Study on the Influence of Magnetorheological Fluid Damper on Vibration in Rotating Machinery

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Abstract: - In day-to-day life, the concept of rotary machines appears everywhere in diverse engineering applications. In rotating machinery, the safety and performance of the entire system are considered as the significant factors which has to be monitored continuously. As the speed of the motor increases, the amplitude of vibration varies rapidly, and the excitation is due to the elements of rotating structure. There are various parameters that affect the vibration in the rotor during different rotating speed. In this paper, rotor made of mild steel and supporting structure made of cork, synthetic rubber was considered, and these parameters were tested for similar condition with and without magnetorheological fluid damper. This damper is used to reduce the vibration in the shaft due to whirling of shaft at critical speeds. The vibration characteristics of the rotary machinery were studied with change in the base material of the supporting structure. From experimental result, it was observed that the rubber base material reduces vibration much better when compared to cork material. The percentage of reduction in the shaft vibration shows that it is better to use rubber base material with Magnetorheological fluid damper rather than the cork material even though vibration was reduced considerably when both base materials was attached to the setup with MR damper.

Keywords: - Synthetic rubber, cork, rotating machinery, amplitude of vibration, Magnetorheological fluid damper, mild steel

1. INTRODUCTION

Rotary machine is a transmission device which has one or more mechanical structures, supported by bearings and influenced by an internal phenomenon that can transmit the rotational energy from one system to another. This rotary machine undergoes various energy losses, reduction in life time of the shaft, bending of the shaft and limited speed of rotation due to the vibration in the shaft. To improve the performance of the rotary machine, factors like the imbalance in mass of the shaft induced by vibration[1], angular misalignment in coupling[2] and critical speed causing whirling of shaft must be reduced[3]. Other factors that influence the whirling effect in the shaft of the rotary motor includes mounting position of shaft, size of the shaft, modulus of elasticity, weights and position of the counter weights added to the shaft[4]. While considering the mounting manner of the machinery, the mounting position and base material of the prime mover is crucial.

Sam Paul et al [5] used ball bearing and taper roller bearing for mounting the shaft and observed that the vibration was much less for ball bearing Also, in other works they mentioned that shaft material made of mild steel provides better performance. In the past few decades, research on mass balance and selection of superior shaft materials in the rotary machine were conducted to study the nature of vibrations occurring in the rotary machine, in effort to make a better damping device. In order to reduce vibration in mechanical components many dampers like hydraulic dampers, elastomeric dampers, and viscous dampers have been used in the past. These dampers have been experimented to develop an ideal damping device in articulated main rotor assemblies [6].

The elastomeric damper has more advantages over hydraulic damper due to less mechanical components, maintenance cost and weight [7]. Prior investigations on viscous dampers, enunciates its relative efficiency in providing temperature compensation over the operating temperature range of the viscous working fluid viscous shear dampers than its counterparts. However, viscous dampers are unnecessarily complicated mechanically, which reduces their reliability component. In order to explore more on formulating a rotary viscous damper, a level of reliability is of prime concern. Generally, silicone fluid is a preferred viscous damper material due to its inherent damping characteristic of withstanding high temperature [8]. However rotary motor applications in aircraft, military equipment require, working temperatures at around 160 F which the conventional silicone fluid cannot suffice since its efficiency is reduced by 50 % when compared to its room temperature efficiency.

Magnetorheological fluid is a better substitute as it permits continuous control over the fluid viscosity by varying the power of the electromagnet [9] which also aligns the magnetic particles suspended in the carrier oil [10]. The passive types of damper have a fixed setting during their lifetime, and hence they are not able to operate satisfactorily in a broad range of road states. This problem can be overcome by active or semi-active suspension systems like the MR damper [11]. By using the MR damper in suspensions, performance indices like ride comfort and vehicle stability has been improved. Sam Paul et al [12], used magnetorheological fluid damper and confirmed its influence on the reduction of tool vibration during metal cutting. The magnetorheological fluid is still vulnerable at very high temperature range and its ability to control vibration depends on the applied current intensity, size of the iron particles and viscosity of the fluid [13], [14]. They also concluded that the concept of magnetorheological fluid damper is much superior to the rest of the passive dampers in all the cases.

From the review of literature it was revealed that vibration is a significant factor in rotating machinery and no attempt was made in the past to control vibration using magnetorheological fluid which was successful in vibration control. In this paper, it was planned to study the effect of vibration in rotating machinery using base material made of rubber and cork and also to study the effect of magnetorheological damper in rotating machinery. In magnetorheological fluid damper, when an electric field is applied to magnetorheological fluid, the fluid becomes a semisolid and this transition is reversible which can achieve in a few milliseconds. Experimental setup was developed and experiments were conducted in rotary machines for base material rubber and cork with and without magnetorheological fluid. Magnetorheological fluid damper used in this study appears to reduce vibration effectively in different operating condition with base materials made of synthetic rubber. From the results it was observed that magnetorheological fluid can be used in rotary machines to control vibration and the intensity of vibration can be suppressed using active control system.

2. MATERIAL SELECTION

In the industrial sector, preventing unexpected failures of the component is paramount which helps to improve the efficiency. In rotating machinery, the amplitude of speed and vibration is directly related with the rotational amount of mechanical issues in machinery like misalignment, imbalance. When the rotational speed increases with imbalance in machinery, it seems centrifugal force will be increased which in turn cause the vibration amplitude to increase accordingly. Also, effects of misalignment are much more complex than unbalance which will also increase the amplitude of vibration abruptly. Other factors which results in high amplitude of vibration during increase in speed would be worning of bearings, improper lubrications, worn seals and poor isolation. In order to control vibration, selection of base material and damper was considered and analyzed in this investigation.

2.1 Selection of material

In this paper, the shaft material is made of mild steel which has high resistance to breakage, is used [4]. Mild steel has high strength due to low amount of carbon content. Due to this property, mild steel can be easily machined and welded. Unlike high carbon steel it cannot be hardened through heat treatment process. In mild steel dislocation occurring inside the iron crystal which allow the lattice layers to slide against each other will be prevented and this resulted in good ductile property. The cost of the mild steel is also comparatively lower than other material.

Table 1. Composition of Mild Steel

Materials	C	Mn	Si	S	P	Cr	Ni	Cu	Fe
% composition in weight	0.205	0.5	0.27	0.035	0.035	0.25	0.25	0.25	rest

2.2. Selection of base materials

The prime mover was mounted on the base material (cork and rubber) to enable the absorption and transmission of the vibration to the bed. Base material which is composed of irregularly shaped dead cells cork was extracted from the tree bark and it has honeycomb like structure with huge vacant areas providing a porous texture. Due to its huge porosity, density of one fourth that of water (450kg/ m^3) and many layers of microscopic bubble wrap, it was considered a better cushioning material with a flexural strength of about 2.25 MPa, after being crushed under a pressure of 96,000 kPa, the cork generally regains 90 % of its original size within 24 hours due to its higher elasticity with an outstanding compressive strength of 1-26 MPa [15]. Cork is highly resistant to wear, used as insulation and is durable [16]. Also, it is capable of acting as friction lining material especially in internal lining of submarines, automatic transmission clutches and external protection layer in rockets against extremely high temperature caused by friction on its re-entry into the earth's atmosphere. It is reckoned as eco-friendly due to its slow-burning, energy absorption ability which allows a very low level of CO_2 gases release.

Besides, the synthetic rubber which is an artificial elastomer possess greater flexibility and resistance to corrosion (due to oil, grease and salt water). This factor controls the damage caused by extensive vibration and extends the machinery's life expectancy [17]. Also, it helps to avoid the need for expensive structural designing of machinery. The elastic characteristic of rubber is mainly due to the presence of resting chains of chemical structure, which can stretch and contract on application of heavy loads and regain its original shape once the tension is removed. In addition to this, the synthetic rubbers are inert in nature and can be readily used without further processing which finds a most common application as a coating material for tanks carrying the highly reactive fluids. In this work, the compressibility and elasticity of cork material and the mechanical resistance and stable inert nature of rubber has been combined to yield the desired base material.

3. DEVELOPMENT OF MAGNETO-RHEOLOGICAL FLUID DAMPER

Magnetorheological fluid belongs to a class of comfortable fluid which has the ability to reversibly change from a viscous liquid to a semi solid in milliseconds when exposed to magnetic field. During magnetization, the suspended particles polarize and interact to form a structure aligned with magnetic field. This change in material increases the fluid viscosity and the fluid develops the characteristics of semi-solid state. The viscosity of MR fluid increases as the strength of magnetic field increases and when the magnetic field is removed, MR fluid revers to its previous position. A line sketch of MR fluid setup developed for this work is shown in Figure1. In this paper, MR fluid was prepared by mixing of iron particles (Size: 38 microns) and oil (Grade: SAE 40) in the optimal 70:30 ratio to get a better damping effect [12]. The shaft was connected with a simple roller bearing with an outer sleeve. The outer sleeve is connected to the piston head of the damper which moves vertically inside the cylinder. The winding coil used is a standard wire gauge 25. The specification of the SWG 25 wire is given as follows:

Diameter = 0.508mm, crosssectional area = 0.203 mm^2, resistance per length = 279 Ω\km, current carrying capacity = 0.800 A.

The coil is equipped with 1500 turns and it is supplied with DC current of 12 V (2 A). The magnetomotive force (A) and magnetic field strength(A/m) are calculated using the formulas given bellow

Magneto motive force

$F_{m=}I*N= 0.8*1500 = 1200A$

where I= current, N= number of turns

$l= 2*\pi*r=2*\pi*0.508=3.191;$

r= radius of the coil

Magnetic field strength (H) = F_m / l =376.17 A/m.

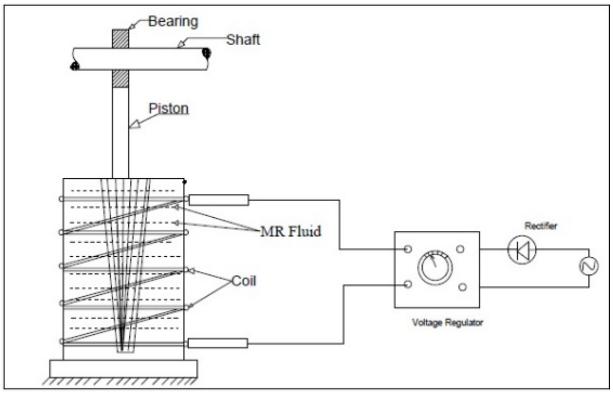

Figure 1. Line sketch of magnetorheological fluid damper.

As shown in Figure 1, magnetorheological fluid setup consists of a piston(P) which moves inside a cylindrical cup containing MR fluid and top end of the piston is attached with ball bearing that matched with the rotating shaft so that piston can be held rigidly without affecting the rotating movement of shaft. The bottom end of the cylinder is rigidly attached to the test bed or base using screws and nuts. MR fluid will be magnetized by passing current through the coil. When the coil is energized, MR fluid is activated and offers resistance to the motion of the piston, thereby damping the vibration. From literature it was observed that the viscosity index of the fluid medium, size if the ferro magnetic particle the current through the coil [12]. In this investigation supply voltage of 30 V was used as higher supply voltage will increase the damping ability. Also, cylindrical shaped plunger with 38-micron size iron particle and oil with viscosity index (SAE 40) was used as these parameters can offer higher resistance to the movement of the plunger while damping the vibration [14].

4. EXPERIMENTAL SETUP

The specification of the required experimental setup is shown in the Table1 and the photograph of the experimental setup is presented in Figure 2.

Table 2. Specification of the experimental setup

Sl. No.	Name of the equipment	Specification
1.	Length of the shaft	780mm
2.	Diameter of the shaft	15mm
3.	Speed of the motor	0-3000rpm
4.	Power of the motor	0.5hp
5.	Aluminum disc diameter	100mm
6.	Mass of the aluminum disc	0.583kg
7.	Bearing Type	Ball bearing
8.	Coupling Type	Love Joint coupling

Experimental test rig shown in Figure2 consists of a DC 0.5hp motor, support plates, counter weight, shaft, bearing and flexible coupling (specification shown in Table 1). A flexible shaft is used to connect shaft with motor in order to reduce the effects of vibration generated by motor. A phase induction motor Permanent Magnet DC motor 230 V which can run in the different speed range is connected to the variable speed control unit for achieving variable speeds. Two bearing are fixed into the mounting housing to enable rotational movement, while reducing friction and handling stress and also to handle pure radial loads, pure thrust loads, or a combination of two loads. A static load is applied by one aluminum disc with 100mm diameter and a mass of 0.583 kg at the center of shaft which is made of stainless steel.

Amplitude of vibration or displacement was measured using a piezoelectric-type accelerometer (RATNA make) where the accelerometer pickup which has a sampling rate 12800Hz, was mounted at the stator near to bearing location area. Although this sensor is capable of measuring acceleration (m/sec^2), velocity (m/sec) and displacement (mm) parameters, amplitude of vibration or displacement parameter was measured in this investigation since it is the most critical parameter which affects the stability of the setup and causes unbalance in rotating machinery. The signals from the pickup were fed to a signal conditioner and an indicator. The output data obtained from this accelerometer is not analog signal but a sequence of discrete values and at any given time it can only take on one of a finite number of values. Since the vibration, particularly in the radial direction, is known to have a deleterious effect on the output performance, the amplitude of vibration in vertical direction was measured in this study. Experiments were conducted with two replications and each experiment lasted for 120 seconds.

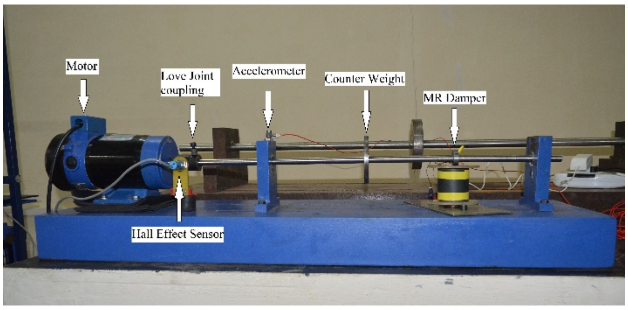

Figure 2. Rotating machinery experimental setup

5. RESULTS AND DISCUSSION

In this paper, an attempt was made to mount the motor on the based material like cork and synthetic rubber to control vibration and also to study the influence of supporting material on vibration. Also, magnetorheological fluid damper was designed, fabricated and mounted at the middle of the mild steel to withstand transverse vibration that occurs at different speeds. Amplitude of vibration in vertical axis measured for the rotating machinery with and without magnetorheological fluid damper along with two base materials at different speeds is shown in Table3.

From the experimental results, it is observed that the amplitude of vibration is increased as the speed increases gradually and the level of amplitude depends on the type of base material used. Also, it was noted that when the rotating shaft member (rotor) is connected to magnetorheological fluid damper, vibration has considerably decreased for varying speed and also for different base material.

Table 3. Experimental results

Shaft Material	Base Material	Speed (RPM)	Amplitude of vibration (mm)	
			Without Damper	With Damper
Mild Steel	Rubber	500	0.0223855	0.0201795
		1000	0.0284180	0.0252170
		1500	0.0351475	0.0276530
		2000	0.0518650	0.0440285
		2500	0.0820390	0.0737390
		3000	0.1408740	0.1038700
	Cork	500	0.0233375	0.0209200
		1000	0.0289490	0.0236550
		1500	0.0353635	0.0295680
		2000	0.0527825	0.0484125
		2500	0.0940510	0.073962
		3000	0.1550510	0.1212320

From experimental results (shown in Table 3) it is observed that in rotating machinery, base material made of synthetic rubber isolates vibration better than cork and also resulting in less vibration. In general, cork material has the tendency to absorb 30 to 70% of tones in the frequency range from 400 to 4000 Hz and all the cork products have good mechanical strength and also has the ability to retain mechanical properties in the temperature range -80°C to 140°C. When the cork is subjected to high forces or pressure, the gas in the cell is compressed, and its structure will reduce in terms of volume. After the cessation of pressure, the cork returns to its original shape. This flexible property inhibited in cork material results in reducing the vibration during rotating machinery. However, the reduction in the vibration level is less when compared to rotating machinery having synthetic rubber as base material. This is due to that fact even though the cork material is capable of absorbing vibration; it does not have the tendency to transmit vibration. Vibrations developed during rotation are not effectively transmitted when cork material is used instead it absorbed the vibrations induced on it which further lead to ineffective isolation. When synthetic rubber was used, vibrations occurring during different speeds were transmitted to the supporting structure (foundation) thereby acting as effective isolation material and also isolating the rotor from the induced vibration.

The calculated percentage reduction of vibration due to the damping effect generated by magnetorheological fluid damper when cork and synthetic rubber was base material as shown in Table 4. From this table it was found that the amplitude of vibration increases suddenly for both cork and rubber material between the rotational speed range of 2250 – 3000[16]. This sudden increase in damping effect is due to the critical speed which causes whirling of the shaft.

Table4. Percentage reduction in vibration

Speed (RPM)	Percentage reduction in vibration using	
	Cork	Rubber
500	10.35	9.85
1000	18.28	11.26
1500	16.38	21.32
2000	8.27	15.10
2500	21.35	10.34
3000	21.81	26.26

The effect of MR fluid on the amplitude of vibration at different speed for the synthetic cork and rubber base material is shown in Figure 3 and 4 respectively. From these Figures it was observed that during minimum speed the effect of MR fluid damper on the amplitude of vibration is negligible. As the speed increases, the damping capability gets increased which resulted in better reduction in vibration. Also, it was noticed that base material made of rubber reduces vibration effectively with and without damper during the similar working conditions.

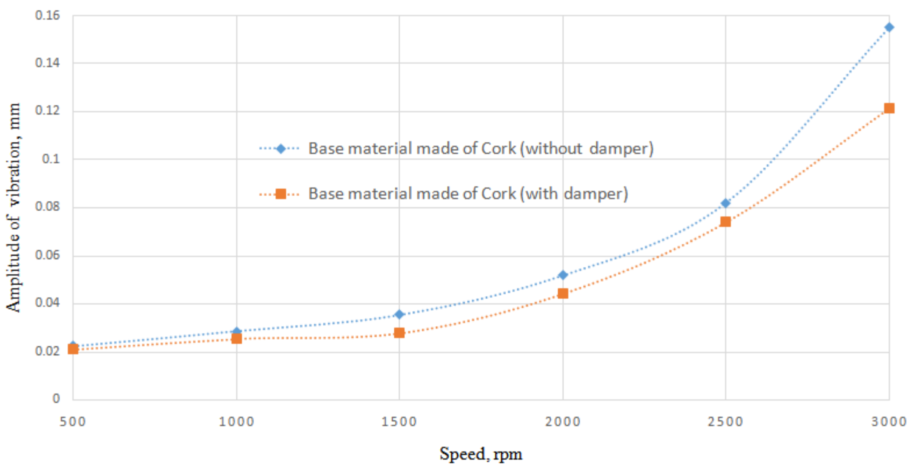

Figure 3. Amplitude of vibration for base material made of cork

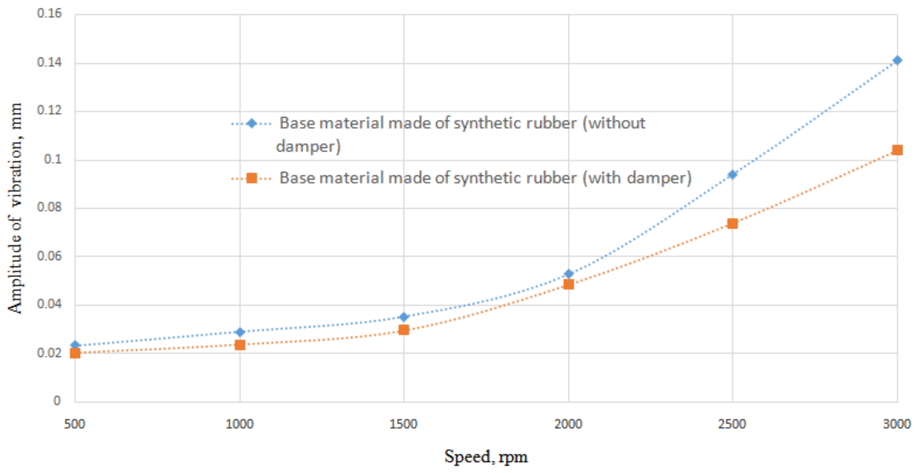

Figure 4. Amplitude of vibration for base material made of synthetic rubber

In this investigation, the vibration in rotor dynamics was reduced to a desired level by changing base material and also by adding magnetorheological fluid damper to the system. From the experimental results it appears that the attachment of the damper with rotor has brought forth better reduction in the magnitude of vibration. The vibration that occurs in the rotating machinery was reduced by 26 percentage due to the damping force developed by the rheological fluid damper when subjected to magnetic field. As the coil in the electrical winding gets energized by the supply of voltage, magnetorheological fluid gets activated and offers resistance to the movement of the plunger which was connected with the rotating shaft, thereby reducing the vibration level. Damping mechanism provided in this paper is simple in construction, economically viable and scientifically efficient to control vibration to a greater extent in rotating machineries.

6. CONCLUSION

In this paper, an attempt was made to study the effect of magnetorheological fluid damper on the amplitude of vibration in rotating machinery at different speed levels. Also, the influence of using base materials like cork, synthetic rubber on vibration was studied. A magnetorheological fluid damper which is suitable for rotating machinery has been developed and series of experiments have been carried out which lead to the following conclusions:

1. A magnetorheological fluid damper can reduce the amplitude of vibration effectively in rotating machinery for different speed.
2. Base material made of synthetic rubber reduces vibration effectively compared to cork material.
3. The amplitude of vibrations occurring in rotating machinery is highly influenced by the material used in fabricating the machinery parts.
4. The presence of magnetorheological fluid system can bring forth reduction in vibration to a maximum extent of 26 % during rotating machinery and commercialization of this technique is sure to benefit the industrial sector.

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