Design of Optimization of Engine Block

J. SURESH BABU[1], Y. YESWANTH REDDY[2], G. SUDHEER KUMAR REDDY[3], K. SANDEEP KUMAR[4], N. THARUN KUMAR REDDY[5], B. EERANNA[6], Y. S. SRAFARAAZ[7]
[1] *Assistant Professor in Department of ME, KSRMCE (Autonomous), Kadapa, AP, India.*
[2, 3, 4, 5, 6, 7] *Student in Department of ME, KSRMCE (Autonomous), Kadapa, AP, India.*

Abstract- A cylinder block is an integrated structure comprising the cylinder(s) of a reciprocating engine and often some or all of their associated surrounding structuresThe various main parts of an engine (such as cylinder(s), cylinder head(s), coolant passages, intake and exhaust passages, and crankcase) are conceptually distinct, and these concepts can all be instantiated as discrete pieces that are bolted together. The purpose of the engine block is to support the components of the engine. Additionally, the engine block transfers heat from frictionto the atmosphere and engine coolant.

From carburetor or fuel injector (fuel and air mixture) is supplied to cylinders of the engine. The fuel and air mixture are injected at high pressure into cylinders of the engine. Due to this applied pressure on the cylinder, the cylinder undergoes some deformation and produce stresses in the cylinder. With respect to stresses, Weight is also important factor in automobile industries, due to heavy weight of engine block, power consumption is high.

In this paper, a research on static and dynamic behaviour of a diesel engine block is carried out in Finite Element Method (FEM) for grey cast iron. Stresses, Natural frequencies and Modal shapes are obtained by FEM calculation. Analysis is carried for grey cast iron. NX-CAD software is used for 3d modeling of engine block and ANSYS software is used for analysis of engine block.

I. INTRODUCTION

An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel.

The internal combustion engine was conceived and developed in the late 1800s. It has had a significant impact on society, and is considered one of the most significant inventions of the last century.

The internal combustion engine has been the foundation for the successful development of many commercial technologies. For example, consider how this type of engine has transformed the transportation industry, allowing the invention and improvement of automobiles, trucks, airplanes and trains.

Internal combustion engines can deliver power in the range from 0.01 kW to 20x103 kW, depending on their displacement. The complete in the market place with electric motors, gas turbines and steam engines. The major applications are in the vehicle (automobile and truck), railroad, marine, aircraft, home use and stationary areas. The vast majority of internal combustion engines are produced for vehicular applications, requiring a power output on the order of 102 kW.

Next to that internal combustion engines have become the dominant prime mover technology in several areas. For example, in 1900 most automobiles were steam or electrically powered, but by 1900 most automobiles were powered by gasoline engines. As of year 2000, in the United States alone there are about 200 million motor vehicles powered by internal combustion engines. In 1900, steam engines were used to power ships and railroad locomotives; today two- and four-stoke diesel engines are used. The two stroke diesel engines are generally employed in marine propulsion. The four stroke diesel engines are generally employed in heavy duty vehicles such as buses, trucks, tractors, diesel locomotives and in earth moving machinery. Today gas turbines are the power plant used in large planes, and piston engines continue to dominate the market in small planes. The adoption and continued use of the internal combustion engine in different application areas has resulted from its relatively low cost, favorable power to weight ratio, high efficiency, and relatively simple and robust operating characteristics.

- Principle parts of an I.C. Engine

The principle parts of an I.C. engine are,

1. Cylinder block, cylinder head and cylinder liner,
2. Piston, piston rings and piston pin or gudgeon pin.
3. Connecting rod with small and big end bearing,
4. Crank, crankshaft and crank pin, and
5. Valve gear mechanism.

- Cylinder block construction

The cylinder-block assembly is the casting housing the cylinders, the crankshaft, and (depending on the design) the camshaft which controls the inlet and exhaust valves. Within the cylinders, combustion produces rapid and periodic rises in temperature and pressure. These will induce circumferential and longitudinal tensile stresses - that is, around the cylinder and in the direction of the cylinder axis.

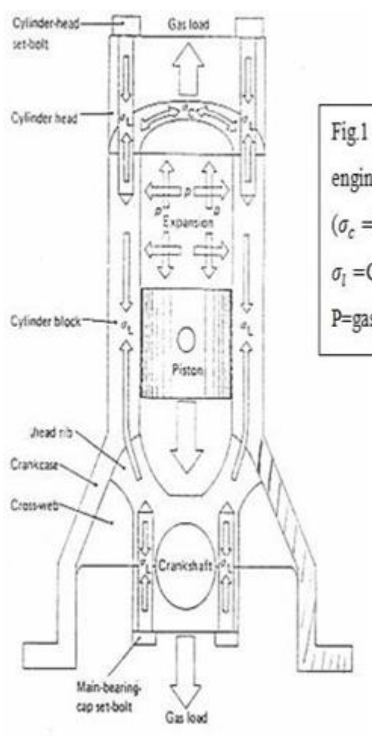


Fig.1 Stress distribution in engine due to gas pressure. (σ_c =Longitudinal stress; σ_l =Circumferential stress; P=gas pressure)

Fig.1 shows cylinder block construction.

The reaction to the gas pressure is shown by the arrows tending to stretch longitudinally the set-bolts of the cylinder head and the main-bearing housing at the opposite ends of the cylinder block. Simultaneously the gas tries to expand outwards against the cylinder walls, so a plan section view of the cylinder walls would show a ring subjected to tensile circumferential stresses trying to expand the cylindrical sleeve. These induced stresses will be of a pulsating nature, so the cylinder will be continuously stretching and contracting while in operation.

II. PROBLEM DEFINIION & SOLUTION METHODOLOGY

In this paper, a research on static and dynamic behavior of a diesel engine block is carried out in Finite Element Method (FEM) for grey cast iron. Stresses, Natural frequencies and Modal shapes are obtained by FEM calculation. Analysis is carried for grey cast iron.

In this study NX-CAD software is used for 3Dmodeling of Engine block, ANSYS software shall be used for the finite element analysis of an Engine block.

The methodology followed in my project is as follows:

- Create a 3D model of the Engine block by using NX-CAD software.
- Perform static analysis on Engine block using ANSYS software and obtain the deflections and von mises stresses values produced in the Engine block.
- Perform modal analysis of the Engine block with grey cast iron and obtain natural frequencies and their mode shapes.
- Perform harmonic analysis of the Engine block and obtain the deflections and von misses stresses at critical frequencies.

III. DESIGN CALCULATIONS OF ENGINE BLOCK

1) Cylinder:

i) the apparent longitudinal stress induced in cylinder is given by,

$$\sigma l = \frac{Force}{Area}$$

$$\sigma l = \frac{\left(\frac{\pi}{4}\right)D^2P}{\left(\frac{\pi}{4}\right)D^2 - D^2}$$

$$\sigma_l = 2.4\ N/mm^2$$

ii) Length of stroke (l) is given by,

$\mathbf{l} = \mathbf{2} * \mathbf{diameter\ of}\ \mathrm{d}\mathbf{ylin}(\mathbf{D})$l = 2 ∗ 60
l = $\mathbf{120mm}$.

iii) Length of the cylinder (L) is given by,

$\mathbf{L} = \mathbf{1.5} * \mathbf{length\ of\ the\ str}(\mathbf{l})$L = 1.5 ∗ 120
L = $\mathbf{180mm}$

iv) The apparent circumferential stress induced in the cylinder is given by,

$$\sigma l = \frac{Force}{Area}$$

$$\sigma l = \frac{D*L*P}{2t*L}$$

Where, D=Bore Diameter of cylinder (mm) = 60mm
L=Length of the cylinder (mm) = **180mm**
P=Maximum pressure inside the cylinder (MPa) = 0.7MPa
t=Thickness of the cylinder wall (mm) =8mm

$$\sigma l = \frac{D*L*P}{2t*L}$$

$$\sigma l = \frac{60*180*0.7}{2*8*100}$$

$$\sigma l = \frac{42}{16}$$

$$\sigma_l = 2.6\ N/mm^2$$

2) Cylinder Flange and Studs:

The cylinders are cast integral with the upper half of the crankcase or they are attached to the crankcase by means of a flange with studs or bolts and nuts. The cylinder flange is integral with the cylinder and should be made thicker than the cylinder wall.

The flange thickness (tf) should be taken as,

tf = 1.2*t
Where, t= the thickness of cylinder wall = 8mm
$t_f = 1.2*8$ $t_f = 9.6$mm

From the above calculations we can conclude that the estimated stress values are less than the yield stress values,hence the estimated design is safe for the above loading conditions.

- Design parameters of Engine block:

1) Length of the engine block = 600mm.
2) Height of the engine block = 300mm.
3) Width of the engine block = 350mm.
4) Bore Diameter of cylinder = 60mm.
5) Thickness of the cylinder wall =8mm.
6) Length of the cylinder = 180mm
7) Diameter of stud = 12mm.
8) Thickness of flange = 9.6mm
9) The distance between the axis of two adjacent cylinders=130mm

IV. 3D MODELLING OF ENGINE BLOCK

The 3D model of the Engine block is created using UNIGRAPHICS NX software from the 2d drawings. UNIGRAPHICS NX is the world's leading 3D product development solution. This software enables designers and engineers to bring better products to the market faster. It takes care of the entire product definition to serviceability. NX delivers measurable value to manufacturing companies of all sizes and in all industries

For this Engine block design, 2D Drawing inputs are taken from previous standard journal only. The Engine block model is single body consists of cylinders, cooling jackets, studies, etc.

- The CAD model of the engine block is shown below: 2D drawing

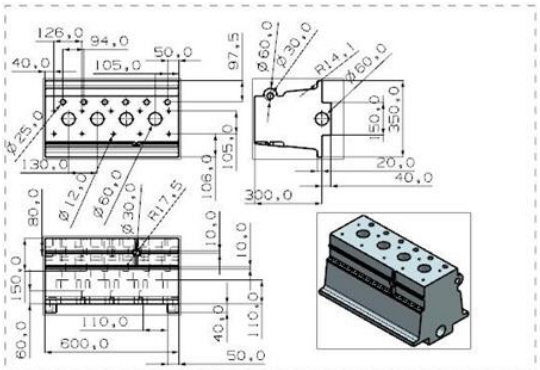


Fig.6 shows the drafting of engine block

- 3D model is generated from 2D input using Unigraphics software

1. The total length of engine block =600mm
2. The height of engine block =300mm
3. The width of engine block =350mm
4. The core diameter of cylinder=60mm
5. Thickness of cylinder =8mm
6. Diameter of the studs =12mm
7. The distance between the adjacent cylinders = 130mm
8. Length of the cylinder =120mm

- 3D modeling:

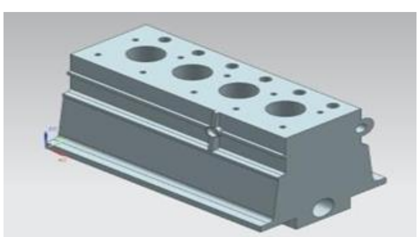


Fig.7 shows CAD model of the inlet manifold

V. 3D MODEL OF ENGINE BLOCK

- Front view of Engine block:

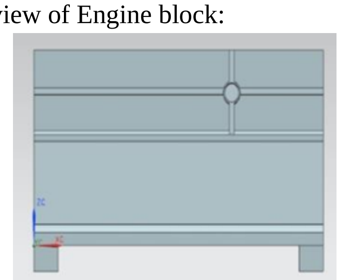


Fig.8 Shows the Front view of Engine block

- Top view of Engine block

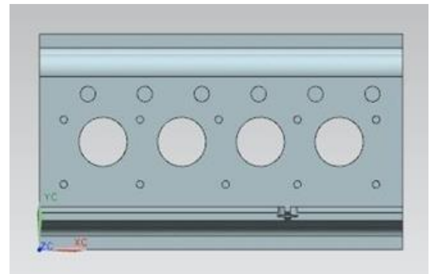


Fig.9 Shows the Top view of Engine block

- Right view of Engine block:

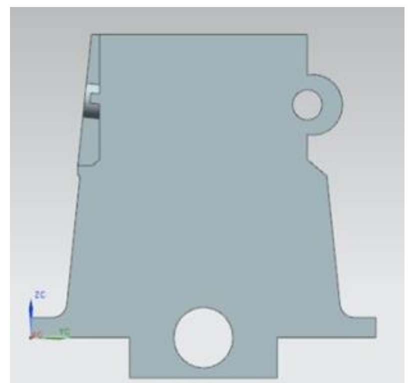


Fig.10 Shows the Right view of Engine block

- Isometric view of Engine block:

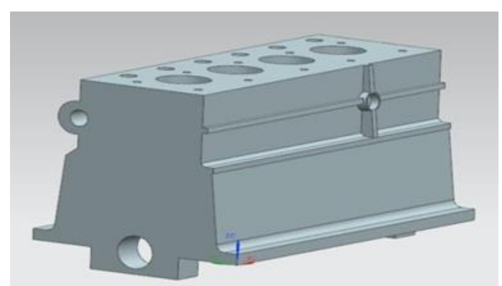


Fig.11 Shows the Isometric view of Engine block

VI. STATIC ANALYSIS OF ENGINE BLOCK

A static analysis can however include steady inertia loads and time varying loads that can be approximated asstatic equivalent loads. The 3d model of the engine block is created in NX-CAD and converted into parasolid. The parasolid file is imported into ANSYS and finite element analysis is carried out using ANSYS software.

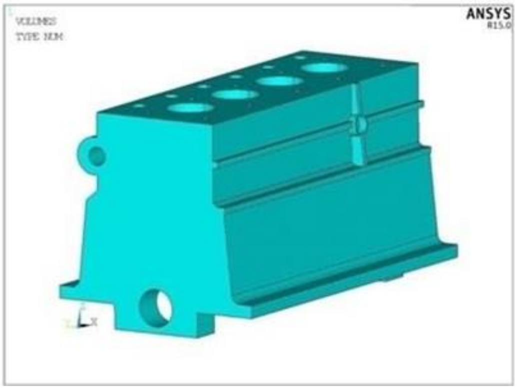


Fig.12 shows the geometric model of the Engine block

VII. MATERIAL PROPERTIES

There are several types of material used to manufacture engine block. The materials are aluminum alloys (A319 and A356.), grey cast iron alloys and compacted graphite alloy. Locally, common engine blocks are usually made of grey cast iron alloys. The materials that used in this project for analysis are grey cast iron alloy.

The materials chosen for analysis are grey cast iron alloy and the reason why these materials is chosen because, of its excellent damping absorption, good wear and thermal resistance, and it is easily machine able and less cost due to its availability.

- Grey cast Iron:

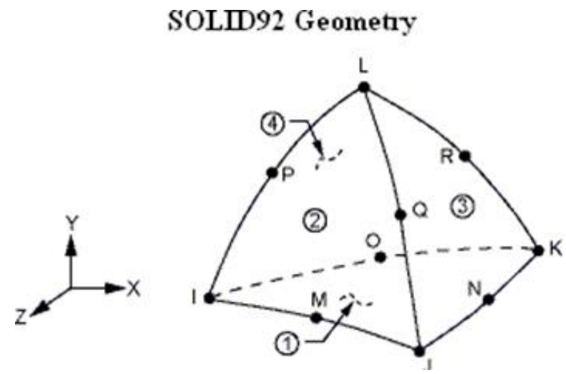
Grey cast iron is a common material widely used in automotive and general engineering applications. It is also a material that most frequently encountered in conventional gas-powered engine blocks. It consist of about 2.5-4 wt.% carbon and 1-3 wt.% silicon, 0.2-1.0 wt.% manganese, 0.02-0.25 wt.% sulfur, and 0.02-1.0 wt.% phosphorus.

Material used for Engine block is grey cast Iron:

Young's Modulus: 130GPa Poisson's Ratio: 0.3
Density: 7200 Kg/m3 Yield strength: 250MPa
Element Types used:
Name of the Element: SOLID 92 Number of Nodes: 10
DOF: UX, UY & UZ

- SOLID92 Element Description

SOLID92 has a quadratic displacement behavior and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.



- SOLID92 Input Data

The geometry, node locations, and the coordinate system for this element are shown in Figure "SOLID92 Geometry".

Beside the nodes, the element input data includes the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Coordinate Systems.

Element loads are described in Node and Element Loads. Pressures may be input as surface loads on the element faces as shown by the circled numbers on Figure "SOLID92 Geometry". Positive pressures act into the element. Temperatures and fluencies may be input as element body loads at the nodes.

Fig.13 shows the meshed model of Engine block

VIII. BOUNDARY CONDITIONS

1. Stud locations at the bottom of engine block are constrained in all Dof.
2. Pressure load of 0.7MPa is applied on inner surface of cylinder.

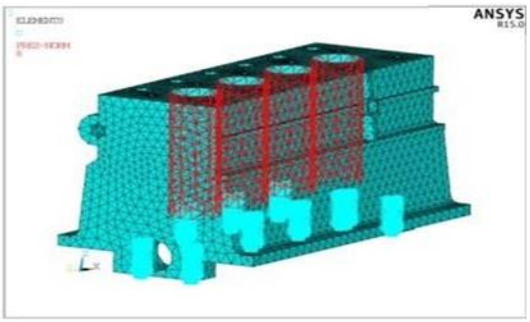


Fig.14 shows the applied boundary conditions and pressure of Engine block.

IX. RESULTS

DEFLECTION:
The Max. Deformation observed 0.0004mm on Engine block in X-dir.

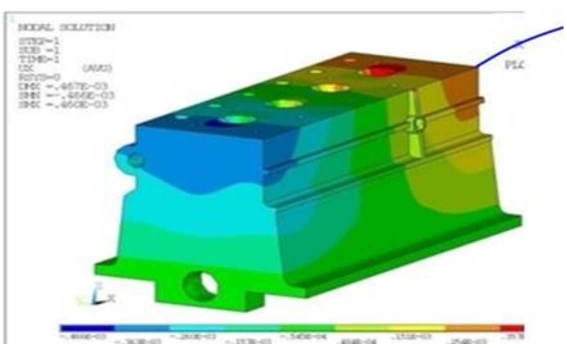


Fig.15 shows the deformation of Engine block in X-dir.

The Max. Deformation observed 0.0003mm on Engine block in Y-dir.

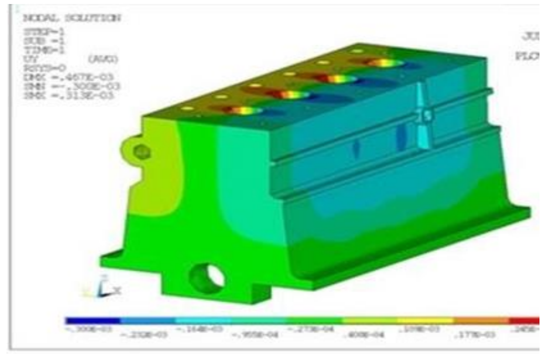


Fig.16 shows the deformation of Engine block in Y-direction.

The Max. Deformation observed 0.0002mm on Engine block in Z-dir.

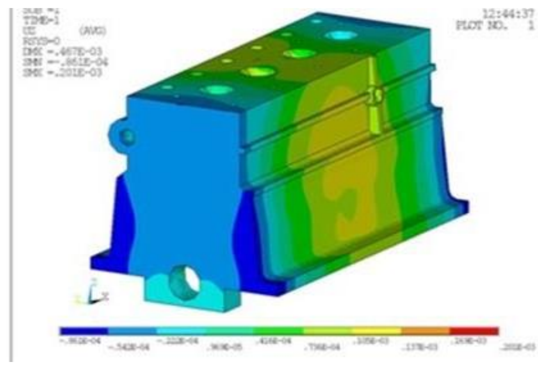


Fig.17 shows the deformation of Engine block in Z-direction.

The Max Displacement vector sum observed 0.0004mm on Engine block

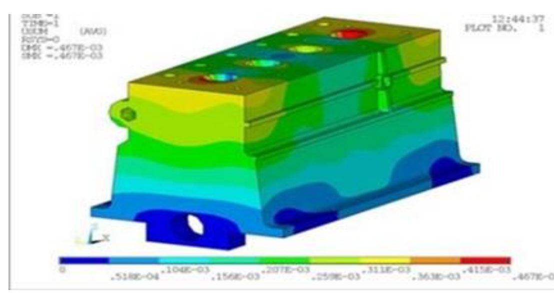


Fig.18 shows the Max. Displacement of Engine block

STRESS

The 1st principal Stress observed 1.378MPa on Engine block

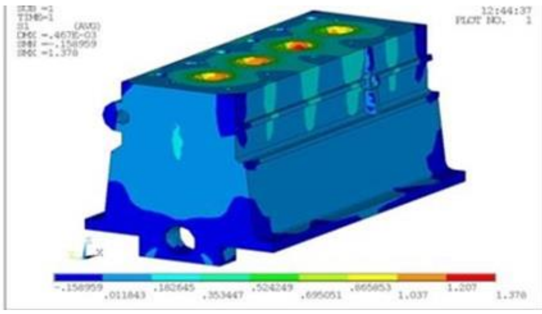


Fig.19 shows the 1st principal Stress of Engine block

The 2nd principal Stress observed 0.251MPa on Engine block

Table.1 shows the max Deflection and Max Stress

S. N O.	DEFLECTION (mm)			STRESS(MPa)			
	UY	UZ	US UM	S1	S2	S3	Von mises
1	0.00 03	0.0 002	0.0 004	1.3 78	0.2 51	0.1 77	1.973

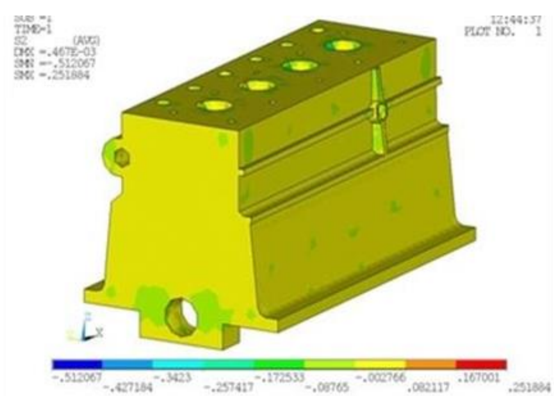


Fig.20 shows the 2nd principal Stress of Engine block

The 3rd principal Stress observed 0.177MPa on Engine block

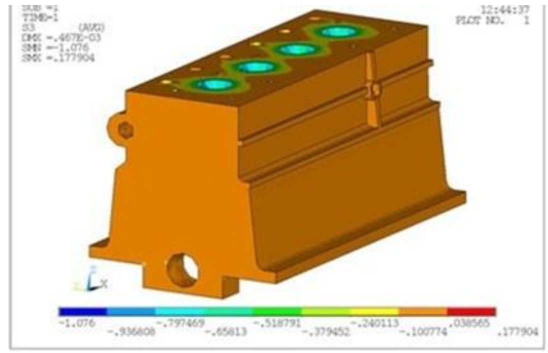
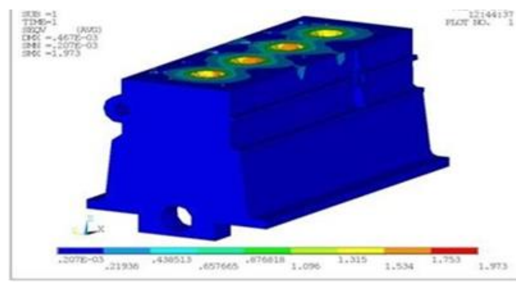


Fig.21 shows the 3rd principal Stress of Engine block

The Max. Von Mises Stress observed 1.973MPa on Engine block



From the above analysis:

The Max Deflection and the Max Avg. Von Mises Stress observed on the Engine block for applied pressure is 0.0004mm and 1.973MPa with respectively. And the Yield strength of the material metal grey cast iron is 250MPa.

Hence according to the Maximum Yield Stress Theory, the Von Mises stress is less than the yield strength of the material. The design of Engine block is safe for the above operating loads.

X. MODAL ANALYSIS

Engine block is subjected to modal analysis to determine the natural frequencies and mode shapes of a structure in the frequency range of 0-2000 Hz.

Boundary Conditions:
Stud locations at bottom of Engine block are fixed in all Dof

Fig.23 shows Applied Boundary conditions on Engine block

From the modal analysis, the natural frequencies are observed in the frequency range of 0-2000 Hz. The mode shapes of these frequencies are

Table.2 Frequencies in the range of 0-2000Hz.

MODE	FREQUENCY	PARTIC.FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	341.927	2.79 E-04	0.399	- 3.91 E-03	7.76 E-08	0.159	1.53 E-05
2	480.328	0.461	- 1.01 E-04	1.20 E-02	0.212	1.01 E-08	1.45 E-04
3	775.505	3.57 E-03	- 5.40 E-03	2.49 E-03	1.27 E-05	2.92 E-05	6.19 E-06
4	908.565	- 1.12 E-2	2.07 E-02	0.430	1.26 E-04	4.29 E-04	0.185
5	986.065	9.99 E-04	0.192	- 3.81 E-02	9.98 E-07	3.72 E-02	1.45 E-03
6	1627.37	7.35 E-03	- 2.57 E-04	3.30 E-03	5.41 E-05	6.61 E-08	1.09 E-05

The mode shapes for the above frequencies are plotted below.

Results –Mode1 @ 341.9 Hz

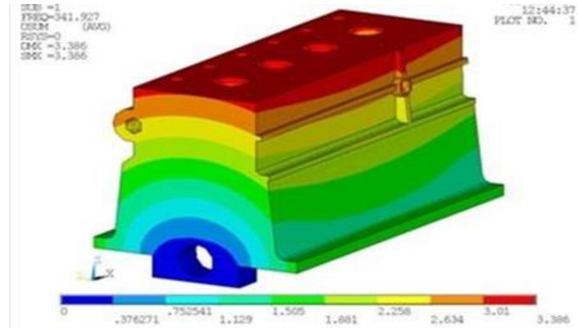


Fig.24 Shows Mode shape 1@341.9Hz for Engine block

Results –Mode2 @ 480.3Hz

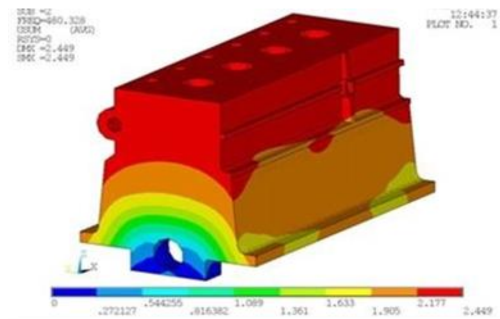


Fig.25 Shows Mode shape 2@ 480.3Hz for Engine Block

Results –Mode3 @ 775.50Hz

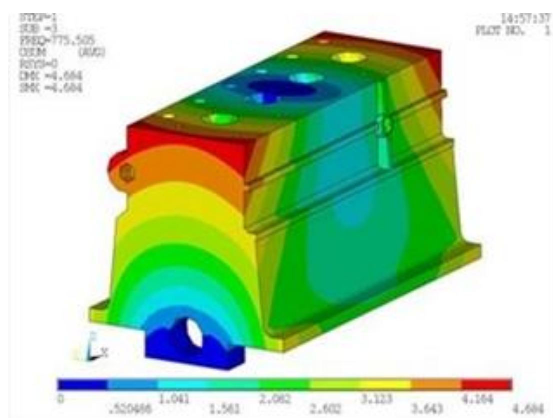


Fig.26 Shows Mode shape 3@ 775.50Hz for Engine block

Results –Mode4 @ 908.56 Hz

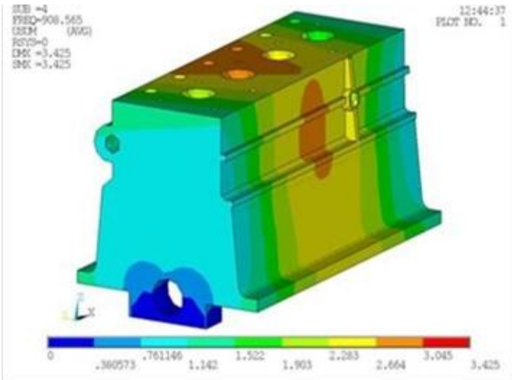


Fig.27 Shows Mode shape 4@908.56Hz for Engine block

Results –Mode5 @ 986.06Hz

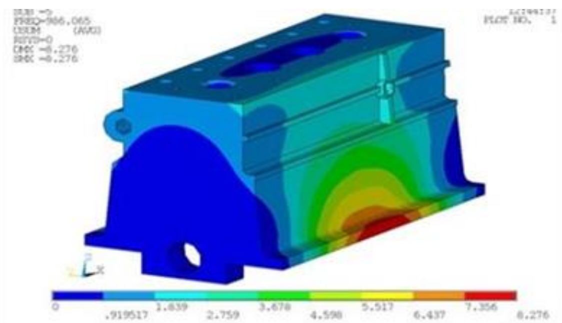


Fig.28 Shows Mode shape 5@ 986.06Hz for Engine block

Results –Mode6 @ 1627Hz

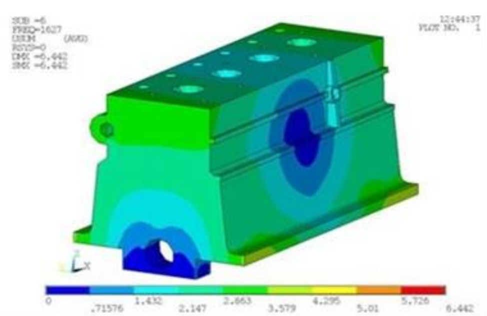


Fig.29 Shows Mode shape 6@ 1627Hz for Engine block from the modal analysis.

The total weight of the Engine block is 0.222Tone.

1. It is observed that the maximum mass participation of 0.212Tone in X-dir for the frequency of 480.6Hz.
2. It is observed that the maximum mass participation of 0.159Tone in Y-dir for both the frequencies of 341.9Hz.
3. It is observed that the maximum mass participation of 0.185Tone in Z-dir for the frequency of 908.5Hz.

To check the structure response at the mentioned frequency due to the operating loads, Engine block is also subjected to harmonic analysis.

XI. HARMONIC ANALYSIS OF ENGINE BLOCK

Harmonic response occurs at forcing frequencies that match the natural frequencies of your structure. Before obtaining the harmonic solution, you should first determine the natural frequencies of your structure by obtaining a modal solution.

A harmonic analysis, by definition, assumes that any applied load varies harmonically (sinusoidal) with time. To completely specify a harmonic load, three pieces of information are usually required: the amplitude, the phase angle, and the forcing frequency range.

Harmonic analysis was carried out on the Engine block to determine the deflections and stress of a structure in the frequency range of 300-2000 Hz. The total number of sub steps defined for the analysis is 17. Natural frequencies obtained from the modal analysis are shown in the below table.

Table.3 Frequencies in the range of 0- 2000Hz

MODE	FREQUENCY	PARTIC.FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	341.927	2.79E-04	0.399	-3.91E-03	7.76E-08	0.159	1.53E-05
2	480.328	0.461	-1.01E-04	1.20E-02	0.212	1.01E-08	1.45E-04
3	775.505	3.57E-03	-5.40E-03	2.49E-03	1.27E-05	2.92E-05	6.19E-06
4	908.565	-1.12E-2	2.07E-02	0.430	1.26E-04	4.29E-04	0.185
5	986.065	9.99E-04	0.192	-3.81E-02	9.98E-07	3.72E-02	1.45E-03

6	1627.37	7.35E-03	-2.57E-04	3.30E-03	5.41E-05	6.61E-08	1.09E-05

This is done to check, the structure behavior for resonance condition. Because, resonance occurs when natural frequency coincides with operating frequency.

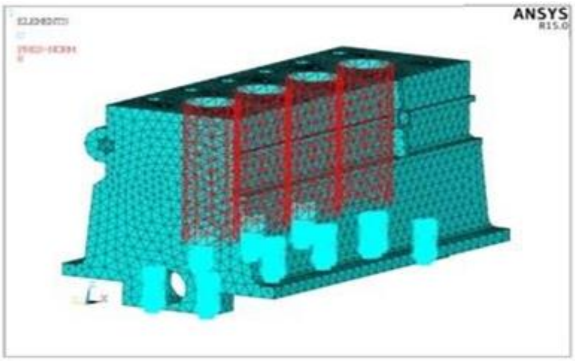


Fig.30 shows Boundary conditions and loading of Engine block.

Harmonic response at stud locations of Engine block in X-direction

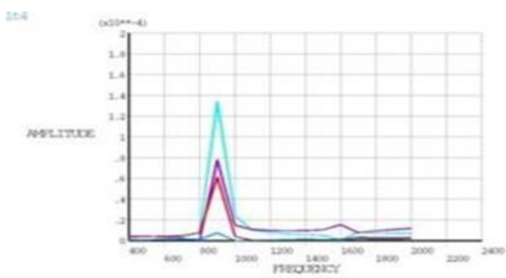


Fig.32 shows harmonic response at stud locations of Engine block in Y-direction.

Harmonic response at stud locations of Engine block in Z-direction

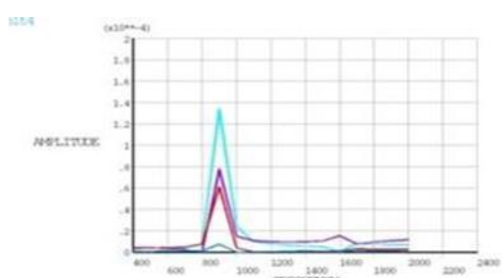


Fig.33 shows harmonic response at stud locations of Engine block in Z-direction.

Table.4 Deflections and von misses stress for critical frequencies

S.N O	FREQUENCY (Hz)	DEFLECTIO NS (mm)	VON MISES STRE SS (MPa)
1	341.927	0.0022	4.65
2	480.328	0.0009	2.41
3	775.505	0.0021	6.20
4	908.565	0.1079	240
5	986.065	0.1878	122.46
6	1627.37	0.0314	113.8

From the above results it is observed that the critical frequencies 341.9Hz, 480.32Hz, 775.50Hz, 908.56Hz, 986.06Hz and 1627.37Hz are having stresses of 4.65MPa, 2.41MPa, 6.20MPa, 2.40MPa, 122.4MPa and 113.8MPa respectively.

Hence according to the Maximum Yield Stress Theory, the Von Misses stress is less than the yield strength of the material. The design of Engine block is safe for the above operating loads.

CONCLUSION

Engine block is subjected to structural analysis. The following observations are observed from structural analysis.

There are three different cases to study the Engine block for structural behavior:

1. Static analysis
2. Modal analysis
3. Harmonic analysis
4. From the static analysis:

The Max Deflection and the Max Avg. Von Mises Stress observed on the Engine block for applied pressure is 0.0004mm and 1.973MPa with respectively. And the Yield strength of the material metal grey cast iron is 250MPa.

Hence according to the Maximum Yield Stress Theory, the Von Mises stress is less than the yield strength of the material. The design of Engine block is safe for the above operating loads.

From the modal analysis:

1. The total weight of the Engine block is 0.222Tone.
2. It is observed that the maximum mass participation of 0.212Tone in X-dir for the frequency of 480.6Hz.
3. It is observed that the maximum mass participation of 0.159Tone in Y-dir for both the frequencies of 341.9Hz.
4. It is observed that the maximum mass participation of 0.185Tone in Z-dir for the frequency of 908.5Hz.

From the harmonic analysis:

It is observed that the critical frequencies 341.9Hz, 480.32Hz, 775.50Hz, 908.56Hz, 986.06Hz and 1627.37Hz are having stresses of 4.65MPa, 2.41MPa, 6.20MPa, 2.40MPa, 122.4MPa and 113.8MPa, respectively.

Hence according to the Maximum Yield Stress Theory, the Von Misses stress is less than the yield strength of the material. The design of Engine block is safe for the above operating loads.

REFERENCES

[1] Structure Analysis and Improvement of Diesel Engine Block by Weineng Zhang, Xiaohui Cao.

[2] Design a four-cylinder Internal Combustion Engine by Radoslav Plamenov Georgiev and Dr. Pedro Villanueva Roldan Dk.

[3] Finite element analysis of the dynamic behavior of an engine block and comparison with experimental modal test results by Walter ott, Hans-Jurgen Kaiser, Jurgen Meyer, Ford-Werke AG, Koln.

[4] Interface Dealing in Engine Block Assembly Modal Analysis by FEM by Shu Ge-Qun Yang Zhi-Yi.

[5] F.E. Analysis of Residual Stresses in an Engine Cylinder Head by M.Durando, R. Bonavolonta, D. Petronio, M. Leghissa.

[6] Vibration Analysis of a VCR Diesel Engine by Sachin pente, Nitin Wankhade, Pankaj Bhoyar.

[7] To Study the Dynamic Behavior of Engine Assembly by Using Altair OptiStruct by Amit Joshi, Devashish Sarkar.

[8] Analysis and study of vibrations in view of combustion gas forces for diesel engine by

[9] Sushant S.Bhansali, Dr. U.V.Kongre, N.D.Shirgire, P.R.Bodade.

[10] 9)TIME-FREQUENCY ANALYSIS OF DIESEL ENGINE NOISE by Sunny narayan.

[11] 10)Design of Internal Combustion Engine by Dr. Mahmoud A. Mashkour.