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ENERGY HARVESTER FOR VIBRATION CONTROL AND ELECTRICITY GENERATION

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ABSTRACT

This paper presents the application of energy harvester for controlling the vibration of marine structures and also at the same time generates the electricity for charging the low power devices. The motivation behind this research is to remove the problem of electricity and at the same time controlling the vibrations of marine structures due to excitation. By using the MATLAB , the amplitudes of marine structure and energy harvester are calculated. A mathematical model was discussed briefly. The marine structure magnitude was calculated as 4.5 mm at the frequency of 10 Hz assuming that the mass of marine structure is 5 tons. After attaching the energy harvester, the marine structure amplitude become 1 mm. The remaining 3.5 mm amplitude was decreased by attaching the absorber. The generated a power of a energy harvester is 1.6µW.

KEYWORDS: Energy harvester; Marine structure; MATLAB.

INTRODUCTION

In ship vibration, the propeller is frequently a trouble source which can cause an excessive ship stern vibration problem. The consequences of excessive vibration in the stern area can be severe. Deterioration of the structural members can be accelerated as a result of fatigue caused by long term cyclic vibration. Excessive vibration can damage or adversely impact the in-service performance of the ship's mechanical and electrical equipment.Prolonged exposure to vibration can also contribute to crew and passenger discomfort, increasing the opportunities for human error. Increased flexibility of the hull girder of larger, and particularly longer, ships with a fine, underwater form can significantly increase susceptibility to vibration. Moreover, as the weight and distribution of steel within ship structures are optimized as shipbuilders attempt to control production and material costs, the propensity for vibration-related troubles, particularly in the stern section of the vessel, increases. As the demand for higher service speeds for many of these vessels also increases, attendant increases in the propulsive power are required. This translates into higher loads on propellers, which in turn lead to greater propeller excitation and an increase in the risk of vibration and vibration-induced failures. Stern vibration problems arise from the unsteady cavities that attach to the surface of the propeller blades. These create an intense, fluctuating pressure impact on the ship's hull. With modern propeller design, a small to moderate amount of sheet cavitation is often unavoidable in order to maintain the required propulsion efficiency. Reconciling the challenges posed by these conflicting technical and operational demands is essential if further improvements in the speed-power-size ratio are to be realized, particularly for ultra-large containerships. To predict propeller-induced hull vibration is not simple. It is a synthetical analysis involving methodologies of many cross-field topics such as Computational Fluid Dynamics (CFD), Finite Element Method (FEM), and fluid cavitation dynamics. In propeller induced hull vibration assessment, the prediction of stern flow is central to the problem of unsteady propeller loads, cavitation, and propeller-induced hull pressure. The solution to these problems requires detailed knowledge of the turbulent stern flow (including thick and perhaps separated boundary layers), bilge vorticity, and propeller/hull interaction. Traditionally, in ship design the technology for these predictions was mainly based on regression and empirical formulae. Another method of reducing propeller induced hull vibration is to attach the vibration absorber to the hull. In this chapter, how a novel lumped mass energy harvester functions to control of propeller induced hull vibration in parallel to generate electricity is discussed through analytical approach in relation to the application of energy harvesters for controlling the vibrations. A mathematical model has been developed. According to the principles of vibration, if a particular system is having large vibrations under its excitation, this vibration can be eliminated by coupling a properly designed auxiliary sprig mass system to the main system. Here the auxiliary system is the lumped mass energy harvester and the main system is the ship structure. This forms the principle of undamped dynamic vibration absorber where the excitation is finally transmitted to the auxiliary system, bringing the main system to rest. The undamped dynamic vibration absorber is extremely effective at one speed only and thus is suitable only for constant speed machines. Where as a damped dynamic vibration absorber can take care of the entire frequency range of excitation but at the cost of reducedeffectiveness.

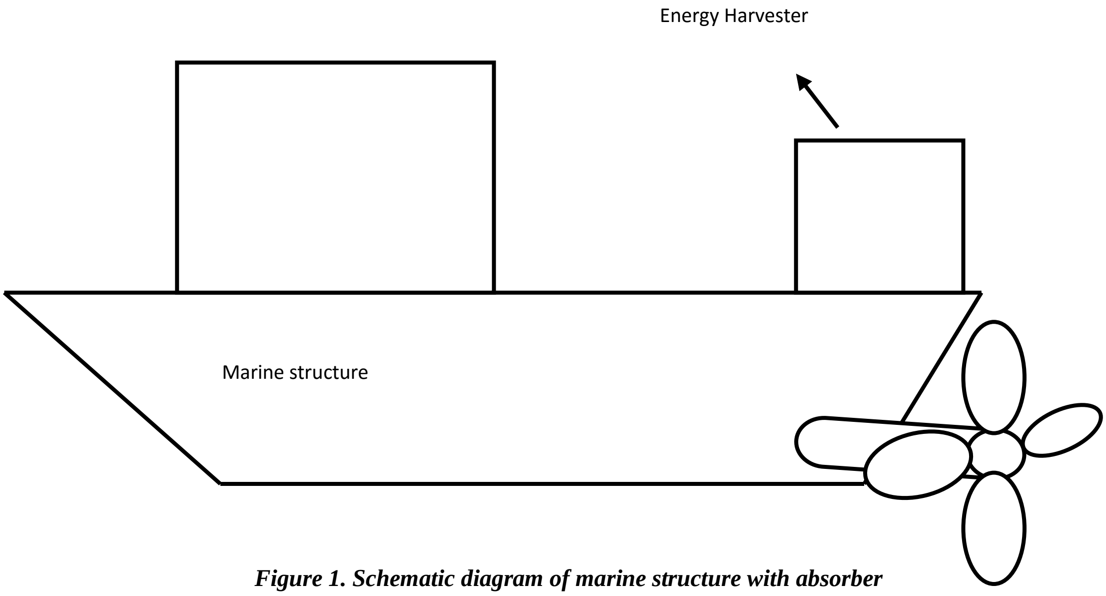

Figure 1. Schematic diagram of marine structure with absorber

Natural frequency of the main system(Marine structure) $=\omega_1 = \sqrt{\frac{k_1}{m_1}}$

Natural frequency of the absorber system(Energy harvester) $=\omega_2 = \sqrt{\frac{k_2}{m_2}}$

Ratio of the absorber mass to the main mass = $\mu = \frac{m_2}{m_1}$

$$\frac{X_1}{X_{st}} = \frac{\left(1 - \frac{\omega^2}{\omega_2{}^2}\right)}{\left[\frac{\omega^4}{\omega_1{}^2\omega_2{}^2} - \left((1+\mu)\frac{\omega^2}{\omega_1{}^2} + \frac{\omega^2}{\omega_2{}^2}\right) + 1\right]} \qquad (1)$$

$$\frac{X_2}{X_{st}} = \frac{1}{\left[\frac{\omega^4}{\omega_1{}^2\omega_2{}^2} - \left((1+\mu)\frac{\omega^2}{\omega_1{}^2} + \frac{\omega^2}{\omega_2{}^2}\right) + 1\right]} \qquad (2)$$

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MATHEMATICAL MODELLING OF ENERGY HARVESTER

Figure 3 shows the prototype of energy harvester.

The displacement of support is $y(t) = Y \sin \omega t$ (3)

$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\ddot{y}(t) \quad (4)$$

Solution for under damped case

$$z(t) = Ae^{-\xi\omega_n t}\sin(\sqrt{1-\xi^2}\,\omega_n t + \varphi) + \frac{Y\left(\frac{\omega^2}{\omega_n{}^2}\right)\sin(\omega t - \varphi)}{\sqrt{\left(1-\frac{\omega^2}{\omega^2{}_n}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \quad (5)$$

$$\frac{z}{Y} = \frac{\left(\frac{\omega^2}{\omega_n{}^2}\right)}{\sqrt{\left(1-\frac{\omega^2}{\omega^2{}_n}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \quad (6)$$

The total power dissipated in the damper under sinusoidal excitation was found to be given in equation (7).

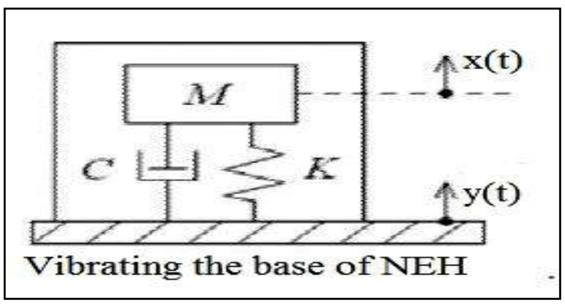

Figure 2. Equivalent mathematical model of Energy harvester

$$p(\omega) = \frac{m\xi Y^2\left(\frac{\omega^3}{\omega_n{}^3}\right)}{\sqrt{\left(1-\frac{\omega^2}{\omega^2{}_n}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \quad (7)$$

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Figure 3. Proto type of Energy Harvester

RESULTS AND DISCUSSION

Equation (1) clearly shows that X1 =0 when ω= ω2 , The amplitude of propeller induced ship hull vibration is zero when the excitation frequency is equal to the natural frequency of energy harvester even though it is excited by a harmonic force.

If we substitute ω= ω2 in equation (2) then $\frac{X_2}{X_{st}} = \frac{1}{-\mu\frac{\omega_2{}^2}{\omega_1{}^2}}$

$$F = -k_2X_2 \qquad (8)$$

The equation (8) describes that the spring force k_2X_2 on the main mass due to the amplitude X_2 of the absorber mass is equal and opposite to the exciting force on the main mass resulting in no motion of the main system. The ship hull vibrations have been reduced to zero and these vibrations have been taken up by the energy harvester system. Hence the name vibration absorber is given to energy harvester. The addition of a vibration absorber to main system is not much meaningful unless the main system is operating at resonance or at least near it. Under these conditions we have ω= ω1 . But

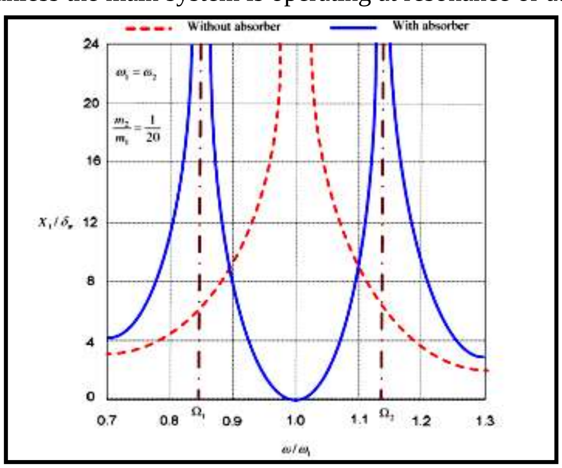

Figure 4. Frequency response of marine structure

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for the absorber to be effective when ω= ω2 . For the effectiveness of the absorber at the operating frequency corresponding to the natural frequency of the main system alone ω1= ω2 , when this condition is fulfilled, the absorber is known to be a tuned absorber.

For a tuned absorber

$$\frac{X_1}{X_{st}} = \frac{\left(1 - \frac{\omega^2}{{\omega_2}^2}\right)}{\left[\frac{\omega^4}{{\omega_2}^4} - \left((2+\mu)\frac{\omega^2}{{\omega_2}^2}\right) + 1\right]} \qquad (9)$$

$$\frac{X_2}{X_{st}} = \frac{1}{\left[\frac{\omega^4}{{\omega_2}^4} - \left((2+\mu)\frac{\omega^2}{{\omega_2}^2}\right) + 1\right]} \qquad (10)$$

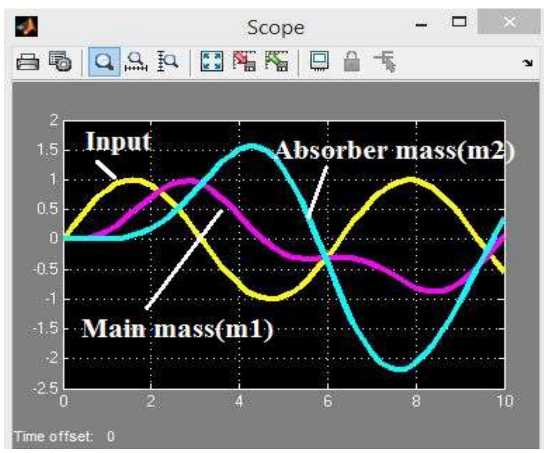

Figure 5. Output of dynamic vibration absorber

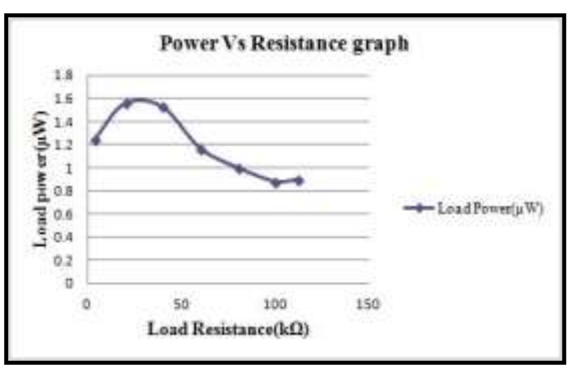

Figure 6 .Power Vs resistance graph

Figures 4 and 5 discusses the natural state of main system and absorber system in displacement configurations. The marine structure magnitude was calculated as 4.5 mm at the frequency of 10 Hz , considering the mass of 5 tons. After attaching the energy harvester, the marine structure amplitude become 1 mm. The remaining 3.5 mm amplitude was decreased by attaching the absorber and developed a power of 1.6 microwatts by using PZT energy harvester as shown in figure 6.

CONCLUSIONS

Energy harvester was employed as a absorber for reducing the vibrations of marine structures and developed a mathematical model .The amplitude of vibration is decreased to 10 mm after attaching the absorber. A power of 1.6µW was ***developed by using*** a energy harvester. This power can be used for charging the low power devices.

REFERENCES

[1] Theory of vibrations by W.T Thomson, Wiley publications, 2014 .