

The stress analysis is carried out for the crankshaft without flywheel in ABAQUS. The stress output file that is generated in ABAQUS (.ODB) is taken as an input file in FE-SAFE. While using the FEA options in FE-SAFE, SN curve option has been selected. The variation of the gas pressure with sample rate of 100 Hz. FE-SAFE creates elastic block one property of the material and deflection cycle is linked. The surface finish values have been assigned and material algorithm is given is FE-SAFE for SAE-90 MARTEN which is very close to C45 steel whose properties are given in the Table 1.0. The FE SAFE directly gives fatigue life values. Fatigue analysis results obtained in FE-SAFE is brought to ABAQUS for visualization. Location of the Crack initiation for a given value of the deflection can be visualized in ABAQUS. One of such visualization is shown in the Figure.6.

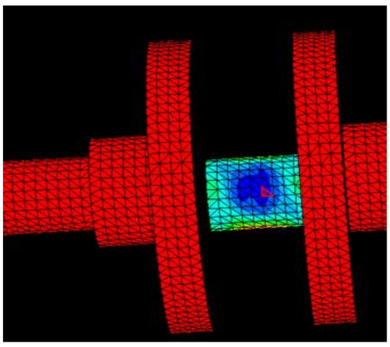

Figure 6. Location of crack

F. Fatigue Analysis with flywheel

The stress analysis results for the crankshaft with flywheel is obtained in ABAQUS. The stress output file that is generated in ABAQUS (.ODB) is taken as an input file in FE-SAFE. While using the FEA options in FE-SAFE, SN curve option has been selected. The variation of the deflection is assumed as white curve of amplitude 1 sample rate of 1000 Hz. FE-SAFE creates elastic block one property of the material and deflection cycle is linked. The surface finish values have been assigned and material algorithm is given is FE-SAFE for SAE-90 MARTEN which is very close to C45 steel whose properties are given in the Table 1.0.

G. Signal Generation and Processing

Signal generation function generates time history files by superimposing defined sine waves and Gaussian white noise signals. For the sine wave function, the specified amplitude is the amplitude of the generated sine wave, whilst for the white noise function the amplitude refers to the root mean square (rms) amplitude of the generated Gaussian white noise. In this paper, only white curve is considered for the analysis.

For signal processing, measurement of service histories-loads, strains and accelerations – are required so that the general information on service loading can be obtained and hence fatigue life of specific components can be determined. Modern signal processing uses a cycle counting algorithm to extract these cycles quickly and accurately. Rain flow counting is the cycle counting algorithm used in FE-SAFE. However, cycle counting is a recent development, possible only with modern computer systems and solid state electronics and many other less relevant methods developed in earlier days are still encountered. The white curve used in this analysis is shown in the Figure 7.

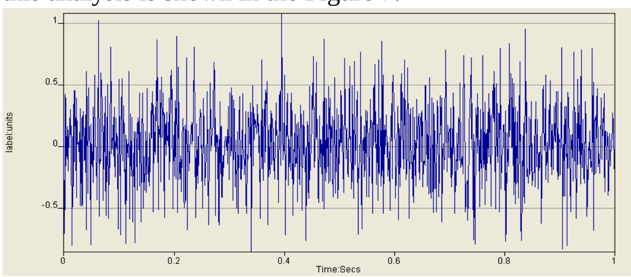

Figure 7. White curve

III. RESULTS AND DISCUSSION

1) Stress analysis of Crankshaft without flywheel with varying gas pressure

When the fuel is ignited in the clearance volume of the combustion chamber, the gas pressure increases and acts on the piston. This high pressure gas acts on piston rotates the crank shaft through connecting rod. The varying gas pressure is possible with varying compression ratio. Therefore the very first analysis carried out is effect of stress on the variation of the gas pressure. The results are shown in the Table 2.0.

It is clear from the Table 1.0 that as the gas pressure increases Von-mises stress also increases.

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Table 1: 2.0 Stress analysis of crankshaft without flywheel for varying gas pressure.

IV. GAS PRESSURE IN MPA	Maximum Von-mises stress in MPa	Maximum Strain in mm	Maximum principal stress in MPa
15	36.15	0.01968	53.2
18	43.37	0.02375	63.83
20	48.18	0.0261	70.91
23	55.41	0.03012	81.55
25	60.23	0.03289	88.64
50	120.5	0.0657	177.3
75	180.7	0.0981	265.9
100	240.9	0.131	354.6
150	361.4	0.1973	531.9
175	421.6	0.2293	620.5
200	481.8	0.2625	709.1

2) Stress analysis of Crankshaft with flywheel with varying gas pressure

Fly wheel stores the excess energy produced during the power stroke and supplies during the suction, compression and exhaust stroke. The fatigue life is also estimated with flywheel and the results are given in the Table 3.0

Table 3.0 Stress analysis of crankshaft with flywheel for varying gas pressure

Gas pressure in MPa	Maximum Von-mises stress in MPa	Maximum strain in mm	Maximum principal stress in MPa
15	36.42	0.04018	51.19
20	48.56	0.0521	68.25
25	60.69	0.06608	85.31
50	121.4	0.1339	170.6
75	182.1	0.2022	255.9
100	242.7	0.2739	341.2
200	485.5	0.526	682.4

3) Fatigue life of Crankshaft without flywheel for various gas pressures

The fatigue life of the crankshaft is one of most important parameter to the designer. Computer aided fatigue analysis will give designer a confidence about the geometrical parameter he selected using the fundamental principles of design. The effect of varying gas pressure on fatigue life, without flywheel is studied. The results are shown in the Table 4.0. It is evident that fatigue life decreases as the gas pressure increase. It is so because as the gas pressure increases, the von-mises stress also increases.

Table 4.0 Fatigue life of crankshaft without flywheel for varying gas pressure.

Gas pressure in MPa	Fatigue life in number of cycles
15	No damage
18	No damage
20	No damage
23	No damage
25	No damage
50	No damage
75	504734.5
100	54504
150	3745
200	733.24

4) Crankshaft with flywheel with varying gas pressures

The fatigue life of the crankshaft for various gas pressure, with flywheel is also studied, the results are given in the Table 5.0.

Table 5.0 Fatigue life of crankshaft with flywheel for varying gas pressure

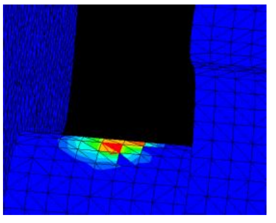
Gas pressure in MPa	Fatigue life in number of cycles
15	No damage
18	No damage
20	No damage
23	No damage
25	No damage
50	No damage
75	494687.625
100	53517.168
200	723.427

The fatigue life decreases with increase in gas pressure. It is also observed that there is marginal difference between the fatigue life of the crank shaft with and without flywheel. It is possibly due to over design of the crankshaft geometry.

5) Crack Location with Flywheel for Varying Gas Pressures

As the gas pressure increases the fatigue life decreases. At a certain gas pressure crack will initiate. The designer should be aware of the maximum gas pressure which initiates the crack. Sometimes the gas pressure spikes are seen due to the jamming of the compression rings and pistons. Table 6.0 shows the map of the crack initiation in the crankshaft without flywheel. This analysis is obtained in the fe-safe. However, fe-safe will not give the life time predication for the given amount of the crack growth.

Table 7.0 Crack location without flywheel

Gas pressure in MPa (no of cycles to failure)	Location of crack
75 (494687.625)	

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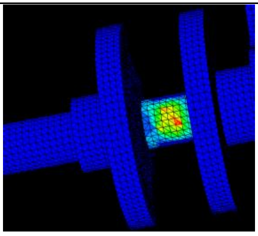
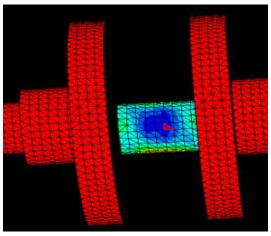
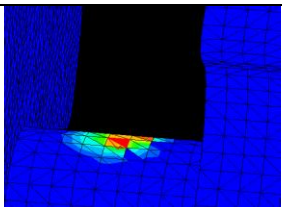
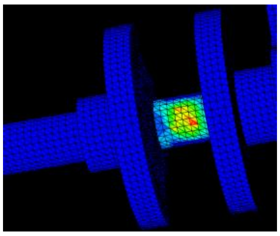
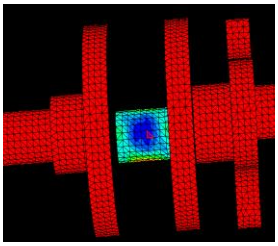
100 (53517.168)	
200 (723.427)	

Table 8.0 shows the map of the crack initiation in the crankshaft with flywheel. It is interesting to note that the crack initiation location do not change appreciably with and without flywheel.

Table 8.0 Crack Location without flywheel For Varying Gas Pressures

Gas pressure in MPa (no of cycles to failure)	Location of crack
75 (504734.5)	
100 (54504)	
200 (733.24)	

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