WEIGHT OPTIMIZATION OF ENGINE BLOCK USING ANSYS

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***Abstract*:** The purpose of the cylinder (engine) block is to support the components of the engine. Additionally, the cylinder block transfers heat from friction to the atmosphere and engine coolant. The air - fuel mixture from the carburetor is supplied to cylinders of the engine at very high pressures and thus the cylinder undergoes stresses and deformations. The main challenge of the mechanical engineer is to design the engine block to withstand these pressures, and also with less weight, because due to heavy weight of engine block, power consumption will be high.

In this paper, a study on static and dynamic behavior of a diesel engine block is carried out in FEM for grey cast iron. Using FEM calculation the Stresses, Natural frequencies and Mode shapes are obtained. Besides, based on the results, the less stress locations on this block are identified to reduce the weight of engine, and model is modified. Further, the Analysis is also carried on modified model for grey cast iron.

Keywords: Diesel Engine Block, Frequency, Stress, Deflection, FEM, etc.

I. INTRODUCTION

Generally, an I.C. is defined as an engine during which the chemical energy is released by fuel inside the engine and directly used for mechanical work, as opposed to an external combustion engine during which a separate combustor is employed to burn the fuel[1, 2].

I.C. engine was conceived and developed in the late 1800s and had a significant impact on society as well as it is considered one of the most significant inventions of the last century. Basically, this type of engine becomes the foundation for the successful development of the various commercial technologies [1, 3]. As an example, considering how this sort of engine has transformed the transportation industry by allowing the invention and improvement of automobiles, airplanes, trains, etc. Depending on displacement, the I.C. engines deliver power within the range from 0.01 kW to 20x103 kW[4]. The complete in the market place with electric motors, gasturbinesand steam engines and its major applications are within the automobile vehicles, marine, railroad, aircraft, etc. The vast majority of I.C. engines are produced for vehicular applications which require a power output, order of 102 kW.A study on static and dynamic behavior of diesel engine block for grey Cast Iron is carried out using FEM where the Stresses, Natural frequencies and Mode shapes are obtained. Based on the results, the less stress locations on the block are identified to reduce the weight of engine, and model is modified& analyzed.

II. METHODOLOGY

A 3D model of the Engine block has been created using NX-CAD software and the static analysis on Engine block is performed using ANSYS software. The deflections and von-mises stresses produced in the Engine block are obtained.The modal analysis of the Engine block with Grey cast iron is carried out and natural frequencies and there mode shapes are obtained.Also, the harmonic analysis of the Engine blocksare performed and the deflections and von misses stresses is obtained at critical frequencies. If any critical condition is found during analysis and design is not found suitable then engine block is again redesign and analyzed to get within limits.

III. DESIGN CALCULATIONS

a) Design of Cylinder:

i) The Longitudinal stress induces in cylinder, $\sigma_L = \frac{\text{Load}}{\text{Area}} = \frac{\frac{\pi}{4}D^2 F}{\frac{\pi}{4}(D_O{}^2 - D^2)}$

Where,

D	=	Inside Diameter of cylinder	=	75mm
D_0	=	Outer diameter of cylinder	=	85mm
F	=	Maximum pressure inside the cylinder	=	$7 * 10^{-1}$ MPa

Apparent longitudinal stress induced in cylinder, $\sigma_L = \frac{\frac{\pi}{4} * (75)^2 * 7 * 10^{-1}}{\frac{\pi}{4}((85^2) - (75^2))} = 2.46\ MPa$

ii) Length of stroke, $l = 1.8 * \text{Inside diameter of Cylinder}$

$$l = 1.8 * 75 = 135\ \text{mm}$$

iii) Length of the cylinder, $L = 1.15 * \text{Lengthofthestroke}$

$$L = 1.15 * 135 = 155.25 \approx 160\text{mm}$$

iv) The circumferential stress induces in the cylinder, $\sigma_c = \frac{\text{Force}}{\text{area}} = \frac{D * L * F}{2t * L}$

Where, t =Thickness of the cylinder wall = 10 mm

The apparent circumferential stress induced in the cylinder,

$$\sigma_c = \frac{D * L * F}{2t * L} = \frac{75 * 160 * 7 * 10^{-1}}{2 * 10 * 160} = 2.6\ MPa$$

b) Design of Cylinder Flange and Studs:

The cylinders were cast integral with the upper half of the crankcase by means of a flange with studs. The cylinder flange is integral with the cylinder and made thicker than the cylinder wall.

i) Flange thickness (t_f) $t_f = 1.4 * \text{Thickness of the cylinder wall}$

$$t_f = 1.4 * 10 = 14\ mm$$

ii) Nominal diameter of stud, d

$$d = 0.75 * flange\ thickness = 0.75 * 14 = 10.5\ mm \cong 11mm$$

As nominal diameter of stud should not be less than 16mm therefore nominal diameter of stud has been taken as 16 mm.

iii) **Diameter of Stud Pitch circle & flange**

(a) Distance of flange from the center of the hole for the stud = d+6 =16+6 = 22 mm

(b) For leak proof, Pitch of studs = $19\sqrt{d} = 19\sqrt{16} = 76\ mm$

From above calculations,it is seen that the estimated stress values are less than the yield stress values and hence, the estimated design is safe for the above loading conditions.

IV. 3D MODELLING and STRUCTURAL ANALYSIS ENGINE BLOCK

The 3D model of the Diesel Engine block has been created using NX-CAD software and the isometric view of the block is shown in fig. no. 1. The FEM analysis of the engine block is performed under pressure condition and the characteristics of stress distribution and high stress location are found. The meshed model of Engine block is shown in fig. no. 2. The boundary condition is considered over engine block i.e. stud locations at the bottom of engine block are constrained in all DOF and pressure load of 0.7mpa is applied on inner surface of cylinder which is shown in fig. no. 3.The Maximum Displacement vector sum observed as 0.0004mm on Engine block as deflection and maximum Von Mises Stress observed as 1.973MPa is shown in fig. no. 4 and 5 repectively.

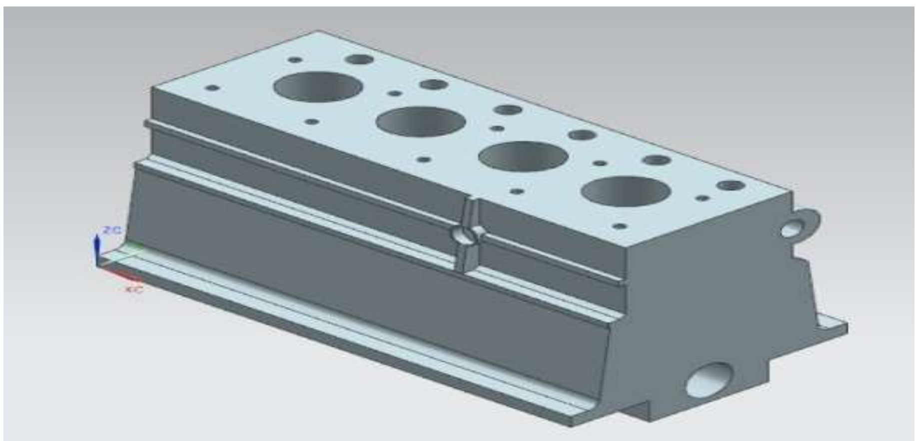


Fig. No. 1 Isometric view of Engine block

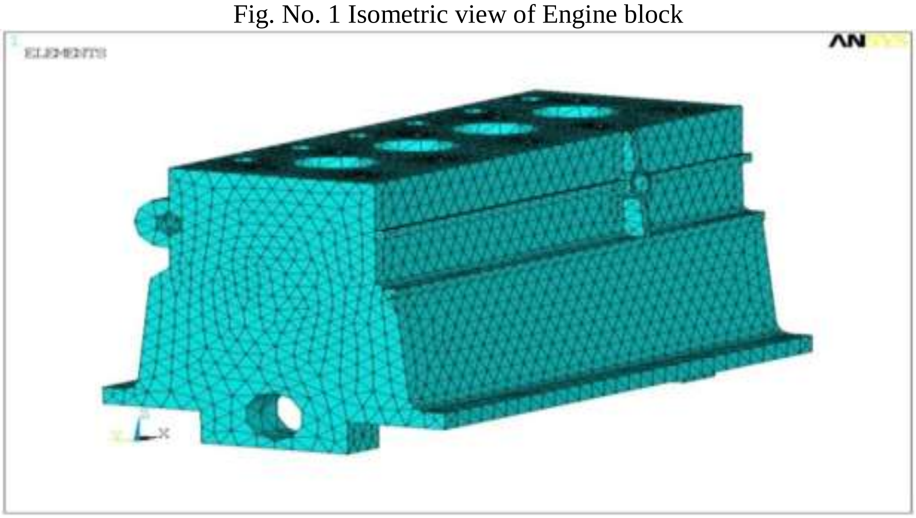


Fig. No. 2Meshed model of Engine block

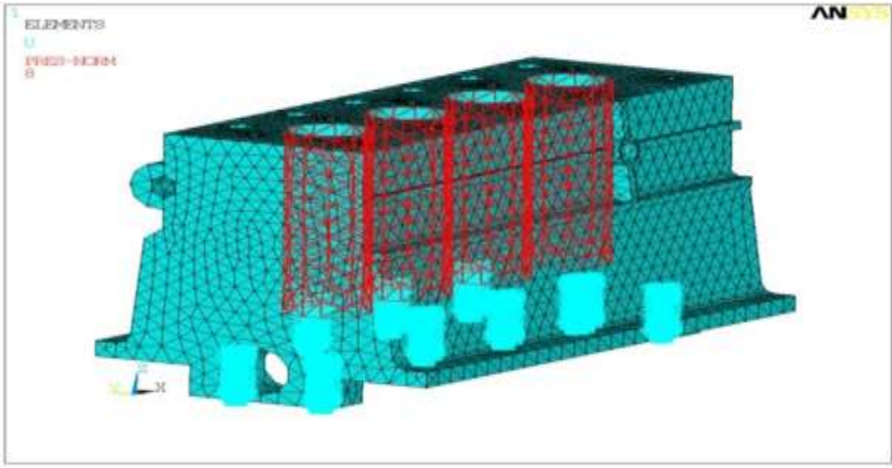


Fig. No. 3Applied Boundary conditions and Pressure of engine block

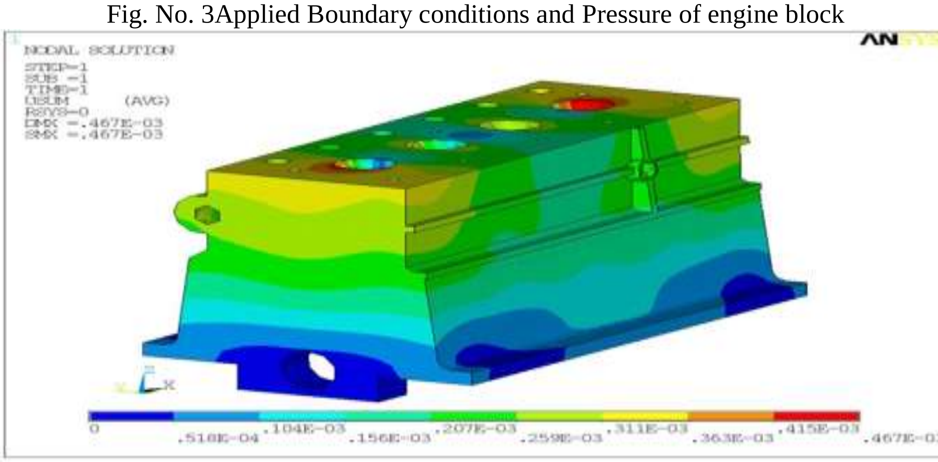


Fig. No. 4 Maximum Displacement of Engine block

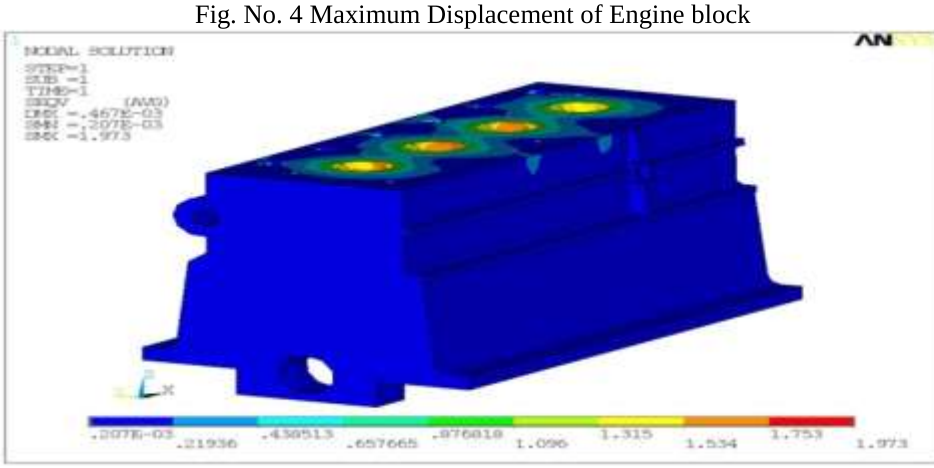


Fig. No. 5 Von Mises stress of Engine block

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

V. MODAL& HARMONIC ANALYSIS OF ENGINE BLOCK

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. Fig. no. 6 shows the applied boundary condition on engine block where Stud locations at bottom of Engine block are fixed in all DOF.

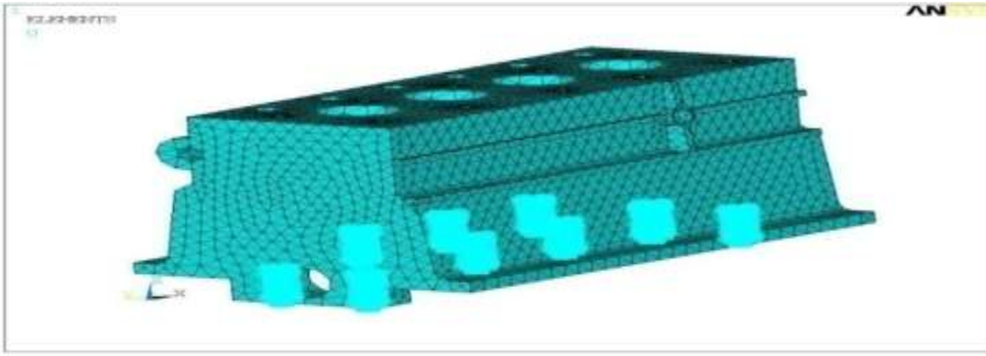


Fig. no. 6 Applied Boundary conditions on Engine block

From the modal analysis, the natural frequencies are observed in the range of frequency0-2000 Hz. Also, thefrequency, participation factor and effective mass of various mode shapes are obtained in X, Y, Z direction in the range of 0-2000Hztabulated in table no. 1. The results of mode shape 1& 6 at the frequency of341.9Hz and 1627Hz for Engine block is shown in Fig. No.7 and 8 respectively.

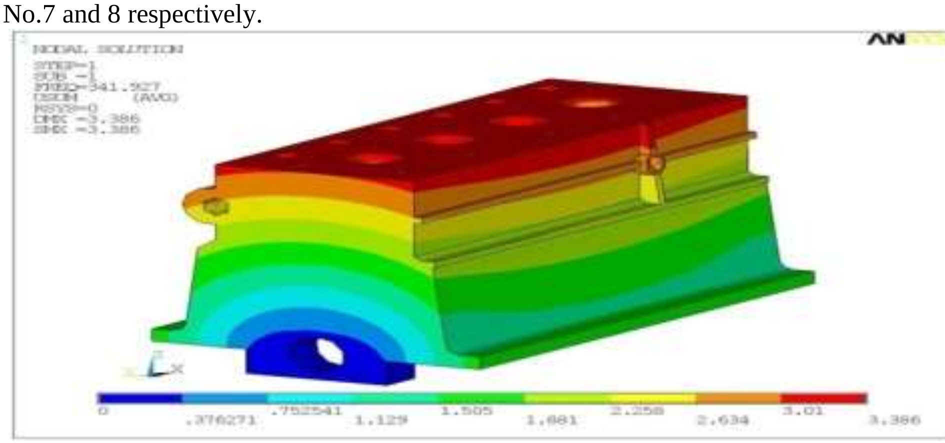


Fig. No. 7 Mode shape 1 at 341.9Hz for Engine block

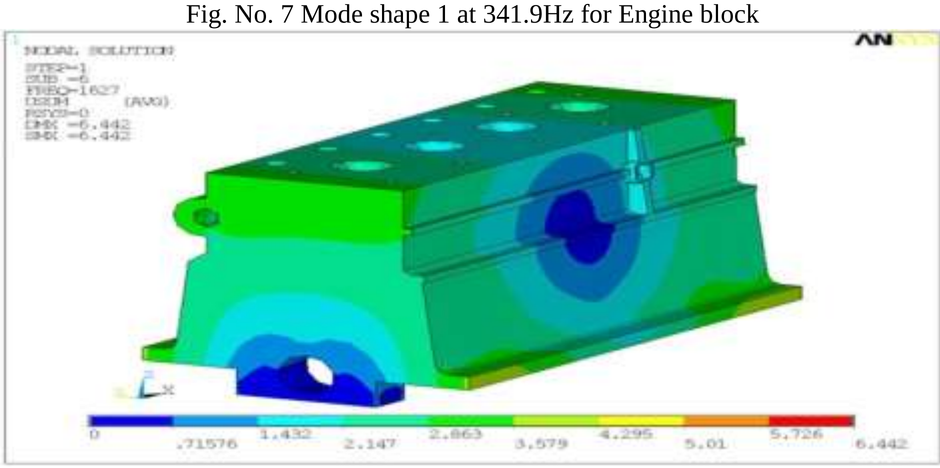


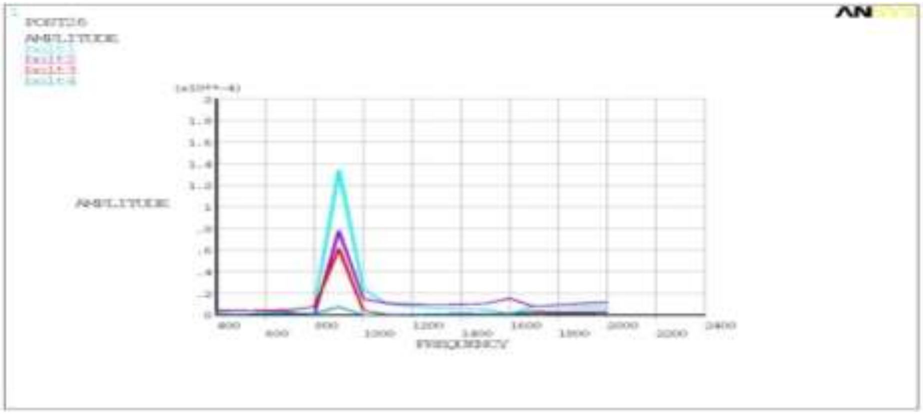
Fig.No. 8 Mode shape at 1627Hz for Engine block

Table No. 1 Frequencies, Participation factor and Effective Mass in the range of 0-2000Hz

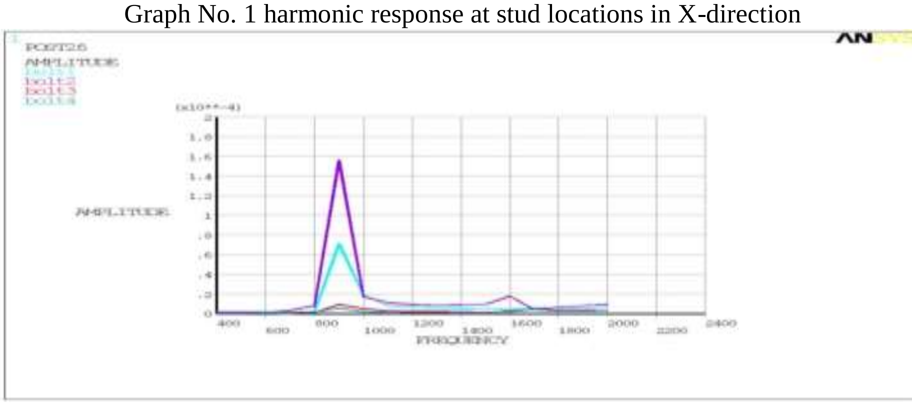
MODE	FREQUENCY	PARTICIPATION FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	341.927	2.79E-04	0.399	-3.91E-03	7.76E-08	0.159	1.53E-05
2	480.328	0.461	-1.01E-04	1.20E-02	0.212	1.01E-08	1.45E-04
3	775.505	3.57E-03	-5.40E-03	2.49E-03	1.27E-05	2.92E-05	6.19E-06
4	908.565	-1.12E-2	2.07E-02	0.430	1.26E-04	4.29E-04	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

From above analysis, the total weight of the Engine block is found as 0.222Ton.The maximum mass participation is obtained in X, Y and Z direction are 0.212 tones,0.159Tone and 0.185Tone for the frequency of 480.328Hz, 341.927Hz and 908.565Hz respectively.

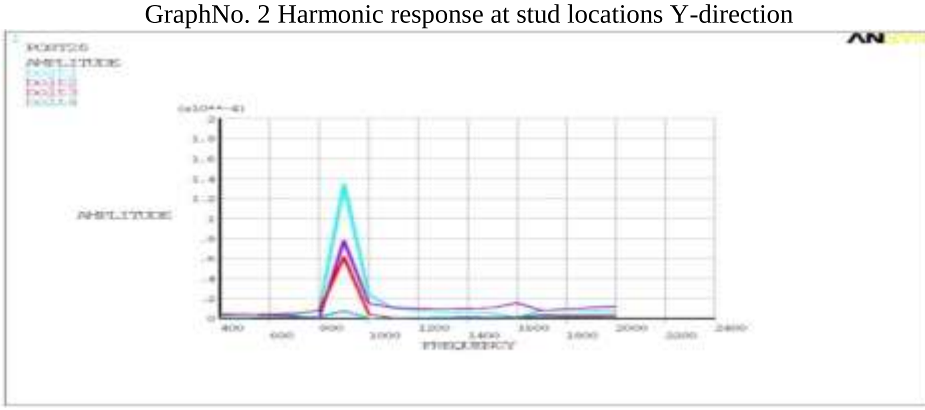
Further, Engine block is subjected to harmonic analysis to check the structure response at mentioned frequency due to the operating loads.The boundary conditions and loading of Engine block where Pressure is applied on inner surface of cylinder of Engine block. Harmonic response at stud locations of Engine block in X, Y and Z –direction are shown in graph1,2&3 respectively.



Graph No. 1 harmonic response at stud locations in X-direction



GraphNo. 2 Harmonic response at stud locations Y-direction



Graph No.3 Harmonic response at stud locations in Z-direction

The deflections and stresses nearest to the above frequencies are plotted below for mode shape 1 and 6. The maximum deflection and stress of frequency at 341.927Hz are shown in figure no.9 and 10 respectively.

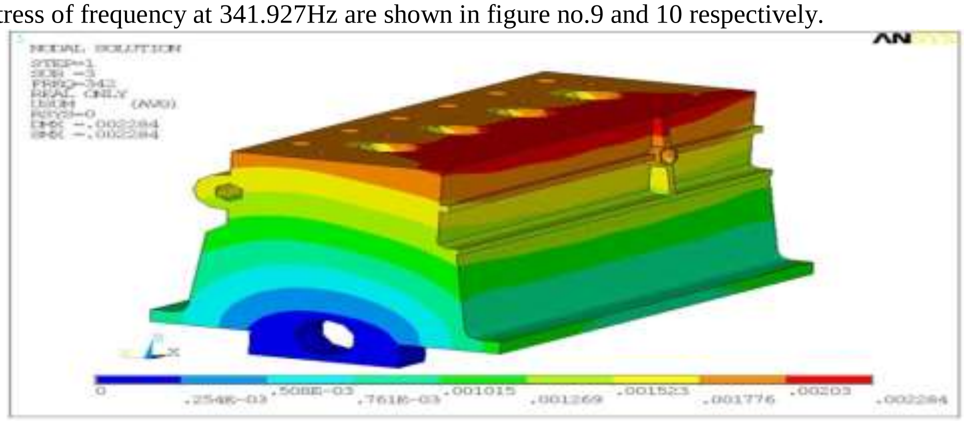


Fig. No. 9Maximum Deflection of Engine block

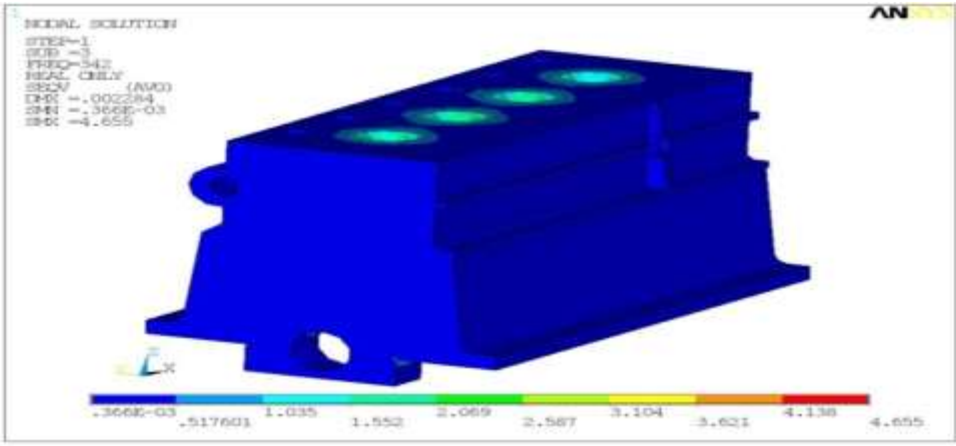


Fig. No. 10VonMises stress of Engine block

The maximum deflection and stress of frequency at 1627.37 Hz are shown in figure no. 11 and 12 respectively.

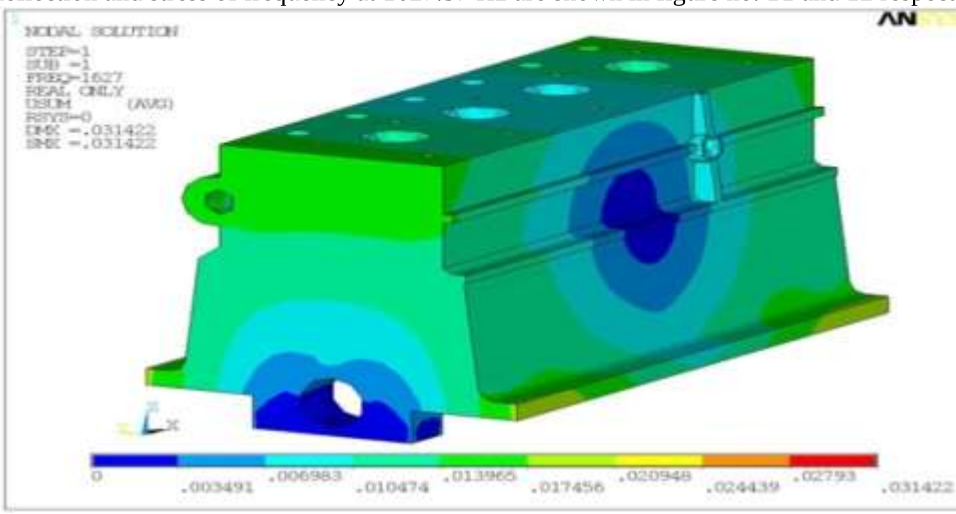


Fig. no. 11 Deflection of Engine block

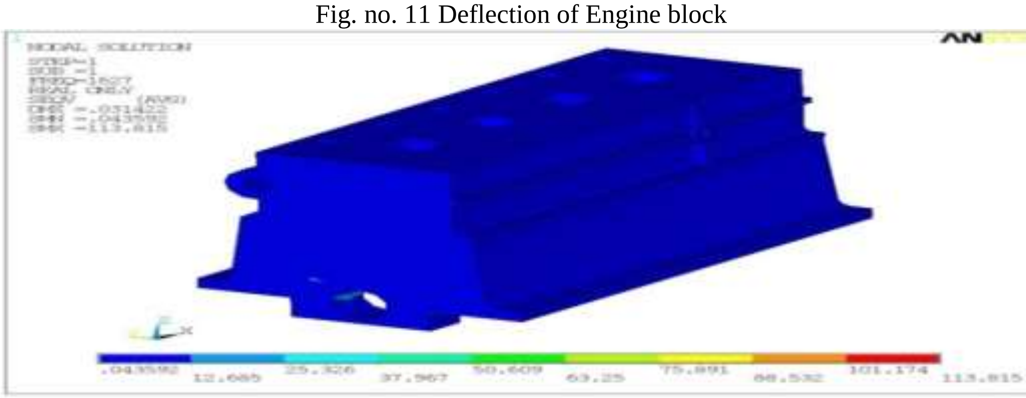


Fig.No. 12 Von Mises stress of Engine block

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. According to 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.But the weight of the engine is too high, so the weight of engine block should be reduced by modifying the block considering the removing of extra material from less stress locations.

VI. 3D MODELLING& STRUCTURAL ANALYSIS OF MODIFIED ENGINE BLOCK

From the analysis Engine block is modified by identifying the low stress regions and the extra material is removed from those areas. The isometric view modified model of engine block is shown below in fig. no. 13. The weight of the modified engine block is obtained as 0.118 Tons.The boundary condition and pressure has been considered as earlier.

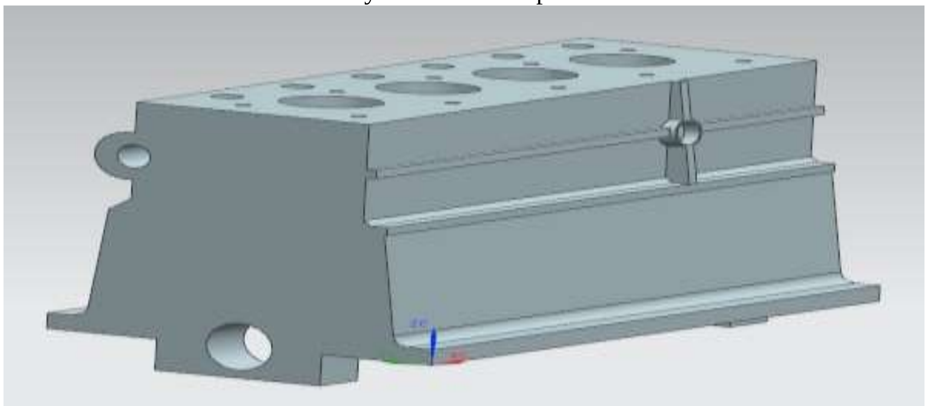


Fig.No. 13Isometric view of modified Engine block

Fig. no. 14 and 15 shows the Maximum Displacement andVon Mises Stress on modified Engine block observed as 0.00047mm &2.095MPa respectively which is less than the yield strength of the material.Thus,the design of modified Engine block is safe for the above operating loads.

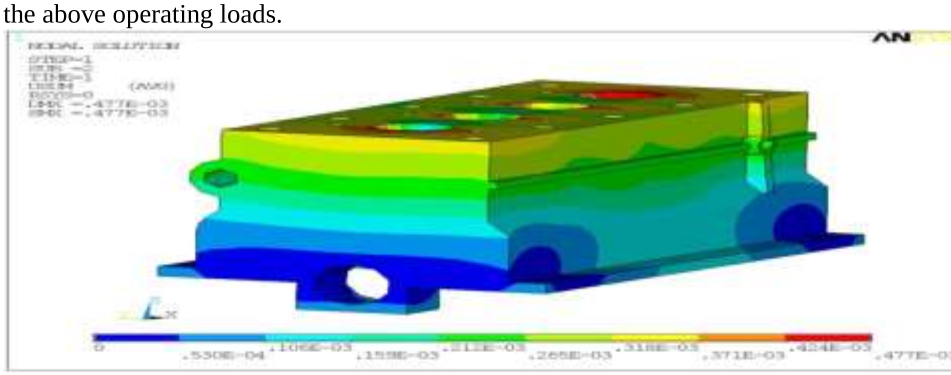


Fig.No. 14 Maximum Displacement of modified Engine block

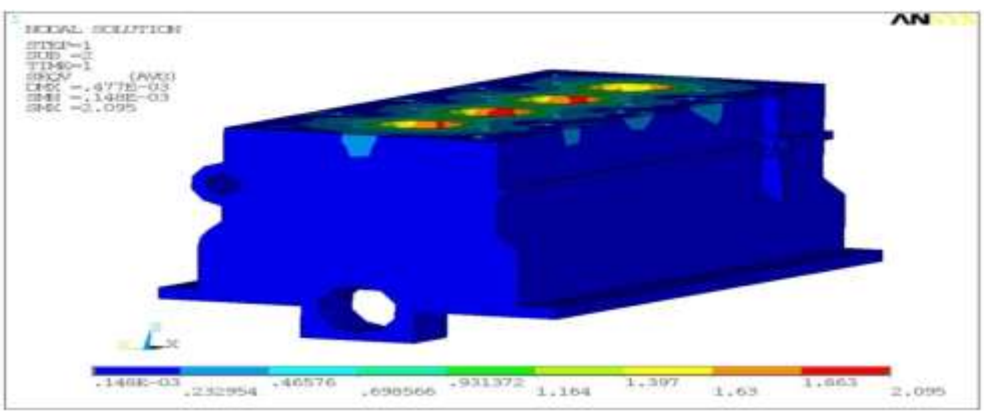


Fig. No. 15Von Mises stress of modified Engine block

VII. MODAL & HARMONIC ANALYSIS OF MODIFIED ENGINE BLOCK

Modified 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. Also, thefrequency, participation factor and effective mass of various mode shapes are obtained in X, Y, Z direction in the range of 0-2000Hz tabulated in table no. 1. The Table no. 2 **Shows**thefrequency, participation factor and effective mass of various mode are obtained in X, Y, Z direction in the range of 0-2000Hz.Arbitrary, mode shapes 1 and 5 is taken and plotted below in figure no. 16 and 17 respectively for the above frequencies.

Table No. 2: Frequency, Participation factor and Effective Massof various modein the range of 0-2000Hz

MODE	FREQUENCY	PARTICIPATION FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	802.853	6.06E-04	0.30208	-4.17E-03	3.68E-07	9.13E-02	1.74E-05
2	1070.73	0.32361	-9.13E-04	-1.23E-04	0.104726	8.33E-07	1.52E-08
3	1191.66	1.46E-03	7.64E-02	1.69E-02	2.14E-06	5.84E-03	2.86E-04
4	1255.29	7.70E-06	2.25E-04	0.30449	5.93E-11	5.06E-08	9.27E-02
5	1522	-1.7E-03	-3.57E-04	1.93E-04	3.07E-06	1.28E-07	3.74E-08

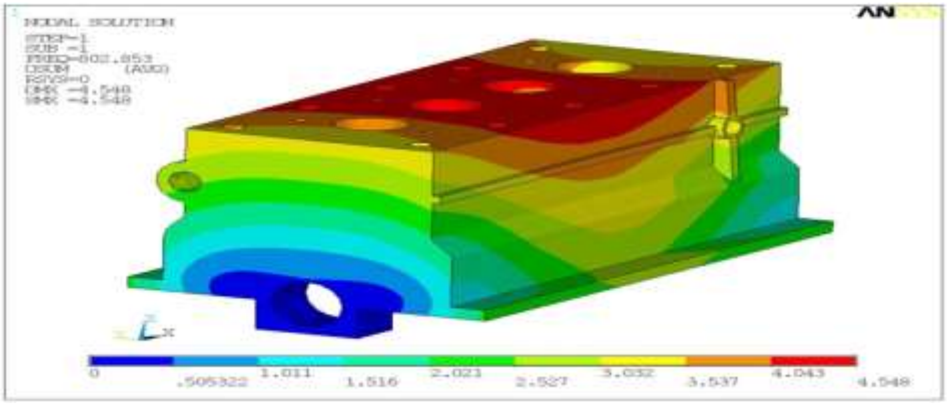


Fig. No. 16 Mode shape 1 at 802.8Hz

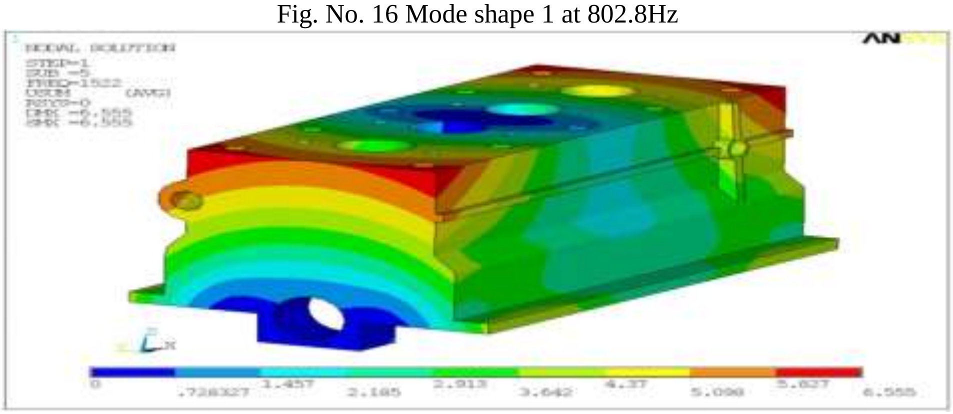
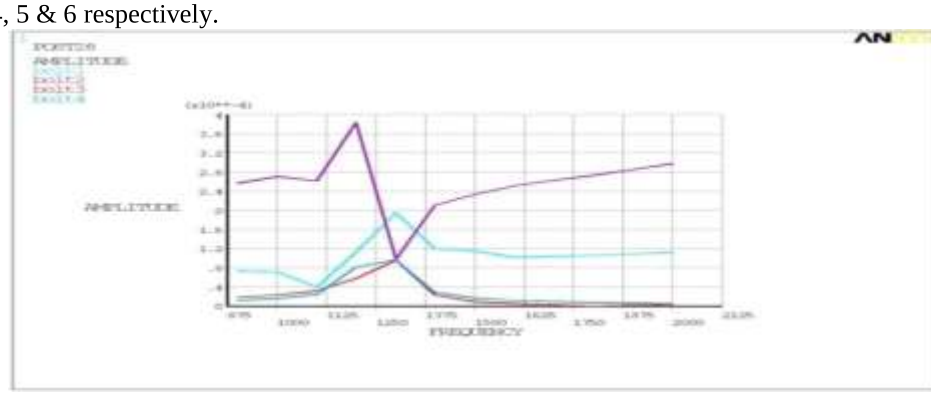


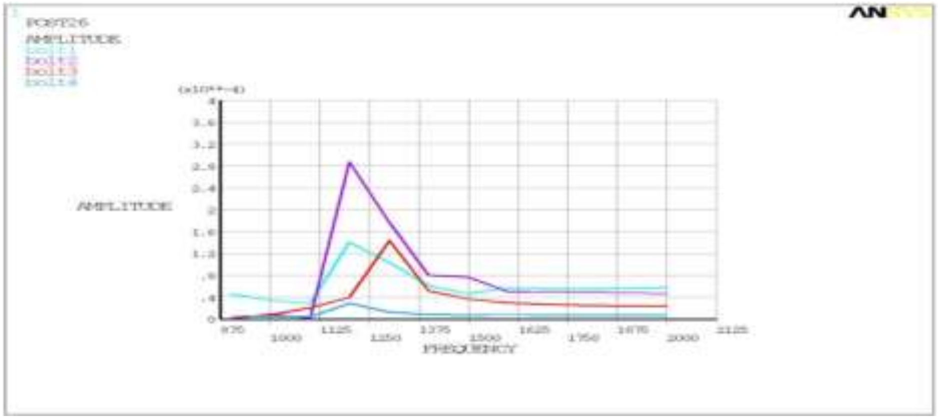
Fig.No. 17 Mode shape 5 at 1522Hz

From the above modal analysis, the total weight of the modified Engine block is 0.118Tone. The maximum mass participation is obtained in X, Y and Z direction are 0.104 tones,0.091Tone and 0.092Tone for the frequency of 1070.7Hz, 802.8Hz and 1255.6Hz respectively.

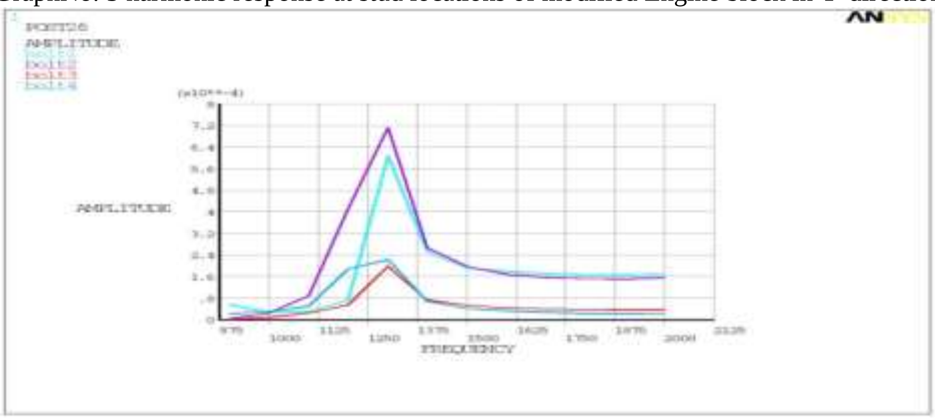
Modified Engine block is also subjected to harmonic analysis, to verify the structure response at the mentioned frequency which occurs due to the operating loads. The boundary condition has been taken in account where pressure is applied on inner surface of cylinder of Engine block. Harmonic response at stud locations of Engine block in X, Y and Z –direction are shown in graph 4, 5 & 6 respectively.



GraphNo. 4harmonic response at stud locations of modified Engine block in X-direction



GraphNo. 5 harmonic response at stud locations of modified Engine block in Y-direction



GraphNo. 6harmonic response at stud locations of modified Engine block in Z-direction

The deflections and stresses nearest to the above frequencies are plotted below for mode shape 1 and 5. The maximum deflection and stress of frequency at 802.3Hz are shown in figure no.18 and 19 respectively.

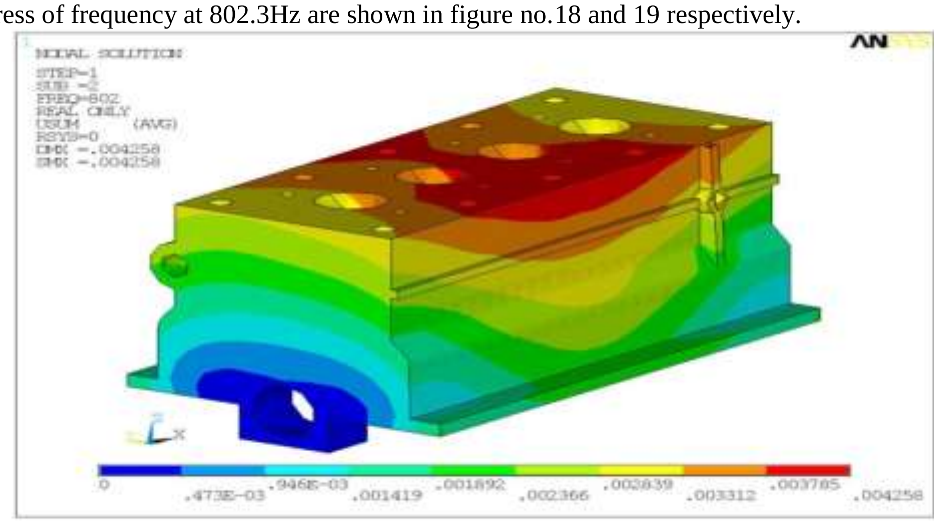


Fig. No. 18maximum Deflection of modified Engine block

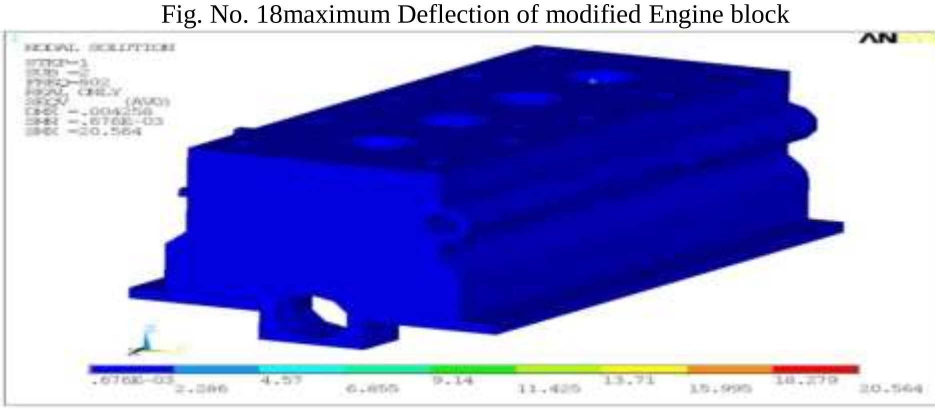


Fig. No. 19 VonMises stress of modified Engine block

The maximum deflection and stress of frequency at 1522 Hz are shown in figure no.20 and 21 respectively.

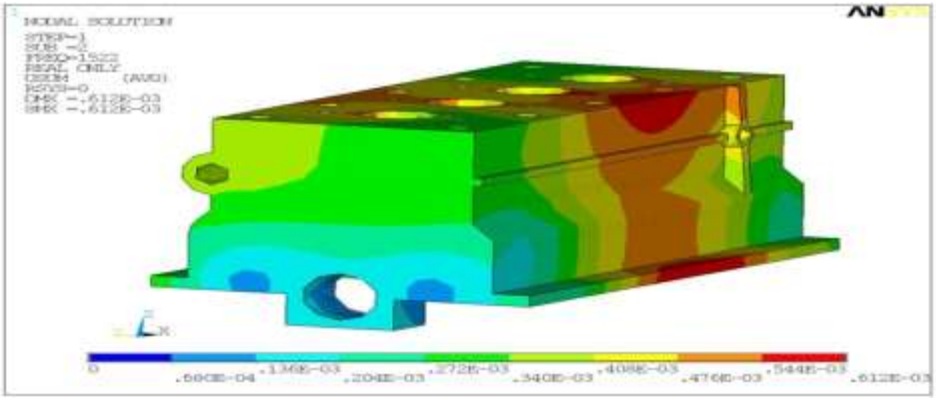


Fig. No. 20 maximum Deflection of modified Engine block

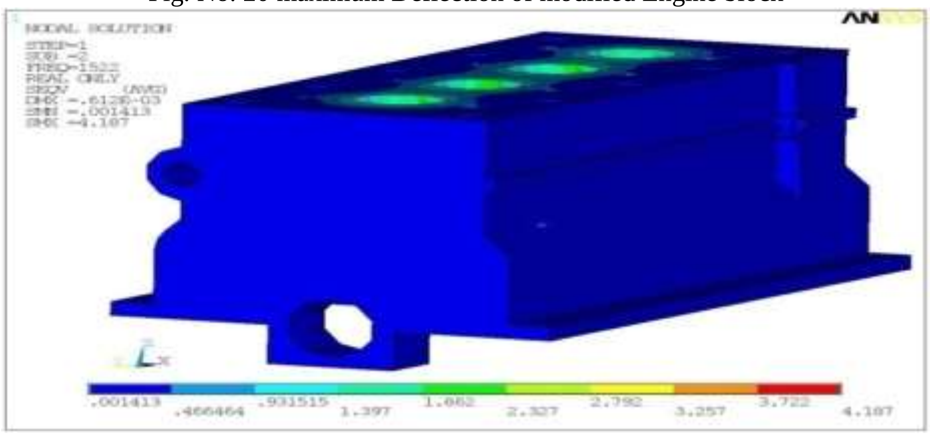


Fig.No. 21 the Von Mises stress of modified Engine block

From the above results, it is observed that various mode shape is obtained at the critical frequencies 802.8Hz, 1070.7Hz, 1191.6Hz, 1255.2Hz and 1521.6Hz and having stresses of 20.5MPa, 3MPa, 2.92MPa, 44.5MPaand 4.18MPa respectively which is well below than the yield strength of the material. The design of modified Engine block is safe for the above operating loads.

VIII. RESULTS

Engine block and modified engine block are subjected to structural analysis and three different cases have been studied for structural behavior. They are Static analysis, Modal analysis and Harmonic analysis. From static analysis, the maximum von mises stress of engine block and modified block found as 1.973 and 2.095 MPA. The frequencies obtained from modal analysis for engine block and modified engine blocks are within limits. The total weight of the Engine blockis 0.222Tonne which is too high. Thus, the weight of engine block has been reduced by modifying the block considering the removing of extra material from less stress locations and the weight of the modified Engine block is found as 0.118 Tone. The stress at critical frequencies of both engine block and modified engine block has been observed from harmonic analysis and found as within limits (i.e. the von misses stress is less than the yield strength of the material), tabulated in table no. 3. Thus, the design of modified engine block is safe for the above operating loads.

Table No. 3: Stress at critical frequencies for engine block and modified engine block

ENGINE BLOCK		MODIFIED ENGINE BLOCK	
Frequency (Hz)	**von mises stress (Mpa)**	**Frequency (Hz)**	**von mises stress (Mpa)**
341.927	**4.65**	**802.853**	**20.5**
480.328	**2.41**	**1070.73**	**3.00**
775.505	**6.20**	**1191.66**	**2.92**
908.565	**240**	**1255.29**	**44.5**
986.065	**122.46**	**152**	**4.18**

IX. CONCLUSION

In the present paper, an engine block and modified engine block has been designed and analyzed for structural behaviors.The total weight of the Engine block has reduced from 0.222Tonne to 0.118 Tonne by modifying the block considering the removing of extra material from less stress locations. From the structural analysis results it is concluded that that the Engine block and modified engine block has stresses and deflections within the design limits of the material used. The deflections and stresses obtained in the harmonic analysis are also under the design limits of the material.

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