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Finite Element Analysis of the Effect of Vibration on a Generator Engine Block Using the Modal Analysis

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ABSTRACT

The finite element analysis of the effect of vibration on a generator cylinder block using a modal analysis has been successfully carried out in this study. The generator cylinder block was singled out for its importance in the internal combustion engine system. The component is the basic structure in the engine system. The component was graphically modeled in the AutoCAD software and exported to the ANSYS environment for analysis. The Modal analysis tool was applied in the analysis. The component was meshed and attached with boundary conditions. The maximum equivalent stress, equivalent strain and total deformation of the engine component were determined to be 25.656 MPa, 0.000132, and 1.1064 mm respectively at a vibration frequency of 60.439 Hz. The effect of the vibration on the engine component reveals that a maximum and minimum total deformation of 1.1064 mm and 0.11239 mm respectively occurred at a frequency of 60.465 Hz . Also, it was noticed that the maximum and minimum total deformation increased to 1.6529 mm and 0.18066 mm respectively at a frequency of 65.211 Hz. It is a pointer that the higher the frequency the higher the rate of deformation, stress impact and vibration.

1. INTRODUCTION

The internal combustion engine is an automobile heat engine that converts generated chemical energy from fuel into heat energy and then finally into mechanical energy (Aliemeke and Oladeinde, 2020). The internal combustion engine is comprised of pistons, cylinder block, sleeves and connecting rods (Ang and Ku, 2021).

The cylinder block is major component of automobile and generator engines (Oladeinde, *et al*. 2016). It is designed to fit into the engine system of automobiles as it is meant to function in multiple dimensions. It bears a hollow compartment that accommodates the trunk pistons of the engine system (Arapatsakos, *et al.* 2015). The internal configuration of the block is expected to be technically precise since it will have to function with relative movement of the other components of the internal combustion engine. The cylinder block serves as the foundational component of the generator engine as it is the major structural framework of the internal combustion engine (Harris and Birkitt, 2016).

Mechanical vibration is an inherent phenomenon said to occur in numerous engineering systems that may involve power transmission and motion (Jagota, *et al.* 2013). Understandably, almost all engineering design systems experience mechanical vibration when subjected to dynamic loading (Chaudhari and Barjibhe, 2016). In internal combustion engines, vibration occurs when unbalanced inertia forces results. Several other factors are reciprocating motion effect of the pistons, rotational motion of the crankshaft, combustion pressure of the engine chambers and interaction between the components (Balamurugan, *et al.* 2011). Vibration effects are inevitable in engine system as they could be transmitted from one engine structure to the other. They are bound to occur and could only be mitigated.

Generators rely on internal combustion engine which transmit chemical energy to heat energy to mechanical energy before electrical energy to attain a dependable energy chain (Asiri, 2022). Generators are known to be subjected to dynamic forces which pave way for the development of vibration which serves to introduce some structural challenges. The study of generator reliability and performance continues to gain positive expression as there exist growing trend in attaining power increase commensurate in overcoming the global power demand. It is very important to increase the durability and structural integrity of internal combustion engine of generators to be able curb adverse effects that may arise during working operations (Deshbhratar and Suple, 2012).

Vibration in cylinder blocks does not necessarily connote a noise-related challenge. It can be seen as a technical issue that may directly affects safety, performance and working efficiency (Meng and Liu, 2021). Constant vibration may bring about the induction of cyclic stresses in the internal combustion engine as such leading to crack initiation, propagation and eventual fatigue failure. Vibration effects have led to structural damage of components, equipment and facilities. Vibration leads to loosening of bolts and nuts, wear on mechanical bearing, poor alignment of rotating components and collapse of equipment or facility structures (Fu and Liu, 2016). With time, vibration effects may result in breakdowns, increased cost of maintenance and reduced efficiency.

Vibration ravaged equipment or facilities tend to pose a huge risk to operators and users alike. There are well-known examples of failed construction bridges and metallic platforms that have occurred as a result of adverse effects of vibration. Consequently, the ability to understand and control the vibration tendencies of cylinder blocks of generators is outright essential for engendering system reliability, performance and component service life (Grujic *et al*. 2018).

In the past, vibration testing has always been carried out through laboratory means such as impact testing experiments, shaker experiments and modal testing (Gu and Zhou, 2021). These experimental techniques made incisive insights in the world of testing vibration effects. They are known to be time-consuming and expensive to carry out. Attempting physical testing entails the deployment of sophisticated prototypes which escalates development cost and restrict the adoption of employing numerous design alternatives (Harris, *et al*. 2019).

The introduction of computational engineering techniques has brought to bear Finite Element Analysis (FEA) as a dependable and efficient approach in determining a behavioural pattern of complex engineering structures (Menaceret *et al.* 2020). It enables scientists and engineers to discretize complex geometries by applying material properties and boundary conditions before simulating the structure in a very short time with utmost accuracy (Murthy,et al. 2013). Modal analysis is a critical tool analysis system of Finite element used to study dynamic characteristics of engineering structures such as cylinder block (Ebhojiaye and Sadjere, 2017). It targets the determination of natural frequencies and structural mode shape of components.

This study targets the application of a modal analysis tool system of Finite Element to investigate the effect of vibration on a generator cylinder block (Patel, *et al.* 2018). The cylinder block system geometry will be created and assigned material properties and boundary conditions. The modal analysis tool system will identify the natural frequencies and mode shapes that govern the vibration behavior of the component structure (Aliemeke and Iyore, 2021).

2. MATERIALS AND METHODS

2.1. Materials

The materials deployed are Finite Element Analysis software ANSYS, AutoCAD software, vernier caliper, and micrometer screw gauge (Sandya *et al.,* 2016).

2.2. Design of the Cylinder Block

Design assumptions were made for the cylinder block as follows:

i. Maximum speed of 2800 rpm
ii. Displacement of volume 85 cm^3
iii. 2-stroke internal combustion engine
iv. Maximum hoop stress 51 N/mm^2

The calculation of the cylinder length and bore diameter was done using Equations (1) and (2) obtained from Shahane and Pwar (2017).

$$R_s = \frac{d_b}{l_p} \tag{1}$$

$$S_w = \frac{\pi n l_p d_b^2}{4} \tag{2}$$

Where R_s=Ratio of the stroke length to the bore diameter

l_p=Stroke length in mm
d_b=cylindrical bore diameter in mm
S_w=swept volume in mm^3
n= number of cylinder

The ratio of the stroke length was taken to be 0.9 .

The piston stroke expression was found to be shown as given by Equation (3).

$$d_b = 1.2 \times l_p \tag{3}$$

Considering a swept volume of 85 cm^3, the bore diameter can be determined as shown in Equation (4) .

$$85 = \frac{\pi \times 1 \times (1.2 l_p)^2 \times l_p}{4} \tag{4}$$

2.3. Design of Cylinder Wall thickness

The cylinder wall thickness was determined using Equation (5).

$$T_c = \left(\frac{P_m \times d_b}{2\delta_s}\right) + K \tag{5}$$

Where T_c= cylinder thickness

P_m=Maximum gas pressure (MPa)

δ_s= Hoop stress in N/mm^2

K= reboring factor

2.4. Design of Cylinder Length

The cylinder length is always longer than the piston stroke and as such a clearance on both sides was regarded as 15% of the piston stroke. Hence, the cylinder length was determined using Equation (6).

$$C_l = l_p \times 15\% l_p \tag{6}$$

Whrere C_l =Cylinder length

2.5. Determination of the Cylinder Head Thickness

Cylinder head accommodates the inlet and outlets valves in spark ignition engine. The cylinder head thickness was determined by using Equation (7).

$$C_{ht} = d_b \left(\frac{KP_m}{\delta_s}\right)^{\frac{1}{2}} \tag{7}$$

Where C_{ht}= Cylinder head thickness and K= cylinder head constant

2.6. Determination of the Cylinder Bolt Diameter

The cylinder bolt is used to fasten the cylinder head to the cylinder block. Its diameter can be determined using Equation (8).

$$B_d = d_b \times \sqrt{\frac{P_m}{Zf_c}} \tag{8}$$

Where B_d = bolt diameter in mm and Z= number of stud

The number of stud was determined by applying Equation (9).

$$Z = \frac{d_b}{100} + 4 \tag{9}$$

2.7. Determination of the 0.67Hp Engine Torque

The determination of the generator engine torque is essential in power capacity design. The engine torque was calculated using Equation (10) .

$$T = \frac{M_{bp} \times V_s}{2\pi \times n_r} \tag{10}$$

Where M_{bp}= Brake mean effective pressure

n_r =number of revolution

Vs=Swept volume

2.8. Determination of Engine Power

The developed power needed for power output is known as the indicated power. It can be determined using Equation (11).

$$Mechanical\ efficiency = \frac{Brake\ power}{Indicated\ power} \tag{11}$$

The developed brake power was determined using Equation (12) obtained from Sheth and Kothari, (2020).

$$B_p = 2\pi TN \tag{12}$$

2.9. Determination of Mean Effective Pressure

The mean effective pressure of the 0.67 hp generator was determined using Equation (13).

$$M_p = \frac{2\pi TN}{S_w} \tag{13}$$

Where Mp= Mean effective pressure(Mpa).

3. RESULTS AND DISCUSSION

The various parametric values designed for were used to develop a detailed isometric drawing of the internal combustion engine component. Also, the designed values were juxtaposed with the recommended values from standard texts. The results obtained where found to be in consonance with that obtained in Zheng et al. (2022).

3.1. Summary of the Parameters of the Designed Cylinder Block

The ratio of the stroke length was taken to be 0.9. Substituting the value of the bore diameter from Equation (3) into Equation (4) will yielded a piston stroke of 49.20 mm. Also, by substitution of the piston stroke numerical value into Equation (3) gave a bore diameter of 44.30 mm. The imputation a maximum hoop stress, maximum gas pressure and a reboring factor for bore diameter of 44.3 mm chosen to be 51 N/mm^2, 3.5 N/mm^2 and 1.5 respectively in (5) yielded a cylindrical wall thickness of 3.02 mm. The substitution of piston stroke into Equation (6) yielded a cylinder length of 56.58 mmA cylinder head constant of 0.162 was applied in this study. The cylinder head thickness was determined to be 4.669 mm by the substitution of the bore diameter, hoop stress and maximum gas pressure in Equation (7). The cylinder bolt thickness was determined to be 5.51 mm as a result of the substituted values of bore diameter, hoop stress, number of stud and maximum gas pressure in Equation (8). Applying a brake mean effective pressure of 850 kPa for a 3000 rpm at a swept volume of 85cm^3 in Equation (10) developed an engine torque of 11.46 Nm. The brake power that developed a torque of 11.49Nm at a speed of 3000rpm was determined to be 3591.3 W.

In a bid to attain a mechanical efficiency of 75%, the developed brake power of 3591.3 Watt was substituted in Equation (11) to achieve an indicated power of 4788.4 Watt which was noticed to be within the recommended range of small internal combustion engines as given in Ebhojiaye and Sadjere, (2017).

The parameters of the designed cylinder block are shown in Table 1. The obtained values are similar to that obtained by Ebhojiaye and Sadjere, (2017) and Zheng et al. (2022). Futhermore, the results and the recommended ranges are similar to that obtained by Aliemeke and Oladeinde (2020).

Table 1: Summary of the designed data for the cylinder block parameters

Parameters	Designed value	Recommended range
Bore diameter (mm)	44.30	43-50
Cylinder length (mm)	56.58	50-75
Piston stroke (mm)	49.20	45-76.5
Cylinder thickness (mm)	3.02	3.0-6.0
Brake power (kW)	3.591	1.5-5.0
Indicated power (kW)	4.788	1.5-5.0
Mean effective pressure (MPa)	42.47	-
Cylinder wall thickness(mm)	3.02	2.5-6.0
Engine torque (Nm)	11.46	-
Cylinder bolt thickness(mm)	5.51	4-7

3.2. Graphical Design of the Cylinder block

An isometric drawing of the internal combustion engine component carried out by the AutoCAD design software is shown on Figure 1 while the first angle orthographic projection showing some of perspective views is shown in Figure 2. Figures 1 and 2 show the cylinder bore, bolt holes and fins. The cylinder bore is a region where the piston travels within the engine component. The fins help in the cooling of the dissipated heat in the engine components.

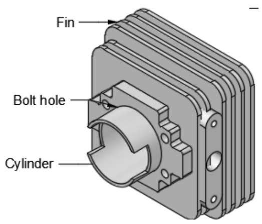

Figure 1: Isometric view of the Cylinder block

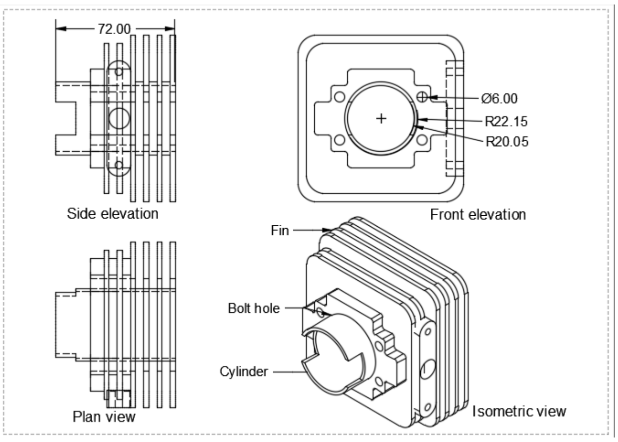

Figure 2: First angle orthographic projection of the cylinder block

3.3. Finite Element Analysis

The finite element analysis was carried out using the modal analysis tool . The nodes and elements developed in the simulation are 19616 and 10190 respectively. The graphically modeled cylinder block was exported to the ANSYS environment as shown in Figure 3. The modal analysis tool system was applied to the exported geometry. The meshed geometry shown in Figure 4 was attached with fixed supports to function as boundary conditions.

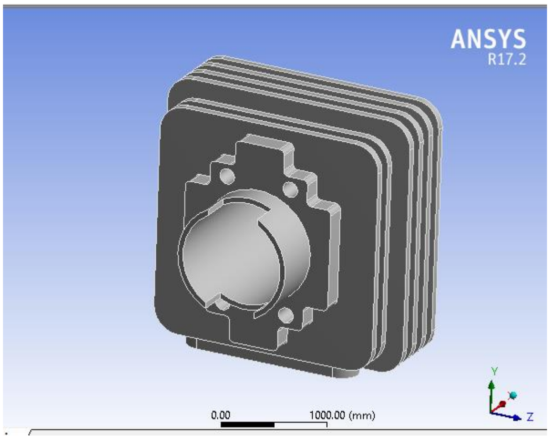

Figure 3: Imported geometry from AutoCAD

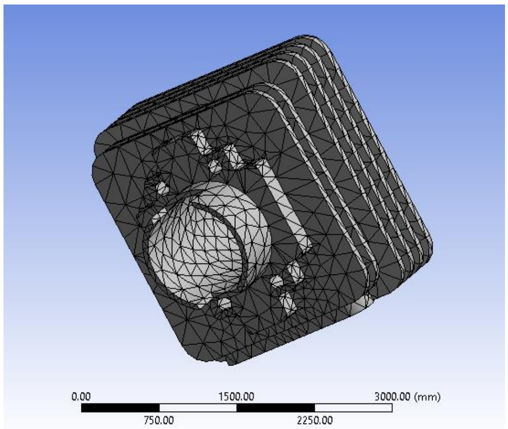

Figure 4: Meshed cylinder block

The frequency was used in analyzing the effect of the vibration on the generator engine block. The equivalent maximum and minimum stress on the block were determined to be 25.656 MPa and 2.85 MPa respectively as shown in Figure 5. This shows that any higher stress added to the cylinder block could pave the way for eventual fatigue. The maximum and minimum equivalent strain were determined to be 0.000132 mm/mm and 1.466×10^{-5} mm/mm respectively as shown in Figure 6. These values for strain produced by the frequency are similar to that obtained by Uluocak and Yawuz (2016). An investigation into the effect of the vibration on the engine component reveals that a maximum and minimum total deformation of 1.1064 mm and 0.11239 mm respectively at a frequency of 60.465 Hz as shown in Figure 7. It was noticed that the maximum and minimum total deformation increased to 1.6529 mm and 0.18066 mm respectively at a frequency of 65.211 Hz as shown in Figure 8. It is a confirmation that the higher the frequency, the higher the rate of deformation, stress impact and vibration as noticed in Figure 9 (Zhao, 2021).

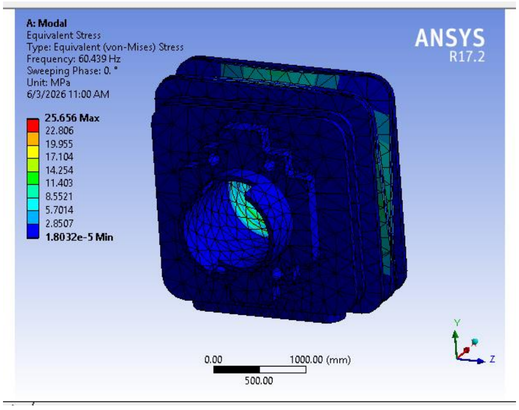

Figure 5: Equivalent stress on the cylinder block

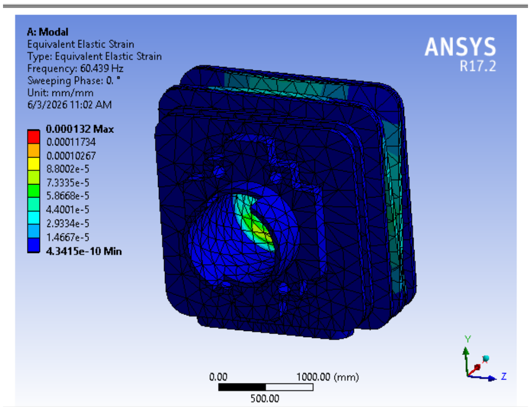

Figure 6: Equivalent strain on the cylinder block

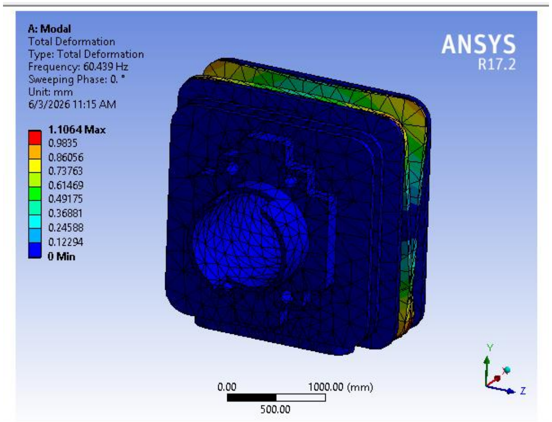

Figure 7: Total deformation on the cylinder block

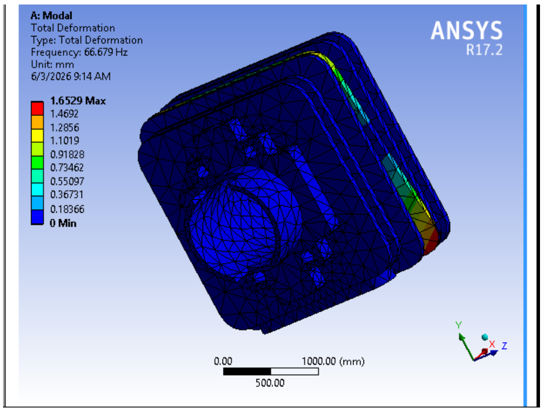

Figure 8: Total deformation on the cylinder block at a higher frequency

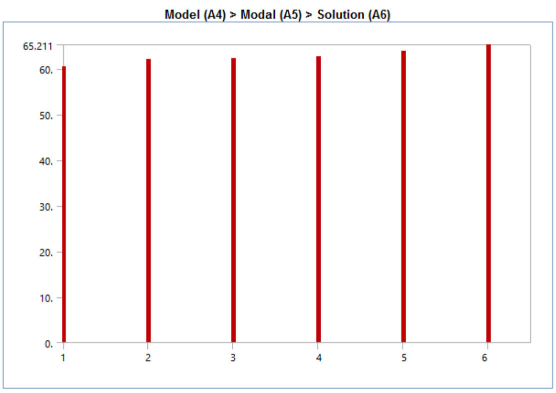

Figure 9: Frequency range bar chart

4. CONCLUSION

The finite element analysis of the effect of vibration on a generator cylinder block using a modal analysis has been successfully carried out. The generator cylinder block was chosen for its importance in the internal combustion engine system. The component is the foundational structure in the engine system. The component was modeled in the AutoCAD software and exported to the ANSYS environment for analysis. The Modal analysis tool was used for the analysis. The component was meshed and attached with fixed supports. The maximum equivalent stress, equivalent strain and total deformation of the engine component was determined to be 25.656 MPa, 0.000132, and 1.1064 mm respectively on a vibration frequency of 60.439 Hz. The highest frequency recorded for the six mode frequencies was 65.211 Hz. At this frequency the total deformation on the cylinder block was noticed to be very high. This adds to the fact that the higher the vibration frequency the higher the total deformation and equivalent stress.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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