Rubber as an Effective Vibration Absorber of Outboard Engine at Small Traditional Fishing Boats from the Human Health and Safety Point of View

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ABSTRACT
The vibration generated by the outboard engine on the boat is transmitted to the foundation block with certain amplitude and if its magnitude exceeds the permissible amplitude then could damage the boat structure, machinery system and should raise side effect on human perception. On this study rubber absorbers are put at the foundation block of the engines and the amplitudes were measured at several points, is revealed that rubber vibration absorbers with dimension 8cm x 5cm x 2cm, $E = 2.3 \times 10^9 N/m^2$ and density $\rho = 1100 kg/m^3$ have reduced the vertical vibration amplitude at the engine block exited by the engines. At engine1 is reduced around 65% and engine2, 59% with amplitudes 0.0276 mm and 0.0282 mm respectively. The magnitudes of the reduced amplitudes that occurred at the engine blocks then are plotted to the graph of maximum permissible amplitude and the result states that there is no damage at the engine and the ship structure as well as health guaranteed for the boat operator and the fishermen.

Keywords: Absorber, rubber, vibration, amplitude

1. INTRODUCTION
Nowadays many small boats still use outboard engine as the main engine even they are not efficient compare to inboard engine, but due to simple engine foundation construction, easy to operate and to maintain, these engines are still attracted to be used. These boats are used especially at small islands beaches where no jettis exist and mostly the boats could ashore directly on the beach.

Outboard engine on small boats could excite vibration on the engine foundation even on the whole structure of the boat, particularly when use engines with high speed. If the vibration at the maximum speed of the engine reach or even exceed the maximum permissible amplitude therefore the engine speed must be reduced to avoid vibration which will damage the engine foundation, boat structure and human perception [1-3]. By reducing the engine speed the boat speed is reduced too and this will affect on the whole fishing activities which is really not the purpose of using an outboard engine on the boat.

This study reveals that using vibration absorber on the foundation block will reduce the exited vibration amplitude by the outboard engine to a certain magnitude less than the maximum permissible amplitude, hence will be no damage effect on the boat structure and the machinery system, and also no disturbance to the human perception.

2. THEORETICAL REVIEWS
2.1 Machine Vibration
Unstable rotating machines are the source of commonly found excitation vibration. The mass spring system is limited only to move vertically, and is being stimulated by the rotating machine. [4] Below are the equations

\[ m \dddot{x} + c \ddot{x} + kx = (me \omega^2) \sin \omega t \]  

(1)

From the equation (1), we may change the solution for a steady state to:

\[ X = \frac{me \omega^2}{\sqrt{(k - Mo^2) + (c \omega)^2}} \quad \text{and} \quad \tan \phi = \frac{c \omega}{k - Mo^2} \]  

(2)
2.2 Rotating Mass
In a mechanical system and the displacement structure, there is an indication of pressures and tension which cause system failure. The resonance condition must be avoided.

The amplitude may be calculated using the following equation:

\[ X = \frac{F_0}{k} \left[ 1 - \left( \frac{\omega}{\omega_n} \right)^2 \right] + \left[ 2\xi \frac{\omega}{\omega_n} \right]^2 \]

The excitation force may be attained by using the following equation:

\[ F_0 = k \cdot X \left[ 1 - \left( \frac{\omega}{\omega_n} \right)^2 \right] + \left[ 2\xi \frac{\omega}{\omega_n} \right]^2 \]

2.3 System’s Transmissibility (TR)
Transmissibility (Tr) is defined as a comparison of amplitude from the transmitted force that is being produced from the system itself. Transmissibility or the passing ability is, basically, the ratio between the force going through the spiral and the damper \((F_T)\) with the proper functioning of the stimulator on the system \((F_0)\). Prior to find the transmissibility of the system, we need to find the values of variables \(m, c, \xi, \omega, \omega_n\).

Formulas for the transmissibility (TR) and the Transmissibility force \((F_{TR})\)

\[ \mu = \left[ \left( 1 - \frac{\omega_n^2}{\omega^2} \right) \right] \left[ 1 + \frac{\xi}{\omega_n} \right] \]

\[ F_{TR} = \frac{F_T}{\mu} \]

The rigidity of foundation spiral \((k_{foundation})\) is found by using the following equation:

\[ k = \frac{3EI}{(l + a)a^2} \]

Where,
\(E\) = Modulus elasticity of the foundation \((N/m^4)\)
\(I\) = Inertia momentum of the foundation \((m^4)\)
\(l\) = Length of the foundation supporting the machine (from fulcrum to bond)
\(a\) = Length of foundation from fulcrum to front

The calculation of system’s natural frequency, damper constant, critical silencing, and silencing factor. The formula for calculation of silencing coefficient \((c)\) is acquired by equation:

\[ c = \sqrt{\frac{E}{\rho A}} \]

Where,
\(\rho\) = foundation’s density \((kg/m^3)\)
\(A\) = cross section area of foundation \((m^2)\)

Since there is no silencing function at this part, therefore the coefficient value is gained from the form of the foundation.

2.4 Critical damping coefficient \((c_{cr})\)
The silencing factor or the silencing ratio \((\xi)\) is acquired through the comparison of the silencing coefficient value \((c)\) and the critical silencing coefficient \((c_{cr})\) which is calculated using the following equation

\[ c_{cr} = 2\sqrt{k_m} \quad \text{or} \quad c_{cr} = 2m.\omega_n \]

2.5 The natural frequency of the system \(\omega_n\) is calculated by using equation (9)

\[ \omega_n = \sqrt{\frac{k}{m}} \]

2.6. Excitation frequency of the system \(\omega\) is calculated using the following equation:

\[ \omega = \frac{2\pi n}{60} \text{rad} / \text{s} \]

The methods used to control the vibration are: [5]
1. Controlling the natural frequency of the system and avoid resonance below the external excitation.
2. Decrease the response of the system by adding a neutralizer (vibration damper)
3. Decrease the transmission of excitation force from one part to another using vibration isolator.
4. Comparison to the currently applied standards. The level of vibration on a machine will affect to the performance of the machine system itself, and also the health of the engine operator. To ensure the safety and comfort of the operator and the system, a limitation is defined for the level of vibration on a machine [6-7].
Table 1. Permissible amplitude

<table>
<thead>
<tr>
<th>Type</th>
<th>Permissible Amplitude (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low speed machinery (500 rpm)</td>
<td>0.02 – 0.025, 0.1 – 0.12</td>
</tr>
<tr>
<td>Hammer Foundations</td>
<td></td>
</tr>
<tr>
<td>High Speed machinery</td>
<td></td>
</tr>
<tr>
<td>a. 3000 rpm</td>
<td>0.002 – 0.003, 0.004 – 0.005</td>
</tr>
<tr>
<td>Vertical vibrations</td>
<td></td>
</tr>
<tr>
<td>Horizontal vibrations</td>
<td></td>
</tr>
<tr>
<td>b. 1500 rpm</td>
<td>0.004 – 0.006, 0.007 – 0.009</td>
</tr>
<tr>
<td>Vertical vibrations</td>
<td></td>
</tr>
<tr>
<td>Horizontal vibrations</td>
<td></td>
</tr>
</tbody>
</table>

The effect of vibration towards human body

Vibrations, on boats, are felt through feet, hand, and body. The vibration transmitted to human body implies to a specific frequency of body or organ. The vibration will then give pressure and stretches on a particular angle towards the body, depending on the intensity, frequency, and direction of the vibration. An excessive vibration may cause psychological and also physical effect, apart from causing fatigue and decrease in performance. The effect caused in short time may directly be felt by human, such as fatigue, headache, slower reaction, nausea, and insomnia.

Human body is divided into several sub-systems where each has its own hand frequency in relation to other sub-system, and being influenced by the position, sitting or standing, the allowed vibration frequencies are as follows:

- Part of human body that is most sensitive to vibration is the abdominal, which resonates on the frequency of 4 to 8 Hz.
- Other parts of the body that resonate are the head and eyeball, on the frequency of 20 to 30 Hz, and 20 to 90 Hz respectively [8].

3. EXPERIMENT

3.1 Engines

This study investigates the vibration on a motor foundation system on an outboard-engine of a traditional fishing boat propelled by 2 high speed engine (2200 rpm). The study itself, technically, aims to answer some questions, such as whether the system is in a safe condition? How great is the vibration of the boat’s engines which is able to be damped by the U profile of the engine foundation? On Fig.1 is shown six measuring points, A and B are located at the engine close to the moving pistons; C, D and E on an aligned manner (left, middle, and right); and point F on the foundation block. [9-10]

3.2 Absorber

How great is the role of rubber as a damper in the system where the problem being focused here is the dimension of the rubber that able to effectively reduce the vibration without change the size of machine’s foundation (Fig.2). Therefore it is necessary to find the effective size of rubber damper which could silence the vibration of the machine until it reaches the value below the maximum permissible value, without changing the size of the foundation.

The determined cross section of the rubber vibration absorber is 0.2cm x 3cm with $E = 2.3 \times 10^9$ N/m² and density $\rho = 1100$ kg/m³ (Fig.3).

3.3 Vibration measuring equipment

The measurement and calculation of vibration was done for two different conditions, with and without rubber vibration silencer. The measurements and analyzing is done using FFT Analyzer (Fast Fourier Transform) Analyzer PL 20 brand INMARSAT (Fig.4a).

The engine speeds is measured using tachometer (Fig.4b) at rpm 550, 1100, 1650, and 2200, then analizing the datas find the vibration amplitudes reduction by the rubber at the measuring points.
3.4 Standard Vibration Requirement

The parameters used as boundaries are the permissible amplitude, and the graphic of allowed limit for structural damage, machinery vibration, and human perception is shown at Fig. 5. The results are then compared with requirements at table 1 to the permissible maximum amplitude and to the standard graphic of allowed limit for structural damage, machinery vibration, and human perception to define that the results are satisfied or not. [11]

Figure 5: Permissible limit for Structural Damage, Machinery Vibration and Human perception.

4. RESULT AND DISCUSSION

4.1. Vibration Amplitude on the installed foundation

At Fig. 6 and Fig. 7 is shown that the magnitudes of the vibration amplitude at point A, B, C, D, E, and F at 550 - 2200 rpm at engine 1 with absorber are less than that without absorber. At point F engine 1 the amplitudes are (27 - 30) μm and (57 - 59) μm with and without absorber respectively. Graphs Fig. 8 and Fig. 9 show the amplitudes at points A, B, C, D, E, F at engine 2 with and without absorber, where at point F the amplitudes are at ranges (25 - 26) μm and (56 - 60) μm.

Figure 4: View of FFT Analyzer (a) and Tachometer (b)

Figure 5: Permissible limit for Structural Damage, Machinery Vibration and Human perception.

Figure 6: Vibration amplitude at various points close to engine 1 with absorber

Figure 7: Vibration amplitude at various points close to engine 1 without absorber

Figure 8: Vibration amplitude at various points close to engine 2 with absorber

Figure 9: Vibration amplitude at various points close to engine 2 without absorber
Figure 8 Vibration amplitude at various points closed to engine 2 with absorber.

Figure 9 Vibration amplitude at various points closed to engine 2 without absorber.

Fig. 10 Amplitude reduction at points around engine 1 with absorber.

Fig. 11 Amplitude reduction at points around engine 1 without absorber.

Fig. 12 Amplitude reduction at points around engine 2 with absorber.

Fig. 13 Amplitude reduction at points around engine 2 without absorber.

Fig. 10, Fig. 11, Fig. 12, Fig. 13 show the reduction percentages of the amplitudes especially that occurred at point F which is the highest, respectively (53 – 65)% and (58 – 62)% at engine 1 and engine 2 with absorber.
5. CONCLUSION
This study shows that without rubber absorber at engine foundation block with dimension 80 x 20 x 50mm, $E = 2.3 \times 10^9 \text{N/m}^2$ and density $\rho = 1100 \text{ kg/m}^3$ the vibration amplitudes exited by the engines at frequencies range (9 – 37) Hz at points A, B, C, D, E and F are at range (58-78)$\mu$m. Plotted these values to the graph at Fig.5 is determined the condition of the boat structure, engine and human as follows:
- No structural damage
- Machine vibration severity is at condition: satisfactory for low frequencies, (9-10)Hz
- unsatisfactory for high frequencies, (11-37)Hz
- The human sensitivity: reduce comfort for long exposure at frequencies (9-37)Hz.

Using rubber absorbers on the engine foundation block reduced the vibration amplitudes at the foundation blocks of the engines from a range (58 - 78)$\mu$m without absorber to a range (25 – 29)$\mu$m or at percentage 53% - 65% respectively at frequencies (9 – 37)Hz.

From the graph at Fig.5 is determined that:
- No structural damage
- Machine vibration severity is at condition: satisfactory for frequencies (9-37) Hz
- The human sensitivity is at condition: threshold of perception at frequencies (9-10) Hz, but at frequencies (10-37)Hz, is at condition: reduce comfort for long exposure.

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7. REFERENCES