



International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013

Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)

On 12th to 14th December Organized by

Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

STUDIES ON UNDERWATER VIBRATION ISOLATION MODULE

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ABSTRACT

Vibration Isolation Module is used in towed under water acoustic sensor systems to control mechanically induced tow noise. In general, they have a gel filled in a polymeric outer hose and tensioned polymeric strength members running through it. Vibrations passing through the strength member are to be eliminated and for this purpose strength member is placed in a viscoelastic gel. Finite element analysis of the Vibration Isolation Module has been carried out. The modelling has been done with ANSYS. Damping characteristics of strength member in viscoelastic gel has been analysed. Modal analysis is performed on the structure to obtain the natural frequencies and mode shapes of the structure. In order to obtain the dynamic responses of the vibration isolation module a harmonic analysis is performed and responses are observed for various end conditions.

NOMENCLATURE

ξ_j = modal damping

α = uniform mass damping multiplier

β = uniform stiffness damping multiplier ξ = constant damping ratio

E Young's Modulus μ Poisson's Ratio

ρ Density

1. INTRODUCTION

Sound Navigation and Ranging (SONAR) is a modern technology which used to track submarines, fishes, ship wrecks, to map the sea bed and for navigational purposes. SONAR systems consist of four main components, viz; a high power transmitter, an efficient transducer, a sensitive receiver and an acoustic communication system. The basic working of the SONAR takes place when an electrical impulse from a transmitter is converted into a sound wave by the transducer and sent into the water. When this wave strikes an object, it rebounds or echoes. This echo strikes the transducer, which converts it back into an

electric signal, which is amplified by the receiver and sent to the display. Since the speed of sound in water is constant, the time lapse between the transmitted signal and the received echo can be measured and subsequently the distance to the object determined. Towed array SONAR is an array of SONARS that is towed behind a submarine or surface ship. Towed arrays are long cables with hydrophones trailed behind the ship when deployed. The hydrophones are placed at specific distances along the cable. The array's hydrophones are used to detect sound sources. Array element dimensions are small compared to the acoustic wavelength and hence the sensors are operating below their first mechanical resonance. The hydrophones subjected to a number of acoustic and mechanical disturbances along with the signals from acoustic targets. The response of the hydrophones to these disturbances is called tow noise. Ambient sea noise, mechanical and flow noise are the various sources of disturbances. Mechanically induced noise is caused by transverse motion and perturbations in the longitudinal motion of array. This includes ship noise transmitted along the cable and array. The major component of tow noise is vibrations due to mechanically induced noises.

Vibration is the motion of a particle or a body or system of connected bodies displaced from the position of equilibrium [1]. Vibration is undesirable since it may even lead to the failure of the structure. Vibration isolation seeks to reduce the vibration level in one or several selected areas. A Vibration Isolation Module (VIM) is used for the elimination of vibrations in the towed array. VIM consist polymeric hose, tensioned polymeric strength member (Kevlar) and viscoelastic gel. The strength member is made of Kevlar fabric and it is surrounded by a viscoelastic gel medium.

Horrand Schmidt have explained the fundamental aspects of damping in viscoelastic damper [2]. Park et.al have explained the numerical and experimental investigation into the dynamic behaviour of a towed low tension cable applicable to a towed array sonar system for detecting submarines [3]. Investigations on axial properties of long composite structures have been carried out by Hull [4]. Damping refers to the capability of the structure to dissipate the mechanical energy. A high level of damping in a structure is a standard way to reduce amplitudes of motion. It can be mathematically modelled as any force which is synchronous with the velocity of the object and opposite in direction. Energy of the vibratory system is from it. The energy lost is either transmitted away from the system by some mechanism of radiation or dissipated within the system. Damping is responsible for the eventual decay of free vibration, which explains the fact that the response of a vibratory system excited at resonance does not grow without a limit [1]. Damping effectively controls vibration at or near resonance through energy dispersion usually as heat [5]. Common types of damping are viscous, coulomb and structural damping.

Inviscous damping when a mechanical system vibrates in a fluid medium, the energy is released due to the resistance offered by the fluid to the vibrating body. Amount of energy released depends on size and shape of the vibrating body, viscosity of the fluid, frequency of vibration and velocity of the vibrating body [6]. The term viscoelastic can be explained as the simultaneous existence of viscous (liquid) and elastic (solid) properties in a material. In ideal solids, it is observed that solids recover its properties completely following the removal of the applied stress within the proportionality limit [4]. Viscoelastic material stores some part of the deformational energy elastically as potential energy, and it dissipates the rest simultaneously through viscous forces [4]. Ideal solids obey Hooke's law; according to which the stress is directly proportional to strain within the limits of elasticity. When a stress or strain is applied on a viscoelastic body, rearrangement take place inside the material as it responds to the imposed excitation, real materials take finite time for the rearrangements. Hence the relation between stress and strain or strain rate cannot be expressed by material constants as in the case of purely elastic or purely viscous material. Estimation of damping characteristics and response of strength member cannot be carried out by conventional vibration equations. VIM considered in the present study is in such a way that the vibratory component (Kevlar tape) is immersed in viscoelastic gel. This medium absorbs the energy associated with the vibration and makes the system near noise free. So this can be viewed as energy efficient for VIM. The

application of viscoelastic gel as a damper is the novelty of this paper. The type of polyurethane used as the outer shell has less compressibility factor. The damping effects of outer shell have not been considered in this analysis. The damping effects are assumed to be contributed by the viscoelastic gel only.

The present paper deals with the application of finite element method to estimate the vibration damping characteristics of strength member embedded in viscoelastic medium.

2. FINITE ELEMENT ANALYSIS OF VIM

VIM has been analysed using the finite element commercial software ANSYS. Modal analysis and harmonic are carried out to predict the vibration responses.

2.1 Description of the geometry

Vibration isolation module consists of polyurethane tube, Kevlar tape and viscoelastic gel. The fig.1 shows the schematic diagram of the vibration damper. The length of the vibration damper is 0.400 m and outside diameter is 0.076 m. Strength member is made of woven fabric (Kevlar) with a cross-section of 0.013m x 0.003m.

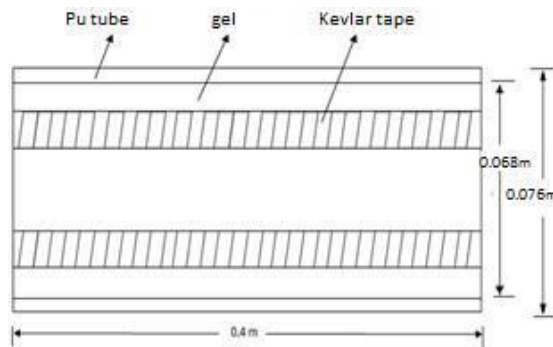


FIGURE1: Schematic diagram of vibration damper

2.2 Description of finite elements used

SOLID185 is used for 3D modelling of solid structures. It is defined by 8 nodes and the orthotropic material properties. It has three degrees of freedom at each node viz; translations in the X Y Z directions. Element loads are described on the nodes. The element has viscoelasticity, hyper elasticity, stress stiffening, creep, large deflection and large strain capabilities. It also has mixed formulation capability for simulating deformation of nearly incompressible elasto-plastic materials and fully incompressible hyper elastic materials. The effects of pressure load stiffness are automatically included for this element.

2.3 Modal analysis

The real application of modal analysis is in the case of continuous nonhomogeneous structure defined as a multiple degree of freedom system. At this point, the modal frequencies, the modal damping and the modal vectors, or relative patterns of motion, can be found via an estimate of the mass, damping and stiffness matrices.

2.4 Harmonic analysis

Harmonic response analysis or frequency response analysis helps to predict the sustained dynamic behaviour of a structural system and enables us to verify if the design will successfully overcome resonance, fatigue and other harmful effects of forced vibration[7]. A harmonic load will produce a

sustained harmonic response in a structural system. The idea is to calculate the response of the structure at several frequencies of the harmonic force and obtain a plot showing the relation between the response (displacement, velocity, acceleration) and frequency [9]. This analysis technique calculates only the steady state forced vibration of a structure. The transient vibration, which occurs at the beginning of excitation, is not accounted for in a harmonic response analysis. The frequency response plots are diagrams showing how the amplitude and the phase angle of the response vary as the exciting frequency changes. This provides a broader picture of the response characteristics than that provided by a time response, which is limited to a given excitation frequency.

The viscoelastic gel, polyurethane tube and Kevlar tape are modelled using SOLID185. The finite element model of vibration isolation module has 2295 nodes and 1984 elements. Input for modal analysis is given in table.1.

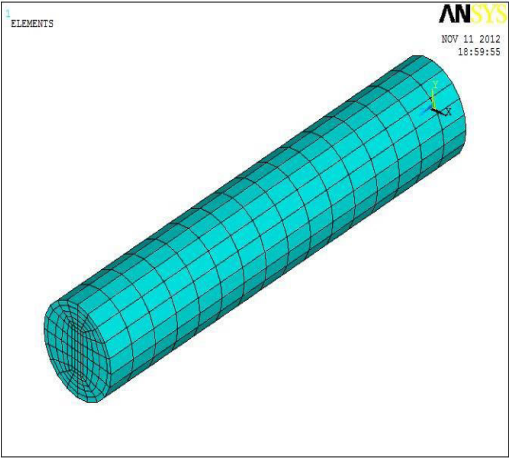


FIGURE 2. Isometric view of the meshed model

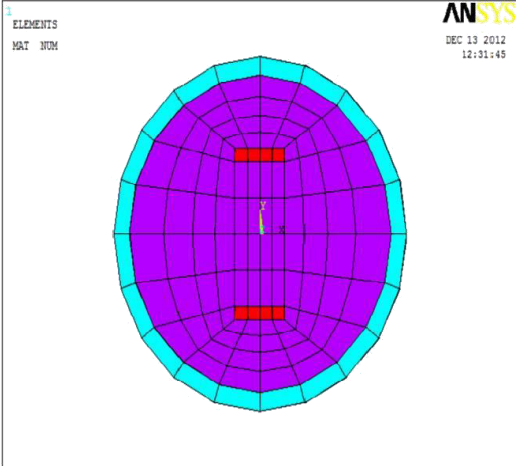


FIGURE.3 Cross-sectional view of meshed model

Table 1. Input for modal analysis

Inputs	Modal analysis		
	Outer shell	Gel	Kevlar tape
Young's modulus, E(N/m ²)	2.5 x 10 ⁷	3 x 10 ⁴	1.12 x 10 ¹¹
Poisson ratio, μ	0.25	0.3674	0.36
Density, ρ (kg/m ³)	1140	780	1440

Input parameters for modal analysis are material properties. Excitation frequency range of VIM and amplitude of harmonic load are the additional input parameters for harmonic analysis besides those defined for modal analysis. Young's modulus and density of components must be defined for both harmonic analysis and modal analysis.

Harmonic analysis has been carried out after a modal analysis. In modal analysis no load is acting on the structure whereas in the case of a harmonic analysis a unit load acts on the vibration isolation module over a frequency range. Damping effects has been brought in to the analysis by choosing the option of constant damping ratio in ANSYS. Values for mass damping and constant ratio are provided by 0.1 and which brings out the damping effects on the structure.

$$\xi_j = (\alpha/2\omega_j) + (\beta\omega_j/2) + \xi + \xi_j^m \quad (1)$$

Vibration amplitude is the relevant responses in this study and the values are noted with care near the natural frequency to ascertain resonance.

3. RESULTS AND DISCUSSIONS

3.1 Modal Analysis

Modal analysis is to determine vibration characteristics (natural frequencies and mode shapes) of a structure. Natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. Table 2 presents the natural frequencies of Kevlar tape in viscoelastic medium.

Table2. Natural frequency of Kevlar tape in viscoelastic medium

Mode number	Natural frequency (Hz)
1	34.77 5
2	40.55 4

3.2 Harmonic analysis

A cyclic load will produce a sustained cyclic response (a harmonic response) in a structural system. A sine wave of unit amplitude is passed through the Kevlar tape and responses observed for two different end conditions [10]. Translations of gel are not arrested in first case and translations in Z direction are arrested in second case. Tube is simply supported at the ends in the first condition. Gel has been considered with closed end conditions in the second case. Distance between two end blocks of the VIM have been modeled for the analysis. In the given analysis a sine wave of unit amplitude is applied and the responses of the vibration isolation module are observed. The amplitudes of harmonic responses of the vibration isolation module are presented in Table.3 and the harmonic responses are shown in fig.4 and fig. 5.

Table3. Harmonic response using ANSYS

Sl no	end conditions	Cases	Amplitude at entry, m	Amplitude at exit, m
1	Z direction not arrested	Without gel	1.0381	1.0074
		With gel	5.61×10^{-6}	5.03×10^{-6}
2	Z direction arrested	Without gel	3.57×10^{-8}	1.78×10^{-8}
		With gel	3.31×10^{-7}	1.51×10^{-7}

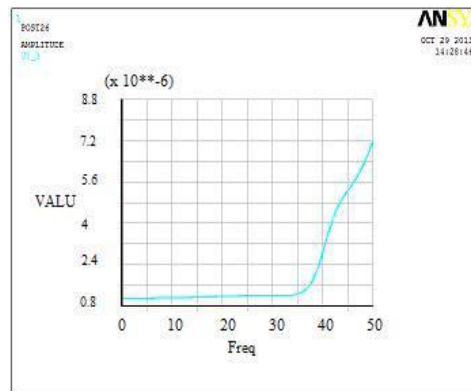


FIGURE 4. Harmonic response at the first node with damping

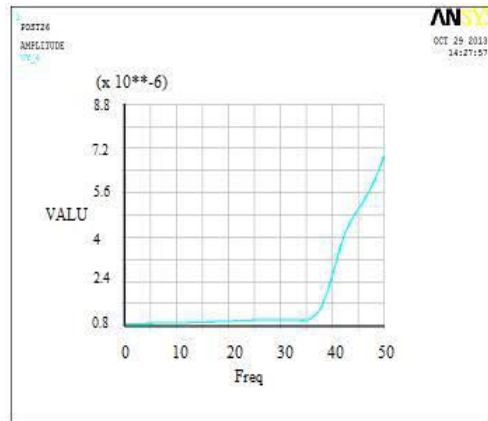


FIGURE 5. Harmonic response at the end node with damping

4. SUMMARY AND CONCLUSIONS

Analyses have been performed by using ANSYS based on finite element method. Modal analysis has been performed on VIM in order to obtain the fundamental frequency and mode shape. Harmonic responses of the Kevlar tape in a viscoelastic medium for various end conditions have been studied. Due to the damping effect of the gel there has been reduction of 20% in the noise level so that efficiency of the VIM has increased. The damping effect of the viscoelastic medium on the response of the vibration isolation module for the harmonic analysis has been studied and reported.

ACKNOWLEDGEMENT

First author acknowledges with gratitude for the support and guidance given by Dr Sunil K Narayankutty, Professor Department of Polymer Science and Rubber Technology, CUSAT, Kochi- 22.

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