RESEARCH PAPER | Engineering | Volume : 2 | Issue : 3 | December 2012 | ISSN - 2249-555X

Comparative Analysis of Viscoelastic Material Support for Rotating Machinery

KEYWORDS: Vibration, Viscoelastic material, FFT.

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ABSTRACT *The demand for silent machine operation in any of the organization is prime need in today's environmentally conscious world. The legal aspects of noise control requires a silent and noise free operation of the machine. The vibration and noise resulted due to it is the common phenomena in any dynamic machinery. In this paper an attempt has been made to found a suitable Viscoelastic material which can minimize the vibration and results into less noise and efficient operation.*

1.0 INTRODUCTION

The demand for low noise machinery has become an increasingly important issue in our society. Typical examples of nuisance caused by noise are often experienced in household appliances such as vacuum cleaners, washing machines or refrigerators. At work the inconvenience due to noise can be caused by computers, air conditioning systems or industrial machines. Noise, the term for unwanted sound, is closely related to the occurrence of structural vibrations. The vibrating surfaces of a structure excite the surrounding medium, in most cases air, causing pressure disturbances which are experienced as noise. This phenomenon is known as noise radiation. In many cases where noise is a problem, rotating machinery such as electric motors or gear boxes is involved. The vibration source in these types of machinery are electromagnetic forces, the meshing of gears or mechanical vibrations caused by imbalance of the rotating parts. Often, the resulting vibrations are transmitted from the rotating parts to the surrounding structure, which in the end radiates noise. Generally, the rolling bearings in such applications are relatively flexible components. Therefore, the bearings play a crucial role in the application as a vibration transmitter. As a vibration source, the rolling bearings have become less important, mainly due to improved quality. In order to reduce the noise level of rotating machinery, the source, the transfer or the radiation of noise can be suppressed. The transfer and radiation of noise can be reduced by a smart (re)design of the structural components of the application. The transfer of noise can also be reduced by decoupling the components in such a way that the noise path is interrupted. This can be achieved by adding noise reducing treatments to the structure such as elastic elements, masses, local shielding or damping layers. In the present investigation, the use of viscoelastic damping layers as a noise reducing measure in rotating machinery is considered.

1.1 Vibration isolation and damping

Vibration isolation is the process of isolating an object, such as a piece of equipment, from the source of vibrations.

Passive isolation

"Passive vibration isolation" refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, as opposed to "active vibration isolation" or "electronic force cancellation" employing electric power, sensors, actuators, and control systems.

Passive vibration isolation is a vast subject, since there are many types of passive vibration isolators used for many different applications. A few of these applications are for industrial equipment such as pumps, motors, HVAC systems, or washing machines; isolation of civil engineering structures from earthquakes, sensitive laboratory equipment, valuable statuary, and high-end audio.

Active isolation

Active vibration isolation systems contain, along with the spring, a feedback circuit which consists of a piezoelectric accelerometer, a controller, and an electromagnetic transducer. The acceleration (vibration) signal is processed by a control circuit and amplifier. Then it feeds the electromagnetic actuator, which amplifies the signal. As a result of such a feedback system, a considerably stronger suppression of vibrations is achieved compared to ordinary damping.

The principles of vibration isolation and vibration damping can easily be explained with the help of simple mass-spring systems. Let us consider a vibrating object transmitting vibrations to a certain structure via a specific stiffness. In the two-dimensional example this system is represented by two masses M1 and M2 and springs K1 and K2 on an excited support (see Figure 1.1a). The vibrating support, for example, could represent a shaft, whereas the two masses could represent a housing with 2 degrees of freedom.

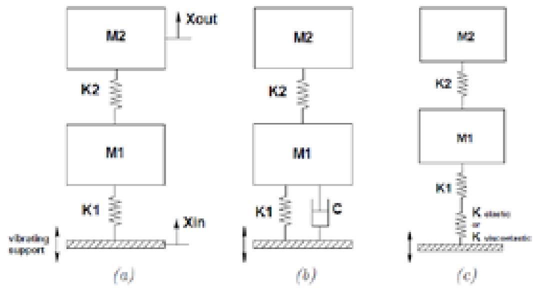

Figure 1.1: Two-dimensional mass-spring systems on an excited support:
(a) Reference system, (b) viscously damped system and (c) viscoelastically supported system.

Vibration damping can be achieved by adding a parallel damper C to the system (Figure 1.1b). Vibrations of the support can be isolated by use of a soft elastic or viscoelastic support, indicated by Kelastic and Kviscoelastic, respectively, in Figure 1.1c.

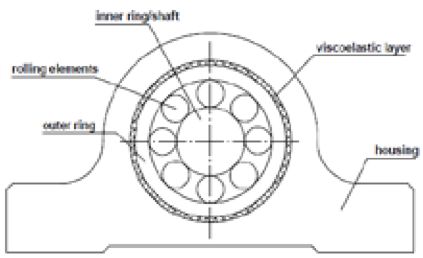

Figure 1.2: A viscoelastic layer mounted between the bearing outer ring and the housing.

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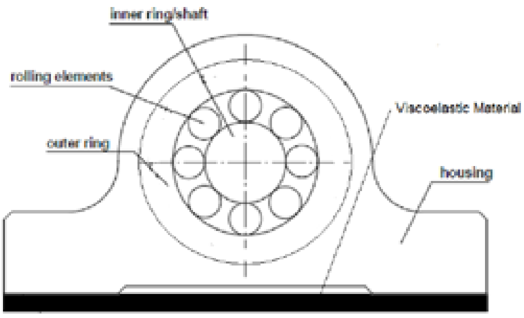

Figure 1.3: A viscoelastic layer mounted beneath the bearing housing.

The viscoelastic layers can be added between the external layer of the roller bearing and the bearing housing or underneath the bearing housing, as shown in Fig. 1.2 and Fig. 1.3. In the former case, the inertia of the bearing can be neglected while, in the latter, it must be considered. In the current work, it was used the second alternative (Fig. 1.3) only, with and without layers of viscoelastic material.

1.2 Viscoelastic Materials
Viscoelastic materials exhibit both viscous and elastic characteristics when undergoing deformation.

Some phenomena in Viscoelastic materials are:
1. if the stress is held constant, the strain increases with time (creep)
2. if the strain is held constant, the stress decreases with time (relaxation)
3. if cyclic loading is applied, hysteresis (a phase lag) occurs, leading to a dissipation of mechanical energy

Properties of Viscoelastic materials
1. Creep (if the stress is held constant, the strain increases with time) and Recovery
2. Stress Relaxation (if the strain is held constant, the stress decreases with time)
3. Energy Absorption.

List of common Viscoelastic materials (metals)
Copper-manganese alloy
Zinc-aluminium alloy
Metals at high temperatures exhibit Viscoelastic properties

List of common viscoelastic polymeric materials
Acrylic Rubber, Butadiene Rubber, Butyl Rubber, Chloroprene, Chlorinated Polyethylene, Ethylene-Propylene-Diene, Fluorosilicone Rubber , Fluorocarbon Rubber, Nitrile Rubber, Natural Rubber, Polyethylene, Polystyrene, Polyvinyl chloride (PVC), Polymethyl Methacrylate, Polybutadiene, Polypropylene.

Common Viscoelastic Materials Application
Grommets or Bushings, Component Vibration Isolation, Aircraft fuselage Panels, Submarine Hull Separators, Mass Storage Disk Drive Component, Automobile Tires, Stereo Speakers, Bridge Supports, Caulks and Sealants, Lubricants, Fiber Optics Compounds.

1.3 Typical Elastic behavior Vs Viscoelastic behavior

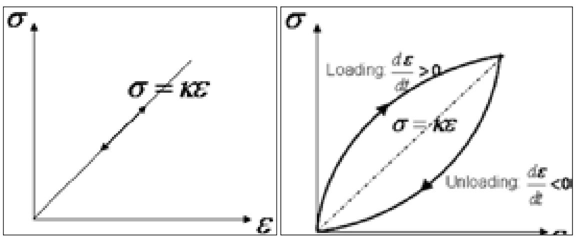

Figure 1.4a Elastic Material **Figure 1.4b Viscoelastic Material**
Stress and strain curves during cyclic loading-unloading.

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. The viscosity of a viscoelastic substance gives the substance a strain rate dependent on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed. However, a viscoelastic substance loses energy when a load is applied, then removed. Hysteresis is observed in the stress-strain curve, with the area of the loop being equal to the energy lost during the loading cycle. Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. Plastic deformation results in lost energy, which is uncharacteristic of a purely elastic material's reaction to a loading cycle.
Specifically, viscoelasticity is a molecular rearrangement. When a stress is applied to a viscoelastic material such as a polymer, parts of the long polymer chain change position. This movement or rearrangement is called Creep. Polymers remain a solid material even when these parts of their chains are rearranging in order to accompany the stress, and as this occurs, it creates a back stress in the material. When the back stress is the same magnitude as the applied stress, the material no longer creeps. When the original stress is taken away, the accumulated back stresses will cause the polymer to return to its original form. The material creeps, which gives the prefix visco-, and the material fully recovers, which gives the suffix -elasticity.

2.0 LITERATURE REVIEW
Rotor dynamics as a subject first appeared in the last quarter of the 19th Century due to the problems associated with the high speed turbine of Gustaf de Laval who invented the elastically supported rotor, called de Laval Rotor, and observed its supercritical operation.

Recently, viscoelastic damping materials have also been used in rotor dynamic applications. For rotor stability improvement, viscoelastic bearing supports have been studied by some researchers (Dutt and Nakra, 1992; Panda and Dutt, 1999). The dynamic behavior of viscoelastically supported bearing applications has been analyzed by Dutt and Nakra (1993), Akturk and Gohar (1994) and Shabaneh and Zu (2000).

Snowdon, J.C. [1] described the manner in which the internal damping and the dynamic elastic modulli of rubber like materials depend upon frequency and temperature. Examples are presented of the frequency dependence of the dynamic shear modulus and shear damping factor of low- and high-damping rubbers in the range 1 c/s through 10 kc/s at the temperatures 5, 20and 35° C. These results have been deduced by the method of reduced variables from the experimental data of other workers. They relate to the low-damping materials natural rubber, natural rubber reinforced with carbon black, and SBR rubber; and to the high-damping materials Thiokol RD rubber, butyl rubber reinforced with carbon black, and plasticized polyvinyl acetate.

Panda K. C., Dutt J. K. [2] in their paper frequency dependent characteristics of the polymeric supports have been found by simultaneously minimizing the unbalanced response and maximizing the stability limit speed. This process yields better support characteristics than those obtained by minimizing unbalance response alone. Optimum characteristics have been found for the rotor shaft system mounted on (a) rolling element bearings and (b) plain cylindrical journal bearings at the ends having polymeric supports. The effects of viscous internal damping in the shaft, support mass and gyroscopic effect due to non-symmetrical location of the disc have been considered in the analysis. A procedure of controlling the slope of the support characteristics versus frequency of excitation has been used and found to be very suitable for obtaining feasible support characteristics. Examples have been presented to justify the above conclusions.

Shabaneh, N.H. and Jean W. [3] in their work, the dynamic analysis of a rotating disk–shaft system with linear elastic bearings at the ends mounted on viscoelastic suspensions is investigated. The flexibility of the shaft is incorporated utiliz-

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ing the Timoshenko shaft model and the rotor is considered rigid having a mass and moment of inertia. The viscoelastic support of the linear bearing is modeled as Kelvin–Voigt model which accounts for the in-phase stiffness and the loss coefficient of the material. The equations of motion are derived and both free and forced vibration analysis are performed. The effects of stiffness and damping parameters of the viscoelastic supports on the complex natural frequencies are studied. The forced response due to the disk mass unbalance is also investigated.

Dutt, J.K. and Toi T. [4] used polymeric material in the form of sectors as bearing supports for improving the dynamic performance of rotor–shaft systems, which often suffer from two major problems (a) resonance and (b) loss of stability, resulting in excessive vibration of such systems. Polymeric material in the form of sectors has been considered in their work as bearing supports. Polymeric material has been considered in their work as both stiffness and loss factor of such materials varies with the frequency of excitation. Stiffness and loss factor have been found out for the proposed support system comprising of polymeric sectors. Depending upon the frequency of excitation the system matrix, in this case, changes and dynamic performance of the rotor–shaft system also changes accordingly. Here in this work avoidance of resonance and application of optimum damping in the support have been investigated by finding out the optimum dimension, i.e., the optimum thickness and optimum length of the sectors. It has been theoretically found that use of such sectors reduces the rotor unbalanced response, increases the stability limit speed for simple rotor–shaft systems and thus improves the dynamic characteristics. Parameters of the system have been presented in terms of non-dimensional quantities.

Espindola J. J., Silva Neto J. M. and Lopes E. M. O., Carlos Alberto Bavastri [5] introduced a new approach for characterization of viscoelastic materials via generalized derivatives. It is shown that, as derived by modeling generalized various functions transmissibility, obtained at various test temperatures, can be used simultaneously for the characterization of integrated material interest. Results with butyl rubber and silicone were presented and discussed.

Espindola J. J., Silva Neto J. M. and Lopes E. M. O. [6] attempted a new approach for the identification of the dynamic properties of viscoelastic materials, based on the fractional derivative model in their paper. Numerical and experimental results are produced and discussed.

N. Venugopal, C.M. Chaudhari, Nitesh P. Yelve [7] applied Taguchi's concept of Orthogonal arrays for designing experiments to study the transmissibility ratio of viscoelastic materials and factors affecting it. Experiments are carried out with different process parameters like material, thickness, frequency. They used three viscoelastic materials namely Natural rubber, Neoprene rubber1, Neoprene rubber2. The results obtained are then analysed using ANOVA (Analysis of Variance). Thus the factors to be given importance while choosing the viscoelastic material as damping media are identified and also laid down the procedure for the same by making use of Taguchi's Orthogonal array technique for Design of experiments and ANOVA.

M. I. Friswell, J. T. Sawicki, D. J. Inman, A. W. Lee [8] in their paper used internal variable approach to model the viscoelastic material for the transient dynamic responses, and includes an energy dissipation model. They gave an example of a turbo molecular pump, and the difficulty in balancing such machines is demonstrated. This paper has investigated the effect of an elastomer support on the dynamics of a rotating machine. In particular the effect of the frequency and temperature dependent modulus has been demonstrated. Although the example was relatively simple a number of conclusions may be drawn. It was shown that the dynamic characteristics of a machine change significantly with temperature because of the changes in stiffness and damping characteristics of the elastomer.

Carlos Alberto Bavastri, Euda Mara da S. Ferreira, Jose Joao de Espíndola, Eduardo Marcio de O. Lopes [9] in their paper presented a numerical methodology for predicting the dynamic response of a simple rotor system in steady state, with bearings containing layers of viscoelastic material. The model used for the viscoelastic material is the four parameter fractional derivative model, due to its ability of representing the real dynamic behavior of the material. The preceding developments were applied to run a numerical example of a simple dynamic rotor system with two disks (one larger than the other) mounted on roller bearings and viscoelastic layers. The methodology introduced by this work is of foremost importance in guiding vibration and noise control actions on rotor systems by the use of viscoelastic materials.

3.0 EXPERIMENTAL SETUP

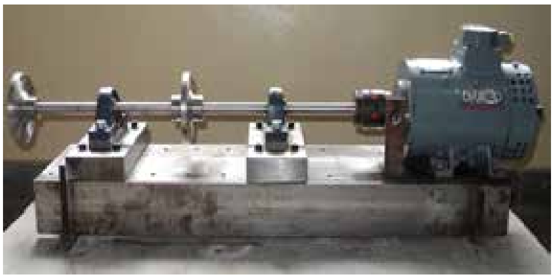
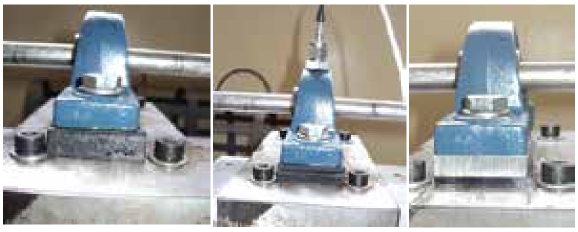


Figure 3.1: Experimental Setup



(a) Corrugated rubber sheet (b) plain rubber sheet (c) PVC sheet

Figure 3.2 Viscoelastic Material Placed Under Support (Bearing)

Figure3.3. FFT Analyzer (OROS 34)

4.0 VISCOELASTIC MATERIALS FOR COMPARATIVE STUDY

Various parameters like material, thickness, rpm of rotating shaft, location of flange on which unbalanced mass is attached, Distance between Bearing Supports are varied and experiments are conducted.

Table 4.1: Factors and their levels of experiment

Variables	Levels		
	1	2	3
Material	Natural rubber plain sheet	Natural rubber corrugated sheet	PVC plain sheet
Thickness	3	5	12
Rpm Of Rotating Shaft	300	600	900
Location of Unbalanced Mass	I	II	-
Distance Between Bearing Supports	300	390	-

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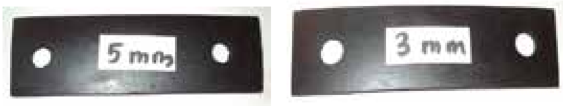
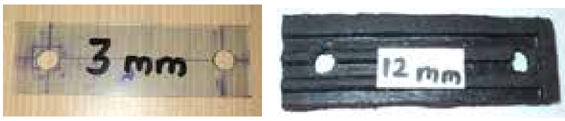


(a) Natural rubber plain sheet 3mm thick (b) Natural rubber plain sheet 5mm thick



(c) Natural rubber corrugated sheet 12mm thick (d) PVC sheet 3mm thick

Figure 4.1 Viscoelastic Materials

5.0 EXPERIMENTAL PROCEDURE

Experiments were carried out on specially developed vibration test rig which can facilitate the change of bearing support location, location of unbalanced mass, change in mass position, change in operating frequency (i.e. speed can be varied) etc. For each case 18 no. of readings were taken. The speed (frequency) is measured using non-contacting type speed sensor with digital display, an accelerometer attached to FFT analyzer is mounted on both bearing support (i.e. near to the drive and away from the drive), the signal received from the accelerometer with the help of FFT analyzer is acquire and displayed on PC using NVGate software.

The vibration spectrum is captured under two sets of conditions;

(I) distance between bearing supports = 300mm.

Case 1: 3mm thick Plain rubber sheet + 9mm thick M.S. plate beneath bearing housing
Case 2: 5mm thick Plain rubber sheet + 7mm thick M.S. plate beneath bearing housing
Case 3: 12mm thick Plain rubber sheet beneath bearing housing
Case 4: 12mm thick corrugated rubber sheet beneath bearing housing
Case 5: 3mm thick PVC sheet + 9mm thick M.S. plate beneath bearing housing
(II) distance between bearing supports = 390mm.
Readings are obtained for following cases:

Case 1: 3mm thick Plain rubber sheet + 9mm thick M.S. plate beneath bearing housing
Case 2: 12mm thick Plain rubber sheet beneath bearing housing
Case 3: 12mm thick corrugated rubber sheet beneath bearing housing
Case 4: 3mm thick PVC sheet + 9mm thick M.S. plate beneath bearing housing

6.0 RESULTS

Table 6.1 (I) distance between bearing supports = 300mm

Expt. No.	RMS Value	Expt. No.	RMS Value	Expt. No.	RMS Value	Expt. No.	RMS Value	Expt. No.	RMS Value
Case 1		Case 2		Case 3		Case 4		Case 5	
1	12.6	1	12.07	1	13.35	1	17.06	1	11.21
2	12.1	2	11.25	2	19.69	2	26.88	2	12.69
3	28.31	3	30.17	3	32.41	3	35.51	3	22.76
4	23.93	4	33.98	4	34.89	4	45.73	4	25.81
5	58.4	5	60.1	5	54.6	5	51.9	5	49.17
6	40.87	6	47.47	6	52.4	6	75.3	6	45.9
7	12.07	7	13.36	7	17.97	7	19	7	14.71
8	12.64	8	12.32	8	20.15	8	28.74	8	15.97
9	13.8	9	10.88	9	14.19	9	19.49	9	12.28
10	13.69	10	13.03	10	16.21	10	29.01	10	15.68
11	27.84	11	30.9	11	36.33	11	35.99	11	25
12	24.28	12	27.47	12	35.52	12	44.07	12	28.41
13	27.95	13	26.93	13	33.32	13	35.16	13	29.66
14	25.2	14	27.29	14	35.56	14	46.84	14	28.63
15	43.54	15	48.04	15	56.8	15	62.7	15	53.5
16	50.6	16	48.1	16	57.3	16	79.2	16	45.49
17	49.3	17	63.4	17	60.7	17	63.3	17	49.78
18	42.8	18	48.98	18	56.3	18	78.5	18	44.5

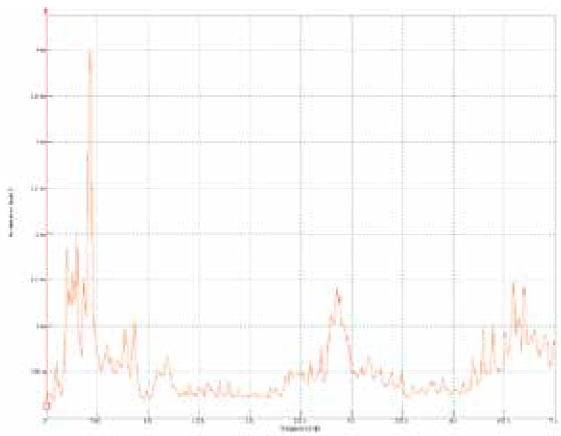


Figure 5.1 Sample Vibration Spectrum (Refer Table 6.1 Case 5 Expt. No. 1)

Similarly the vibration analysis for distance between bearing supports = 390mm were carried out.

6.0 CONCLUSIONS

From above experimental results taken from experimental test setup developed following conclusions were made;

1. It is observed that the vibration level at bearing is less for PVC material used as isolator than that of natural rubber with plain geometry and corrugated profile. Hence PVC material is having more vibration damping capability than natural rubber material with plain geometry and corrugated profiles.
2. It is also observed that as the thickness of natural rubber material increases, vibration damping capability of natural rubber material decreases. Therefore there is need of further research to find out the optimum thickness for the viscoelastic material, which can be placed under the support.

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