Vibration Reduction of Rotating Machinery by Using Viscoelastic Material Support

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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.

Keyword – Viscoelastic material, Vibration, FFT analyzer.

I. 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 are 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. Source reduction, for example, can be achieved by altering the running conditions such as, if possible, the rotational speed or the bearing preload. 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.

II. VISCOELASTIC MATERIALS

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like honey, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and, as such, exhibit time dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.
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, Fluoro-silicone Rubber, Fluorocarbon Rubber, Nitrile Rubber, Natural Rubber, Polyethylene, Polystyrene, Polyvinylchloride (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.

III.PLANNING OF EXPERIMENTS

The selection of viscoelastic material is based on the ease of availability, installation, replacement and cost. Following viscoelastic materials were used for evaluating their effectiveness in minimizing the effect of vibration

1. Natural rubber sheet with plain geometry (thickness 3, 5, 6,12mm)
2. Natural rubber sheet with corrugated profile (thickness 12mm)
3. PVC (polyvinyl chloride) sheet (thickness 3, 6, 12mm)

Sr .No.	**DESCRIPTION**	**PICTURE**
1	**Natural rubber sheet with plain geometry 3mm thick**	
2	**Natural rubber sheet with plain geometry 5mm thick**	
3	**Natural rubber sheet with plain geometry 6mm thick**	
4	**Natural rubber sheet with plain geometry 12mm thick**	
5	**Natural rubber sheet with corrugated profile 12mm thick**	
6	**PVC (polyvinyl chloride) sheet 3mm thick**	
7	**PVC (polyvinyl chloride) sheet 6mm thick**	
8	**PVC (polyvinyl chloride) sheet 12mm thick**	

Table I: Viscoelastic Materials used for experiments

The above selected materials with different thickness and geometry are used as vibration isolators (damping agent to absorb the vibrations). The other parameters for vibration analysis were rpm of rotating shaft, location of disc on which unbalanced mass is attached and distance between bearing supports. The following table shows the various parameters and its variables taken under consideration for conducting the experiments.

Parameter	**Variables**			
	1	**2**	**3**	**4**
Viscoelastic Material	**Natural rubber sheet with plain geometry**	**Natural rubber sheet with corrugated profile**	**PVC (polyvinyl chloride) sheet**	-
Thickness (mm)	3	5	6	12
Speed (Frequency) rpm of Rotating Shaft	300	600	900	-
Location of Unbalanced Mass	Disc 1	Disc 2	-	-
Distance Between Bearing Supports (mm)	300	390	-	-

Table II: Parameters and variables

IV.EXPERIMENTAL SETUP

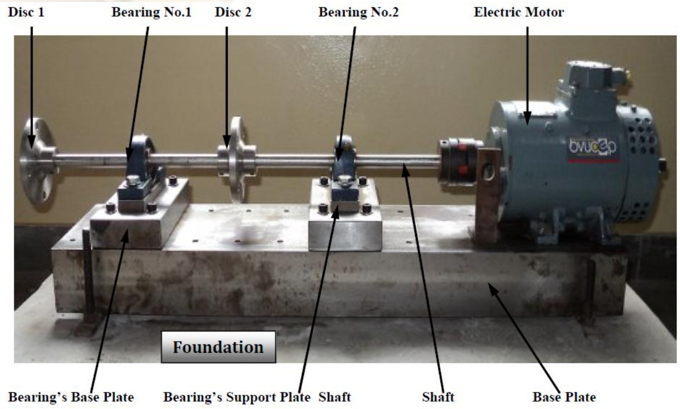


Fig.1 Experimental Setup

Experimental setup consists of electric motor (0.37 kw), shaft (material stainless steel of Φ 15 mm diameter of full length 630), two bearings, two discs, bearing's base plate, bearing's support plate, base plate and jaw coupling. The major part of this test setup is base plate which is made up from C – Channel having dimensions 200x100x25mm. The base plate also facilitated with number of holes to change the bearing support positions according to the requirement at various locations. The main objective of bearings support plate is to give rigid and firm support to the bearings of the test setup. The dimensions of plate are 200 mm x 100 mm x 33 mm. the main objective of fabrication of this setup is to reveal actual unbalance condition of any rotating machinery.

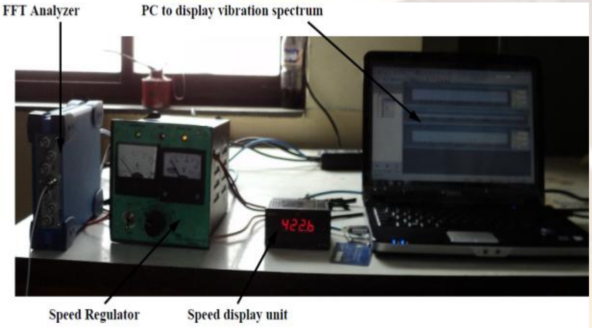


Fig. 2 Experimental Setup Instrumentation

Experimental Setup Instrumentation consists of

- Accelerometer (for sensing vibrations at the bearing locations)
- Inductive pickup sensor (for measuring speed (frequency) rpm of shaft)
- FFT analyser (to record the vibration signal)
- Speed regulator (to control speed of motor)
- Speed display unit (to display speed (frequency) rpm of shaft)
- PC (to record vibration spectrum).

The accelerometer is mounted on bearing senses vibration signal sends it to FFT analyser, FFT analyser processes it and converts it into signal form compatible with PC. These vibration signal values are shown in the form of vibration spectrum on the screen of PC.

Specifications of the Experimental Setup

1. Bearings - Type – Self Aligning, Manufacturer - NTP
Inner Diameter - 15mm, Center Height - 30.1 mm.
2. Disc 1 - a) Flange - Φ 100 mm thickness 10 mm
b) Bush - Φ 40 mm length 35 mm
3. Disc 2 - a) Flange - Φ 112 mm thickness 12 mm
b) Bush - Φ 41 mm length 58 mm
4. Shaft - S.S. Rod of Φ15 mm diameter of full length630 mm
5. Jaw Couplings - Cast iron type jaws coupling Albro (A-095) with gasket has been taken
6. Motor - DC shunt motor, 0.37kw, 1500rpm, 230V, 2-4Amp
7. FFT analyser - From 2 to 4 channels, OR34 is the smallest instrument in this series.
Main Features
1. Ultra-light: 1.4 kg (3 lbs)
2. Hand size (A5 foot print)
3. Real-time bandwidth 40 kHz
4. ± 10 V Inputs, 24 bits, ICP®
5. 100 Mbits/s Ethernet
8. Software – Nvgate

V. 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. Following test plan is decided to conduct the experiments under two different support location conditions

- ***Case 1:*** 3mm thick Natural rubber sheet with plain geometry + 9mm thick M.S. plate beneath bearing housing
- ***Case 2:*** 5mm thick Natural rubber sheet with plain geometry + 7mm thick M.S. plate beneath bearing housing
- ***Case 3:*** 12mm thick Natural rubber sheet with plain geometry beneath bearing housing
- ***Case 4:*** 12mm thick Natural rubber sheet with corrugated profile beneath bearing housing
- ***Case 5:*** 3mm thick PVC sheet + 9mm thick M.S. plate beneath bearing housing
- ***Case 6:*** 6mm thick PVC sheet + 6mm thick M.S. plate beneath bearing housing
- ***Case 7:*** 12mm thick PVC sheet beneath bearing housing

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 analyser is acquire and displayed on PC using NVGate software.

VI. RESULTS

As per the test plan discussed in chapter V the experiments were conducted and result tables were prepared. Following result tables referred to the different case and conditions discussed previously.

Case 1		Case 2		Case 3		Case 4		Case 5		Case 6		Case 7	
Test. No.	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**
1	12.6	1	12.07	1	13.35	1	17.06	1	11.21	1	14.58	1	12.59
2	12.1	2	11.25	2	19.69	2	26.88	2	12.69	2	14.4	2	13.54
3	28.31	3	30.17	3	32.41	3	35.51	3	22.76	3	35.01	3	29.5
4	23.93	4	33.98	4	34.89	4	45.73	4	25.81	4	25.93	4	26.97
5	58.4	5	60.1	5	54.4	5	51.9	5	49.17	5	63.8	5	54.3
6	40.8	6	47.47	6	52.4	6	75.3	6	45.9	6	43.33	6	41.35
7	12.07	7	13.36	7	17.97	7	19	7	14.71	7	13.46	7	12.32
8	12.64	8	12.32	8	20.15	8	28.74	8	15.97	8	10.65	8	12.28
9	13.8	9	10.88	9	14.19	9	19.49	9	12.28	9	14.15	9	12.02
10	13.69	10	13.03	10	16.21	10	29.01	10	15.68	10	13.77	10	12.02
11	27.84	11	30.9	11	36.33	11	35.99	11	25	11	35.25	11	29.09
12	24.28	12	27.47	12	35.52	12	44.07	12	28.41	12	29.08	12	23.99
13	27.95	13	26.93	13	33.32	13	35.16	13	29.66	13	25.03	13	29.11
14	25.2	14	27.29	14	35.56	14	46.84	14	28.63	14	26.55	14	22.98
15	43.54	15	48.04	15	56.8	15	62.7	15	53.5	15	58.4	15	51.8
16	50.6	16	48.1	16	57.3	16	79.2	16	45.49	16	43.76	16	41.08
17	49.3	17	63.4	17	60.7	17	63.3	17	49.78	17	63	17	52.2
18	42.8	18	48.98	18	56.3	18	78.5	18	44.5	18	42.31	18	39.84

Table III: Result table for condition (I) distance between bearing supports = 300mm

Case 1		Case 2		Case 3		Case 4		Case 5		Case 6		Case 7	
Test. No.	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**	**Test. No.**	**Vibration Magnitude (RMS Value)**
1	16.42	1	12	1	22.4	1	15.46	1	11.41	1	10.45	1	11.75
2	14.92	2	12.24	2	37.06	2	18.4	2	13.26	2	10.13	2	10.45
3	36.97	3	30.79	3	41.9	3	37.75	3	22.62	3	26.62	3	26.79
4	25.04	4	29.09	4	49.31	4	38.89	4	25.04	4	22.92	4	24.96
5	63.7	5	49.02	5	60.8	5	70.3	5	39.84	5	45.62	5	52
6	40.95	6	39.79	6	65	6	68.9	6	41.57	6	38.66	6	42.42
7	16.5	7	12.26	7	22.19	7	16.28	7	13.92	7	10.66	7	11.97
8	15.12	8	10.26	8	30.34	8	19.36	8	13.54	8	10.2	8	10.72
9	15.87	9	11.45	9	21.27	9	17.35	9	13.64	9	10.04	9	11.82
10	14.42	10	10.86	10	25.69	10	18.36	10	12.97	10	9.63	10	10.39
11	35.29	11	28.25	11	40.24	11	36.73	11	26.05	11	25.78	11	28.33
12	35.84	12	25.47	12	39.47	12	40.82	12	24.24	12	20.87	12	27.95
13	35.6	13	29.75	13	33.12	13	37.48	13	33.36	13	26.72	13	26.36
14	24.26	14	23.48	14	40.42	14	39.58	14	25.01	14	24.63	14	26.83
15	57.6	15	47.49	15	55.9	15	65	15	56.3	15	46.49	15	52.4
16	39.43	16	40.5	16	57.4	16	65.6	16	44.1	16	36.82	16	41.23
17	63.5	17	49.32	17	51.1	17	66	17	58.4	17	50	17	59.8
18	41.15	18	40.33	18	55	18	65.1	18	42.38	18	36.47	18	41.53

Table IV: Result table for condition (II) distance between bearing supports = 390mm

Note: The highlighted cells indicate minimum and maximum vibration magnitude (RMS Value) for corresponding case

VI. CONCLUSIONS AND FUTURE SCOPE

From the experimental results recorded in the result tables of chapter V and the corresponding plots based on these results following conclusions were made;

1. Undoubtedly the Viscoelastic material shows its utility as a vibration damping material and can be used as vibration isolators in variety of applications.
2. The conducted research will provide the comparative study between the different readily available Viscoelastic materials. It helps to evaluate the effectiveness of these materials under various circumstances.
3. The major criterion for evaluating the Viscoelastic materials was the material itself, its size and shape. The piece of materials was placed under the support and vibration amplitudes were recorded (at two different locations i.e. near the drive Brg. 2 and at free end Brg. 1) for different support distances, with and without mass unbalance etc.
4. The PVC material with minimum thickness (3 mm) gives better results for condition (I) i.e. showing less amplitude of vibrations at both the support locations and at all the frequency values.
5. The PVC material with minimum thickness 6mm gives better results for condition (II) i.e. distance between bearing support = 390mm.
6. From the results obtained, for the similar set of conditions the vibration magnitude (RMS Value) for natural rubber is 12.6µm/sec^2, for corrugated rubber is 17.066µm/sec^2, for PVC is 11.216µm/sec^2, and for without viscoelastic support is 21.076µm/sec^2. This shows PVC gives reduction in vibration magnitude by 11%, 34%, and 46% over natural rubber, corrugated rubber, without viscoelastic support.
7. The corrugated profiled rubber material with maximum thickness (12 mm) indicates a less effective material for absorbing the vibrations. (There is a need of paying more attention towards the study of effect of geometry and thickness of the rubber as a viscoelastic material)
8. During the case of mass unbalance where vibration amplitude increases substantially, the PVC material also play vital role in minimizing the effects of vibrations. In this case it is observed that slight increase in thickness (i.e. 6 mm or sometimes 12 mm) gives better results.
9. The PVC material of 3 mm thickness exhibits good performance even when the distance between supports was varied (i.e. from 300 mm to 390 mm).
10. The vibration magnitude (RMS Values) for all above discussed viscoelastic materials are less than the permissible value for general purpose machinery i.e. 100 – 120 µm/sec^2. (reference Shock & Vibration Hand book by Harris chapter17- Shock & Vibration Standard)
11. From the present study and based on above conclusions it is found that the use of Viscoelastic material is one of the best choice of passive vibration isolation technique. Further there is a scope to conduct some part of research in the area of optimized thickness and geometry profile of the PVC sheet as a Viscoelastic material.

REFERENCES

[1] H.G. Tillema, **Thesis Noise reduction of rotating machinery by viscoelastic bearing supports,** University of Twente, Enschede, Netherlands, pp. 2-3, February 2003.

[2] Carlos Alberto Bavastri, Euda Mara da S. Ferreira, Jose Joao de Espindola, Eduardo Marcio de O. Lopes, **Modeling of Dynamic Rotors with Flexible Bearings due to the use of Viscoelastic Materials,** Journal of the Brazil, Soc. of Mech. Sci. & Eng., 3(1), pp. 23-29, January-March 2008.

[3] Severino P. C. Marques, Guillermo J. Creus, **Computational Viscoelasticity,** Springer Heidelberg Dordrecht London, New York, pp. 3, 2012.

[4] Snowdon, J.C., **Rubberlike Materials, Their Internal Damping and Role in Vibration Isolation**, Journal of Sound and Vibration, 2 (2), pp. 175-193, April 1965.

[5] Shabaneh, N.H. and Jean W., **Dynamic Analysis of Rotor-Shaft Systems with Viscoelastically Supported Bearings**, Mechanism and Machine Theory, University of Toronto, Canada, 35 (1), pp. 1313-1330, September 1999.

[6] Dutt, J.K., Toi T., **Rotor Vibration Reduction With Polymeric Sectors,** Journal of Sound and Vibration, Vol. 262 (4), pp. 769-793, May 2003.

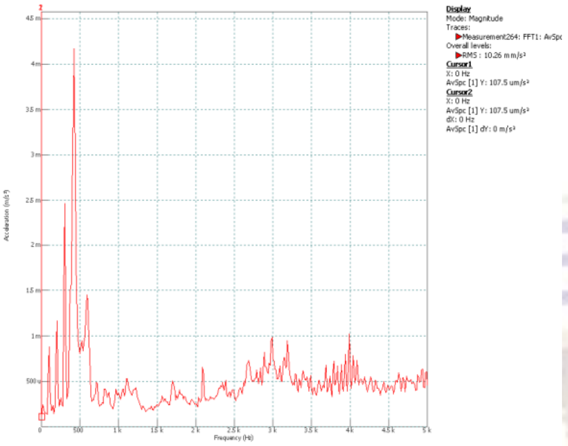
[7] N. Venugopal, C.M. Chaudhari, Nitesh P. Yelve, **An Investigation on Vibration of Visco-elastic materials by Using Taguchi Method & ANOVA,** NCRTM 2006.

[8] M. I. Friswell, J. T. Sawicki, D. J. Inman, A. W. Lees, **The Response of Rotating Machines on Viscoelastic Supports**, International Review of Mechanical Engineering (I.RE.M.E.), 1 (1), pp. 32-40, 2007.

[9] Allan g. Piersol, Thomas L. Parez, **Harris' Shock and Vibration Handbook, Mc-Graw Hill Publication.**

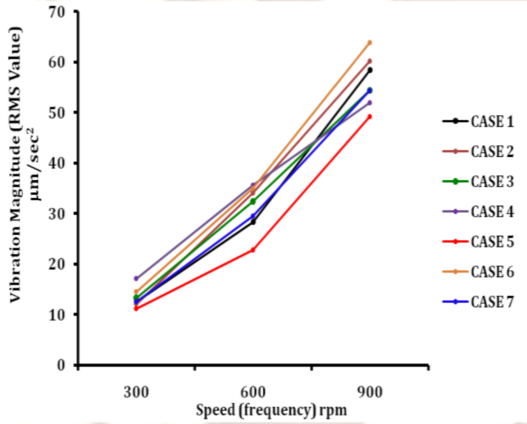
[10]

VII. APPENDIX

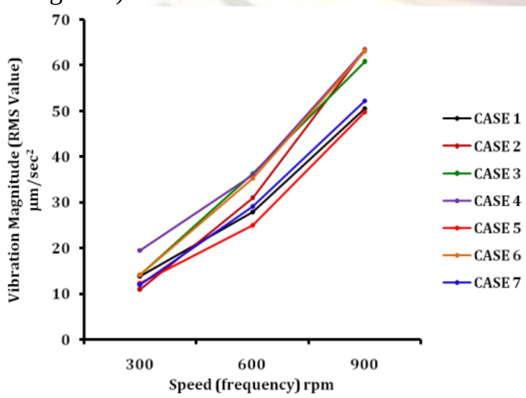


Sample vibration spectrum (Refer Table IV Case 2 Expt. No. 8

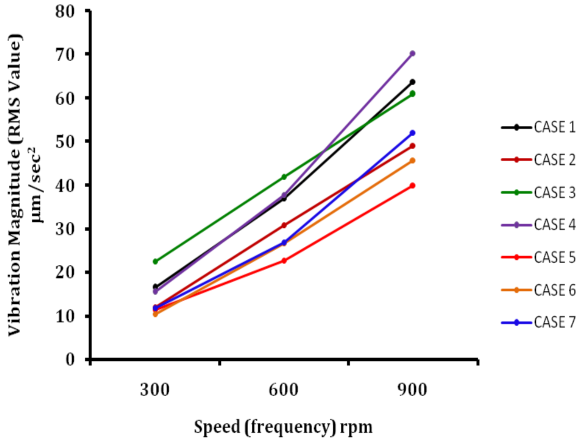
Upcoming figures will show plots of Vibration magnitude Vs Speed for different cases.



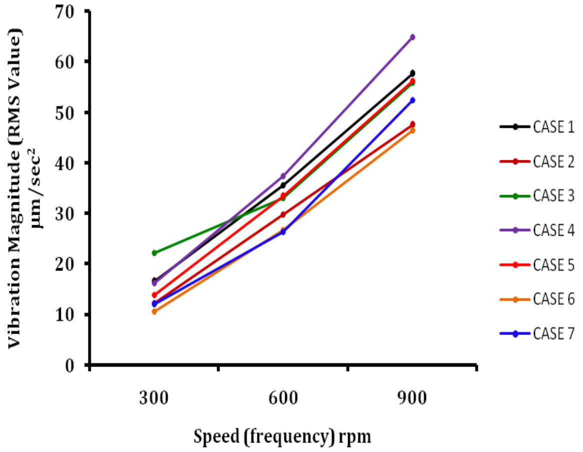
Plot 1: Vibration magnitude (RMS Value) mm/sec2 Vs Speed (frequency) rpm plot for support distance 300mm without mass on disc (At Bearing no.1)



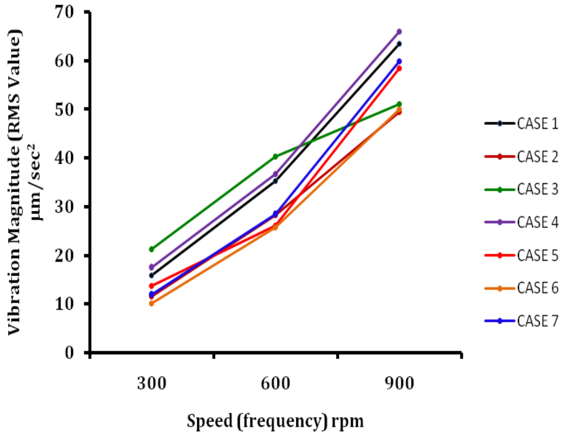
Plot 2: Vibration magnitude (RMS Value) µm/sec^2 Vs Speed (frequency) rpm plot for support distance 300mm with mass on disc 2 (At Bearing no.1)



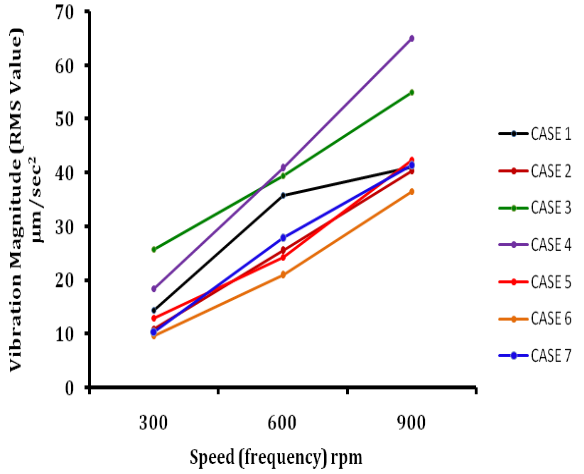
Plot 3: Vibration magnitude (RMS Value) µm/sec^2 Vs Speed (frequency) rpm plot for support distance 390mm without mass on disc (At Bearing no.1)



Plot 4: Vibration magnitude (RMS Value) µm/sec^2 Vs Speed (frequency) rpm plot for support distance 390mm with mass on disc 1 (At Bearing no.1)



Plot 5: Vibration magnitude (RMS Value) µm/sec^2 Vs Speed (frequency) rpm plot for support distance 390mm with mass on disc 2 (At Bearing no.1)



Plot 6: Vibration magnitude (RMS Value) µm/sec^2 Vs Speed (frequency) rpm plot for support distance 390mm with mass on disc 2 (At Bearing no.2)