International Journal of Mechanical and Industrial Engineering

Volume 1 | Issue 1 Article 9

July 2011

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Recommended Citation

Chandran, S.Surendar and K., Srinivasan (2011) "Development Of A Quick Approach For Engine Block High Cycle Durability Analysis," *International Journal of Mechanical and Industrial Engineering*: Vol. 1 : Iss. 1 , Article 9.
Available at: https://www.interscience.in/ijmie/vol1/iss1/9

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Development Of A Quick Approach For Engine Block High Cycle Durability Analysis

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Abstract: ***The present work deals with understanding the current process of estimating the fatigue safety factors for engine block. To capture the loading in cylinder block, real time rotating and reciprocating loads are applied at the initial firing angle and at every subsequent 5 or 10 degrees of crankshaft rotation. This could results in 144 or 72 analysis load steps to represent the complete cycle. This involves enormous computation time and adversely affects the design cycle time. This work involves the identification of the crank angles which contribute to maximum and minimum stresses that are acting during operation. Thereby reducing the number of analysis steps with a benefit of saving time and high performance computation and quicker design solution. A method is proposed to minimize the number of crank angles using Abaqus for estimating the engine block fatigue. Using the new approach reassessment was made on the fatigue calculation.***

Key words: ***Fatigue safety factor, Inline engine block, superimposing***

1.0 INTRODUCTION

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading even when the nominal maximum stress values are less than the ultimate tensile stress limit of the material. Generally fatigue is classified into two categories low cycle fatigue and high cycle fatigue. In high cycle fatigue the cyclic plasticity are not taken into account. The term high cycle fatigue implies that the fatigue mechanisms of macroscopic cyclic plasticity are not present. Under high cycle, low stress fatigue situations prevails and the material deforms primarily elastically; the failure time or the number of the cycles to failure under such high cycle fatigue has been characterized in terms of the stress range.

Fatigue can be developed in four stages. Crack nucleation; stage I crack growth; stage II crack growth; and Ultimate ductile failure. Factors that affect the fatigue-life are cyclic stress state, surface quality, material type, residual stresses, size and distribution of internal defects, direction of loading, grain size, environment and temperature.

Cylinder block is one of the most critical components which are subjected to high cycle fatigue. It is a complex part at the heart of an engine which adapts the cylinder head, crankcase, engine mounts, drive housing and engine ancillaries, with passages for coolants and lubricants. Engine blocks are usually made from cast iron or in modern engines, aluminium and magnesium are used. The loads that are acting in the engine block are Combustion load, Piston side loads, balance shaft loads, main bearing loads, main bolt clamp load, thermal load and head bolt clamp load. These loads are considered for the durability analysis of the engine block. Durability analysis can be used to determine how long a component can survive in a given service environment. In a general case, durability refers to the ability of a component to function in the presence of defects for a given environment/ loading. Hence, the term durability analysis will be used to describe the analysis of a fatigue performance. A finite element method (abbreviated as FEM) is a numerical technique to obtain an approximate solution to a class of problems governed by elliptic partial differential equations. Such problems are called as boundary value problems as they consist of a partial differential equation and the boundary conditions. The finite element method converts the elliptic partial differential equation into a set of algebraic equations which are easy to solve. It has 3 stages; Preprocessing, Analysis and Post processing.

2.0 FINITE ELEMENT MODELLING

The software tools required for the engine cylinder block to carry out the durability analysis are listed in the table 1 below.

Table 1 Software tools

SOFTWARE TOOL	DESCRIPTION
Hypermesh	Meshing the engine cylinder block component
Abaqus	Thermal/Mechanical analysis of the cylinder block
Fe-safe	Fatigue analysis of cylinder block

Generally, to carry out the durability analysis using conventional methodology of the engine block, the entire engine has to be considered for global meshing and after that sub model meshing is done for the analysis. The 3D inline engine is shown in figure1 below.

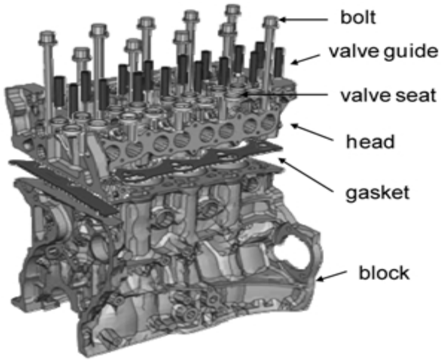

Figure 1 3D inline engine

The entire cylinder block assembly is modeled using hyper mesh software. The element type utilized was C3D10 second order tetrahedral element. The 3D photographic view of inline 3 engine is shown in figure 1.

Figure 2 3D model of inline 3 engine block

Finite element modeling and assembly of the 3 cylinder engine block is done using Hypermesh software.

The Block finite element model is evaluated is checked for quality parameters like aspect ratio, tetra collapse, maximum and minimum angles. The final meshed model of inline 3 engine block is shown in figure2.

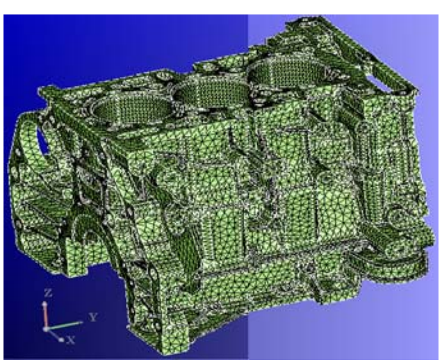

Figure 3 Meshed model inline 3 engine block

2.1 Material properties

The material used is Aluminum alloy (Al-380 Alloy). The properties of the material are estimated for a life of 10^7 cycles. The Properties are listed in table2.

Table 2 Material properties

Ultimate tensile strength (σ_{ult})	324 MPa
Modulus of Elasticity (E)	71 GPa
Poisson's ratio	0.32
Fatigue strength (σ_{fs})	138 MPa
Thermal conductivity (k)	96.2 W/mk
Coefficient of thermal expansion (α)	21.2×10^{-6} /°c

Data source: INTERZINC

3.0 GENERAL METHODOLOGY

The general industry procedure to carry out the durability analysis of the cylinder block considers engine operating loads every at the initial firing angle and at every subsequent 5 or 10 degrees of crankshaft rotation which results in either 144 or 72 load steps in addition to the room temperature and steady state hot assembly.

The engine assembly simulation process is a sequential Thermo-mechanical analysis using a commercial analysis package like Abaqus. The metal temperature distribution in the finite element engine assembly model is obtained from thermal analysis. The coolant, oil and gas side boundary conditions obtained from various computational fluid dynamic simulations predicting operating conditions form the inputs for the thermal analysis. They are Gas side boundary condition, Coolant side boundary condition, Oil side boundary conditions. Post metal temperature predications, sequential mechanical analysis are followed. The assembly loads which include various bolt pre-tension loads and press-fits. After the room temperature and steady state hot assembly simulations are completed, it is followed with engine operating load simulations. The loading considered are cylinder firing loads, main bearing loads and piston side loads. These loads are applied in sequential analysis load steps to map the total behavior representing two revolutions of crankshaft. The resulting stress history obtained from the finite element simulation is used to carry out durability analysis.

The fatigue analysis of the engine block is carried out using commercial software like Fe-Safe. The steps involved in the durability analysis of the engine cylinder block are described in the flow chart and is shown below.

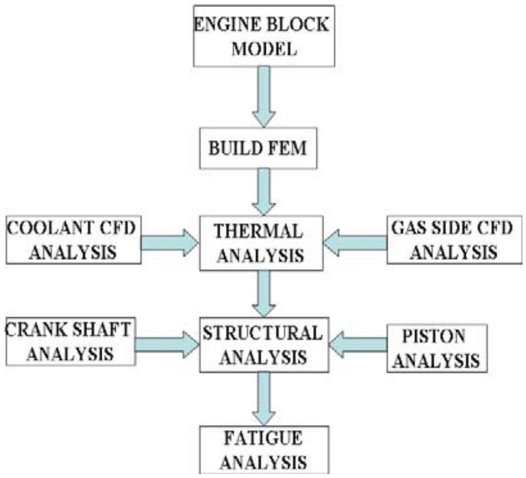

Figure 4 Engine block analysis flow chart

4.0 PROPOSED METHODOLOGY

The conventional approach is very time consuming and expensive due to large number of analysis steps and solution time. To arrive at an optimum quick approach 3 cases are considered to analyze the input main bearing horizontal and vertical loads.

The 3 cases that are considered for these inline engines are as described below:

1. All crests and troughs of vertical and horizontal loads that are acting in the engine block.
2. All crests and troughs of vertical and maximum and minimum of horizontal loads that are acting in the engine block.
3. Maximum and minimum of all the loads.

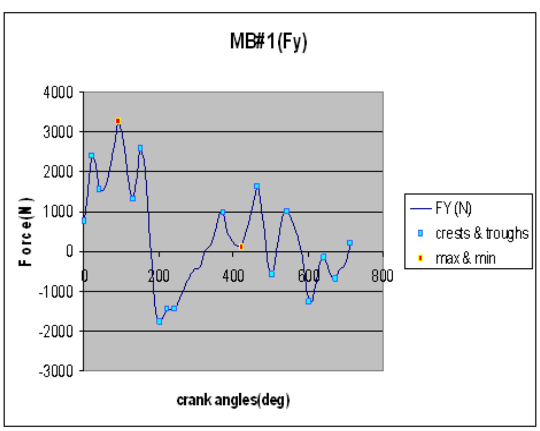

Figure 5 Horizontal main bearing load (front)

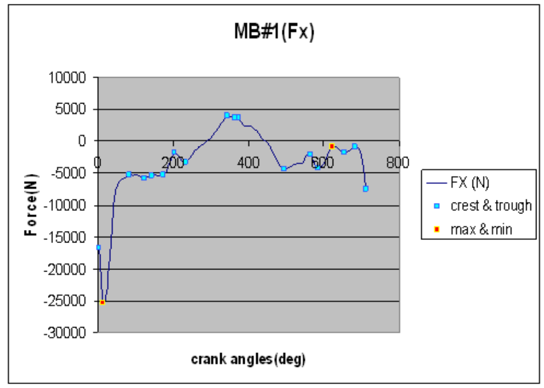

Figure 6 Vertical main bearing load (front)

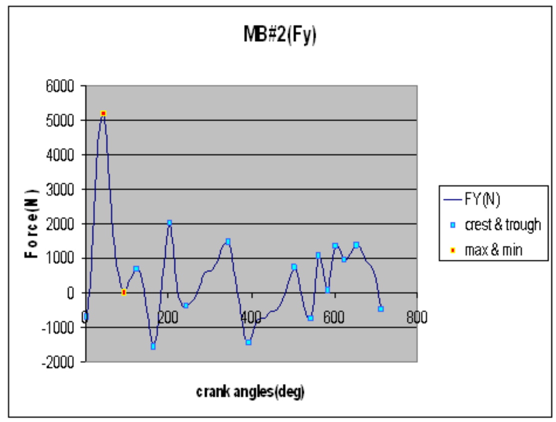

Figure 7 Horizontal main bearing load (intermediate)

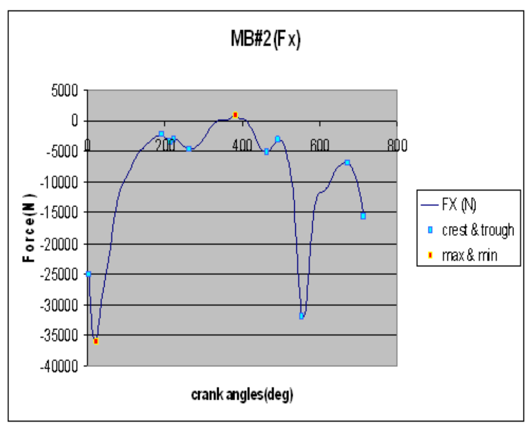

Figure 8 Vertical main bearing load (intermediate)

Similarly, load curves are analyzed for the horizontal and vertical loads acting in the remaining main bearings. The combustion and piston side loads at respective crank angles are applied. Table below shows the proposed methods and resulting analysis steps to capture operating loads.

TABLE 3. Results of the new approach

1	General Procedure (Conventional approach capturing complete behavior)	72/144 steps
2	All Crests and Troughs	61 steps
3	Maximum and Minimum of Horizontal loads + Crests and Troughs of Vertical loads	51 steps
4	Maximum and Minimum of horizontal and vertical loads	20 steps

The selected crank angles based on the three analysis approaches are solved using Abaqus. The output stress history is used to compute fatigue safety factors using Fe-Safe. The results from the individual approaches for every fatigue hot spot is tabulated and compared.

5.0 COMPARISION

The fatigue safety factor values calculated using the proposed methodology were compared with the conventional approach. The values of the hot spots safety factors are listed in table 4 and compared.

Table 4 Comparison of safety factors

node no.	72 steps	61 steps	51 steps	20 steps
1	1.03	1.03	1.03	1.03
2	0.87	0.88	0.87	0.87
3	0.74	0.74	0.75	0.75
4	1.03	1.03	1.03	1.03
5	0.97	0.97	0.98	1.02
6	0.95	0.95	0.95	0.95
7	1.12	1.12	1.12	1.13
8	0.97	0.97	0.98	1.02
9	0.95	0.95	0.95	0.95
10	0.83	0.84	0.83	0.84
11	1.12	1.12	1.12	1.13
12	0.88	0.88	0.88	0.88
13	0.89	0.89	0.89	0.89
14	0.84	0.86	0.86	0.87
15	1.07	1.1	1.11	1.11
16	1.06	1.08	1.08	1.09
17	0.85	0.86	0.86	0.87
18	1.06	1.09	1.09	1.09
19	1.02	1.03	1.03	1.03
20	0.84	0.84	0.84	0.84
21	0.8	0.81	0.81	0.81
22	1.07	1.1	1.1	1.1
23	1.17	1.19	1.19	1.19
24	1.11	1.11	1.11	1.11
25	1.07	1.08	1.08	1.08
26	0.97	0.97	0.97	0.97
27	1.11	1.11	1.11	1.11

Table 5 Comparison of percentage deviation of safety factors with the conventional approach

	percentage deviation		
node no.	61 steps	51 steps	20 steps
1	0	0	0
2	1.14	0	0
3	0	1.33	1.33
4	0	0	0
5	0	1.02	4.9
6	0	0	0
7	0	0	0.88
8	0	1.02	4.9
9	0	0	0
10	1.19	0	1.19
11	0	0	0.88
12	0	0	0
13	0	0	0
14	2.33	2.33	3.49
15	2.73	3.6	3.6
16	1.85	1.85	2.75
17	1.16	1.16	2.3
18	2.75	2.75	2.75
19	0.97	0.97	0.97
20	0	0	0
21	1.23	1.23	1.23
22	2.73	2.73	2.73
23	1.68	1.68	1.68
24	0	0	0
25	0.93	0.93	0.93
26	0	0	0
27	0	0	0

6.0 CONCLUSION AND FUTURE WORK

The factor of safety values of the fatigue hot spots found in inline 3 cylinder engine block of the 72 load steps matches very close to that of the 3 cases but 20 load steps approach has minimum computation time and the percentage deviation is also allowable (less than 5 %) when compared to the 61 steps and 51 steps approach. Thus, 20 load steps approach can be accepted as a quick approach which can be used for the durability analysis of the 3 cylinder inline engine block.

The procedure which is followed in inline 3 cylinder engine block for determining the fatigue hot spots can be extended to inline 4 cylinder engine block durability analysis in future

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