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Development of Smart Squeeze Film Dampers for Small Rotors

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Abstract

Squeeze film dampers (SFD) are lubrication elements which provide viscous damping in rotating systems. Squeeze film dampers in rotating machinery provide structural isolation, reduce the amplitudes of rotor response to unbalance and also assist to suppress rotor dynamic instability. They have been long used to subdue instability and vibration issues that are difficult to solve using conventional bearings like journal or ball bearings. Numerous studies have been tried to produce mechanically tunable dampers which allow the damping to be changed during different mode of operation. Magneto-rheological (MR) fluids are one of the strong contenders for tunable dampers. They provide the possibility to control the dynamic characteristics of conventional fluid dampers. Magneto-rheological fluids are viscous fluids suspended with micron sized ferromagnetic particles which on application of magnetic field undergo changes in their physical and mechanical properties like viscosity, stiffness, etc. This characteristic can be used to build squeeze film damper whose damping properties will change based on the input force. In present work a typical SFD is designed and development using MR fluid and tested for different amount of damping. It is observed that the damping provided by MR fluid increases with increase in magnetic field and the amplitude of vibration reduces by 70% at critical speeds.

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Keywords: MR-Fluid; Squeeze Damper; Apparent viscosity; critical speed

1. Introduction

The present technology in vibration control involves active management of parameters like stiffness and damping using smart fluids. Magneto Rheological (MR) fluids have good damping properties and response time. Moreover, properties of MR fluid can be controlled in required manner with the help of magnetic field. This property of MR fluids fascinates many researchers to explore its use in active vibration control devices like dampers.

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The MR fluid was developed by Jacob Rabinow in 1940's but its practical application was noted in late nineties. Many researchers developed interest in this novel fluid couple of decades back. In preliminary studies Changsheng Zhu et. al (2001) reviewed the concept of SFD using smart fluids in shear and squeeze film operation mode. Authors experimentally investigated the dynamic characteristics of the MR-SFD and inferred that MR fluid can be used in SFD for effective damping of rotor vibrations. J. Wang et. al (2006) derived and solved the Reynolds equation for MR-SFD based on the Bingham model. The velocity, pressure distribution, film force, and the magnetic pull force of the damper were determine theoretically and the unbalance response of the rigid rotor mounted on MR-SFD was predicted. A typical configuration of the MR-SFD is analyzed using FEMM program for different input current values by Keunet. al (2012). It is observed that the MR fluid saturated at the magnetic field density of 1.4 Tesla.

MR fluid can be used in different modes, the present work aims at the design of MR-SFD in shear mode, determination of the rotor dynamics characteristics of the system under different operating conditions and experimental evaluation of the designed MR-SFD for the desired performance.

1.1. Magneto Rheological Fluid

A magneto rheological fluid (MR fluid) is a type of smart fluid. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity to the point of becoming a visco-elastic solid. Importantly, the yield stress of the fluid when in its active ("on") state can be controlled very accurately by varying the magnetic field intensity. The upshot of this is that the fluid's ability to transmit force can be controlled with an electromagnet, which gives rise to its many possible control-based applications.

Low shear strength has been the primary reason for limited range of applications. In the absence of external pressure the maximum shear strength is about 100 kPa. If the fluid is compressed in the magnetic field direction and the compressive stress is 2 MPa, the shear strength is raised to 1100 kPa. If the standard magnetic particles are replaced with elongated magnetic particles, the shear strength is also improved [4].

Ferro particles settle out of the suspension over time due to the inherent density difference between the particles and their carrier fluid. The rate and degree to which this occurs is one of the primary attributes considered in industry when implementing or designing an MR device. Surfactants are typically used to offset this effect, but at a cost of the fluid's magnetic saturation, and thus the maximum yield stress exhibited in its activated state. The MR fluid selected for this study is MRF-140CG manufactured by Lord Corporation.

2. Design of MR-Fluid

To study the performance of MR-SFD experimentally, the rotor bearing system is designed such that the first rigid critical speed falls below 5000 rpm. The stiffness in the bearing plane is calculated to be 0.75 MN/m for the shaft diameter of 30 mm and bearing span of 200 mm. The schematic of the designed test rig is shown in Fig. 1. The rotor is supported on two bearings and MR-SFD is in a plane between two support bearings.

a

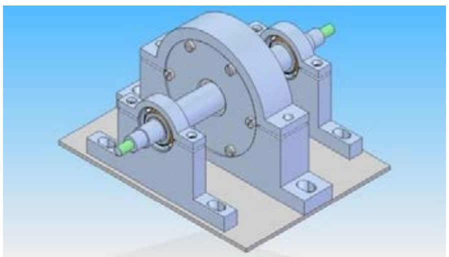

Fig. 1. (a) Isometric View of Test Rig.

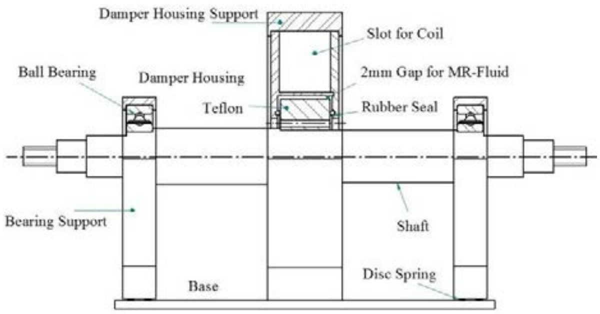

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Fig. 1. (b) Front Half Sectional View of Test Rig.

The MR fluid in MR-SFD is supported between damper housing and Teflon bush mounted on the shaft. Damper housing is made up of aluminum due to light weight and relative magnetic permeability of unity. It does not affect the strength and distribution of the magnetic field. Journal is made up of Teflon to avoid the eddy current losses. Fig. 2 shows the construction of squeeze film damper with sealing system. MRF-140CG fluid is filled inside the annular space provided and sealed to avoid leakages.

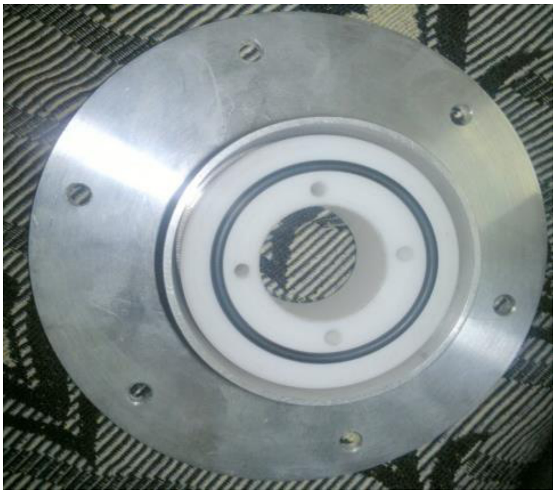


Fig. 2. Squeeze Film Damper Construction.

2.1 Design of Electromagnetic Coil

It is well known fact that when current passes through the solenoid the magnetic field will generate around it. The magnetic field multiplies if the solenoid core is made up of ferromagnetic material. Ampere's law can be used to determine the magnetic field generated by a solenoid for given value of current. The Ampere's law for an infinite length solenoid is given in eq (1) but it also provides a good approximation of the field in long solenoids.

$$B=\mu NI/L \tag{1}$$

Where $\mu=\mu_o\mu_r$

In present study the solenoid has 300 turns of 1.35 mm wire and has a length of 31 mm. The magnetic field generated in MR fluid at different current values is given in table 1.

Table 1. Magnetic field intensity in MRSFD at different current levels

Current (A)	Magnetic field intensity (tesla)
0.1	0.02
0.2	0.05
0.3	0.07
0.4	0.10
0.5	0.12

3. Experimentation

The designed MR-SFD and test rig components are fabricated and assembled on a base plate. It is instrumented with eddy current probe and optical key phasor for the vibration data acquisition system. The electromagnetic coil is power with constant source power supply unit. Fig. 3 shows the instrumented test setup for MR-SFD characterization.

The tests are carried out without and with MR fluid in the SFD. In MR fluid filled case the magnetic field is varied by varying the current in the coil from 0 to 0.5 A. The rotor response under different damping conditions is captured using dedicated data acquisition for rotors, ADRE-408 (Automated Diagnostics for Rotating Machinery).

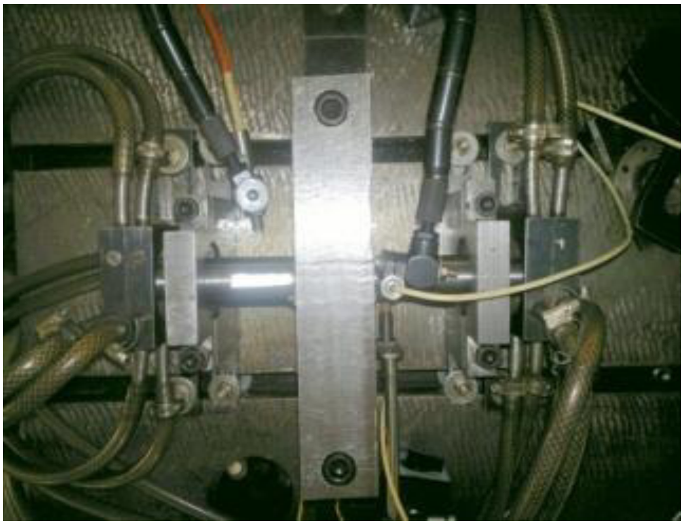
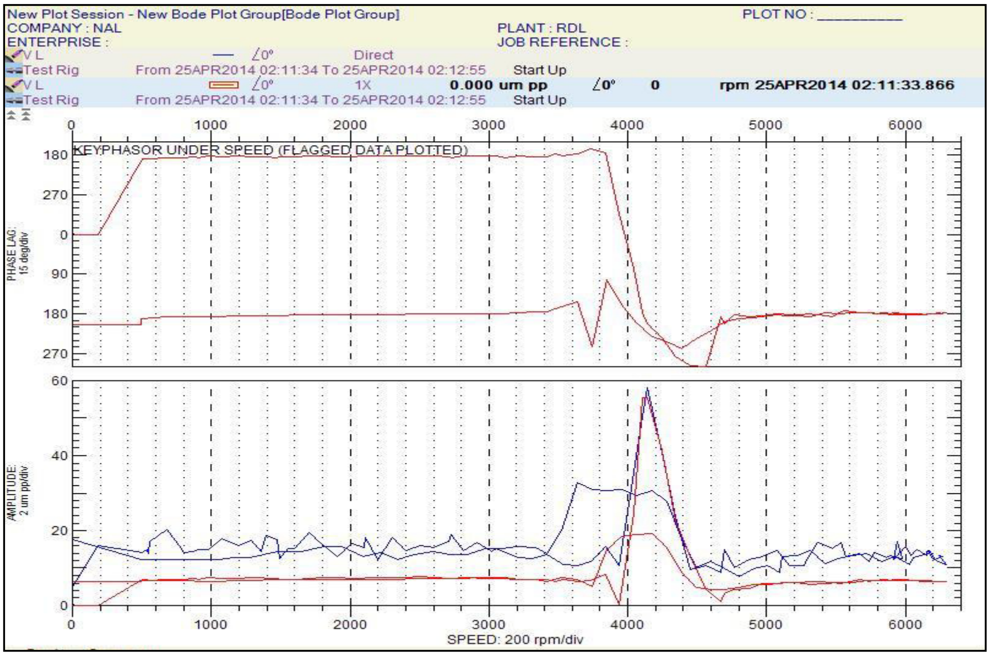


Fig. 3. Photograph of Instrumented Test Rig Setup.

4. Results and Discussions

The performance of any SFD can be evaluated by determining the reduction in the vibration amplitude at critical speed. The Bode plot representing the frequency response and phase shift for speeds up to 6000 rpm is shown in the Fig. 4. In a response plot for the case without MR-SFD it is observed that the response is maximum at the speed around 4200 rpm, this is in line with the design considerations. The shift in phase supports the presence of critical speed. Overall vibration amplitude is about 60 microns at the critical speed without MR fluid and goes on decreasing in subsequent stages of experimentation. At 0.5A of current it reduces to 18 microns and the response becomes almost flat.



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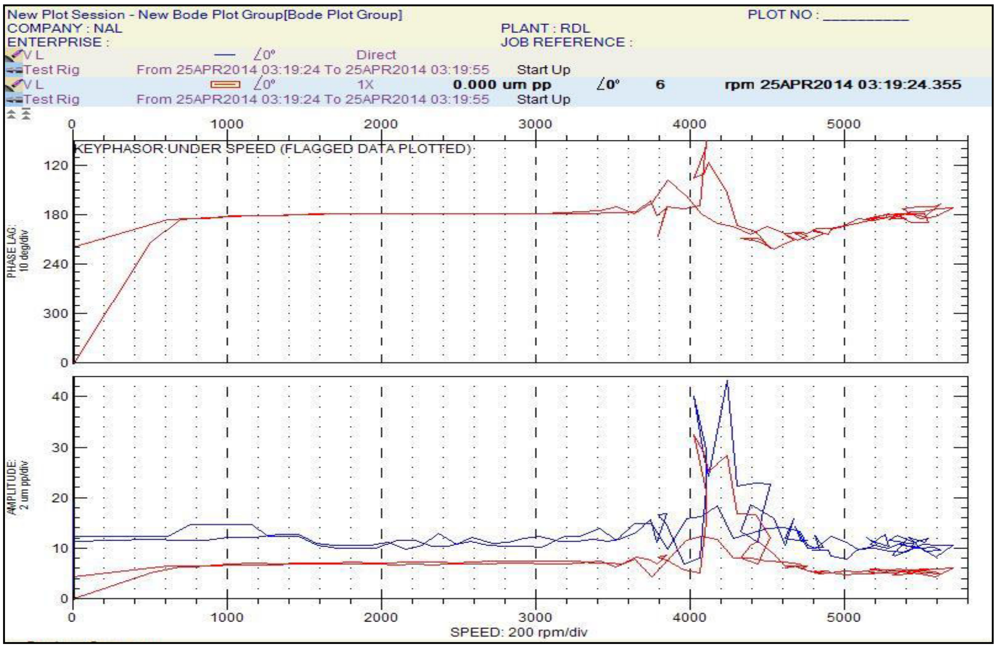

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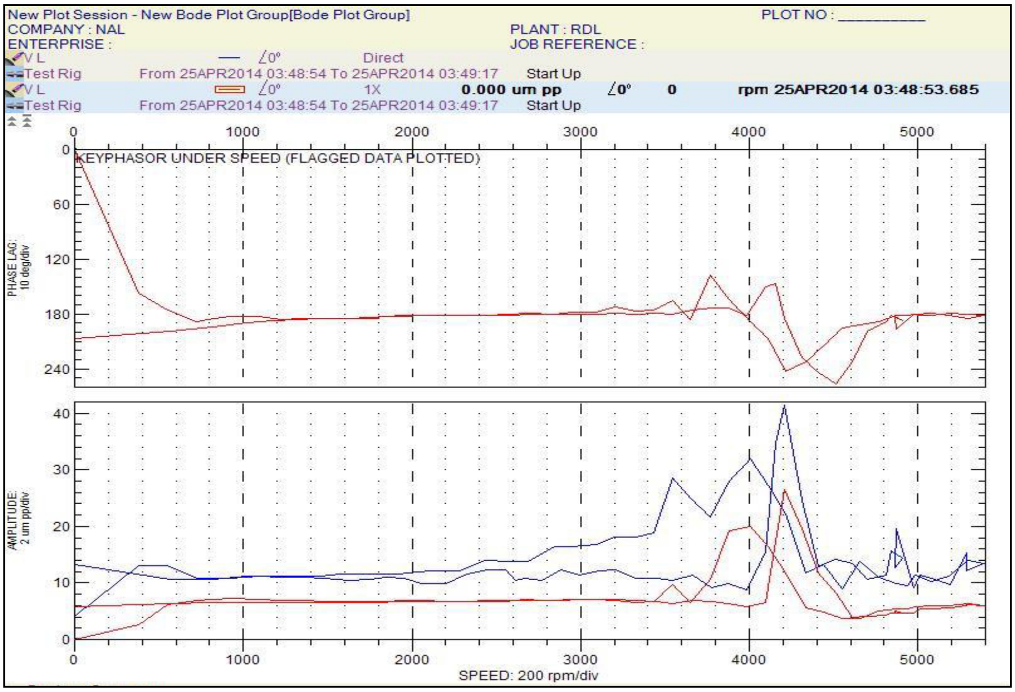
(a) Without MR-SFD; (b) With MR-SFD & 0A Current.



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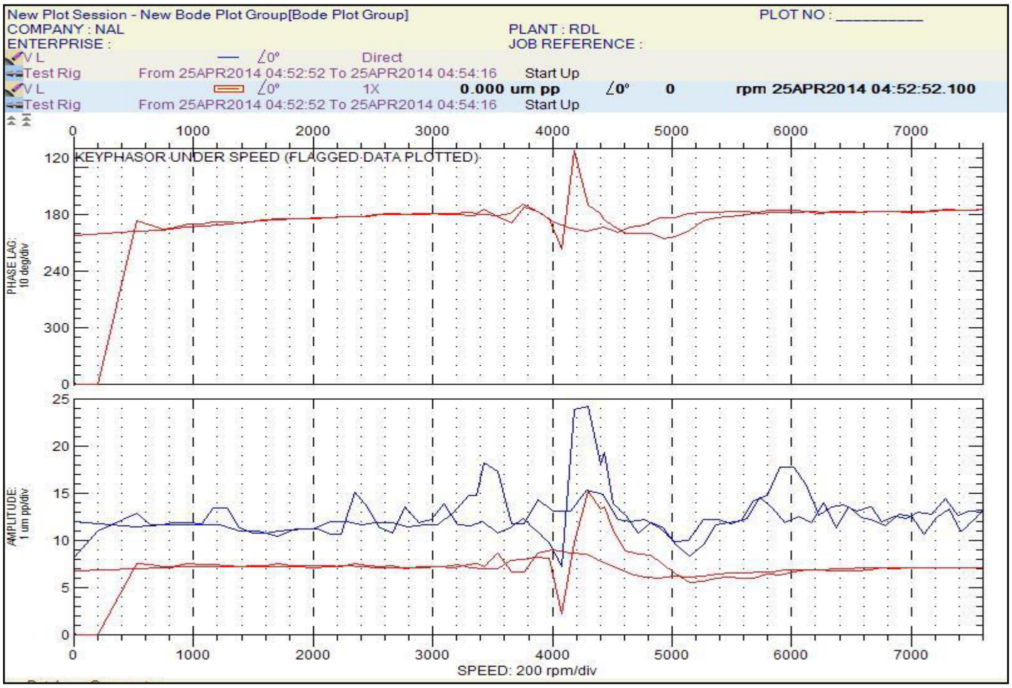

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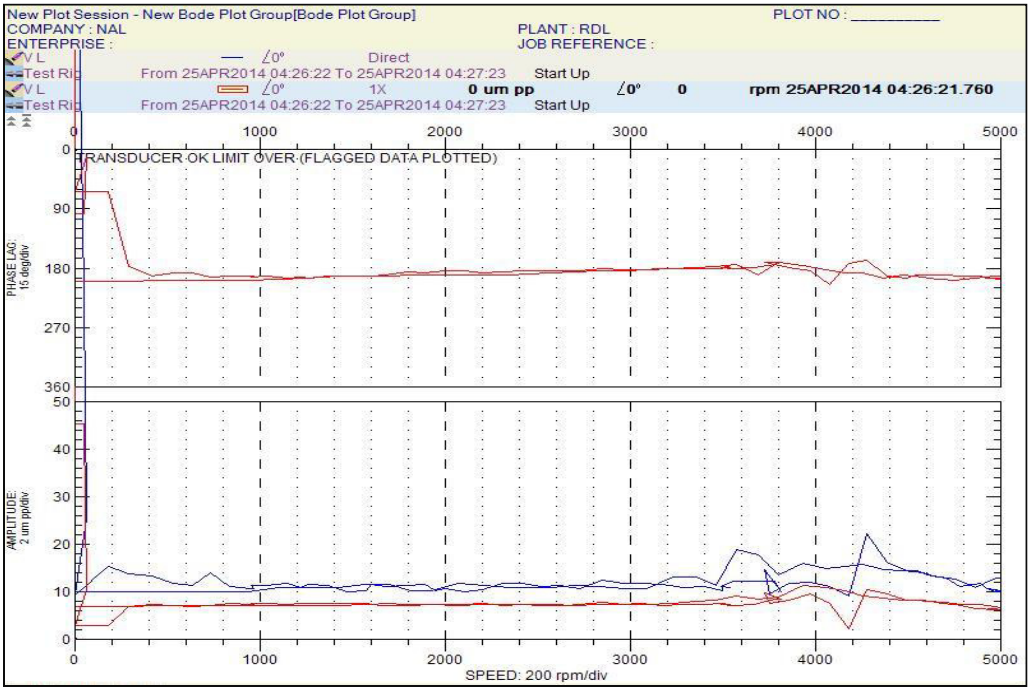
(c) With MR-SFD & 0.1A Current; (d) With MR-SFD & 0.2A Current.



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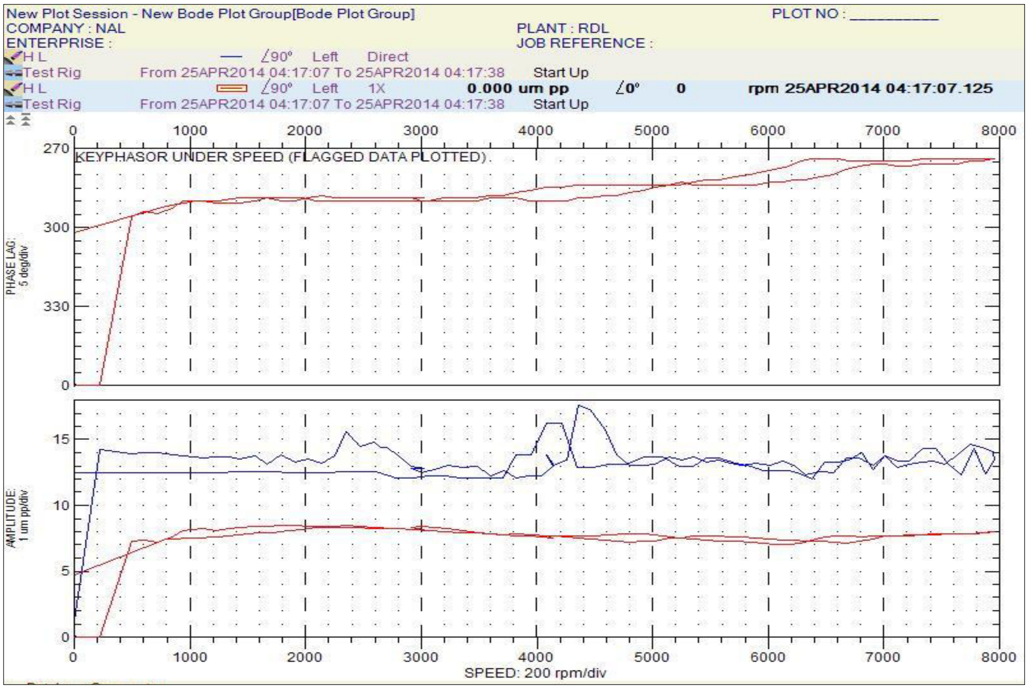

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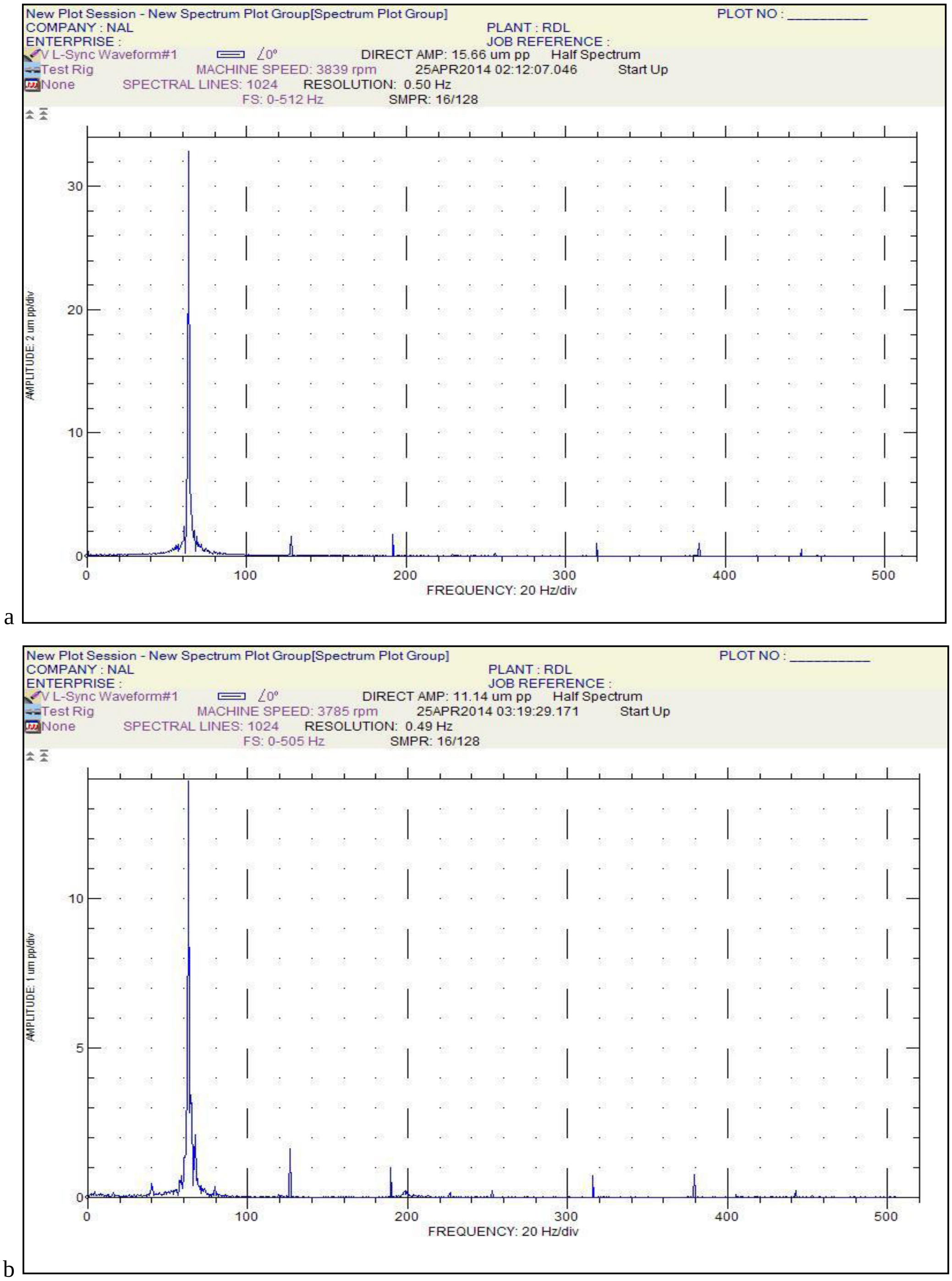
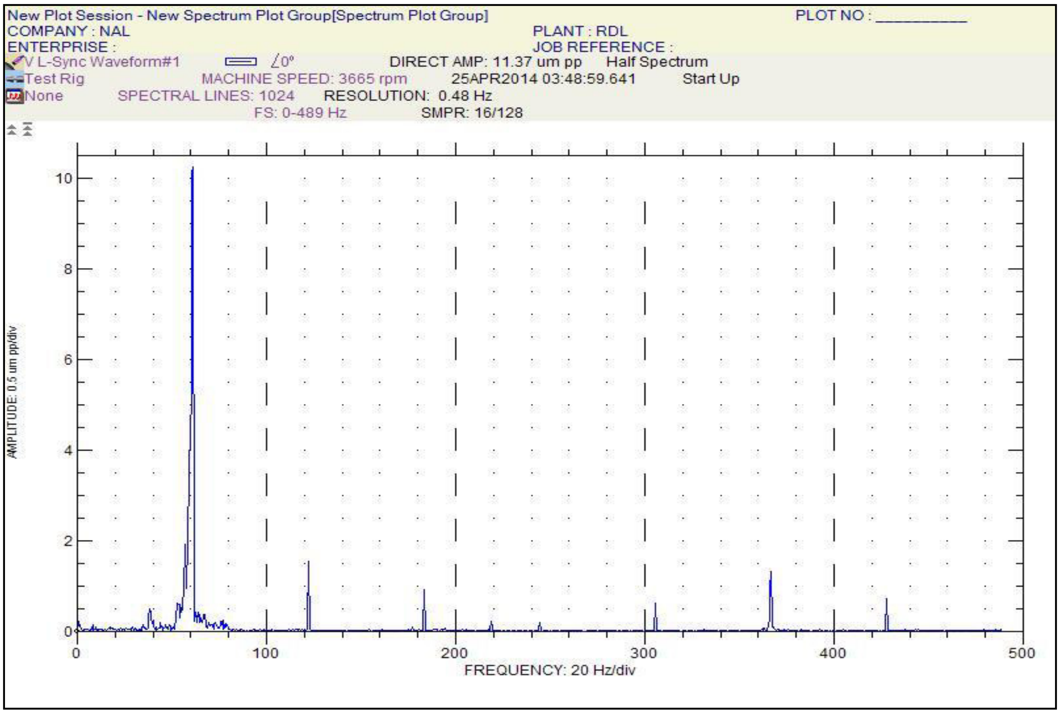
(e) With MR-SFD &0.4A Current; (f) With MR-SFD &0.5A Current.

Fig. 4. Bode Plot of rotor system with MR-SFD.

The frequency domain response of the system is shown in Fig. 5. The 1X amplitude reduces from 31 microns for the without MR-SFD case to 8 microns for with MR-SFD and 0.5A current case.



(a) Without MR-SFD; (b) With MR-SFD & 0A Current.



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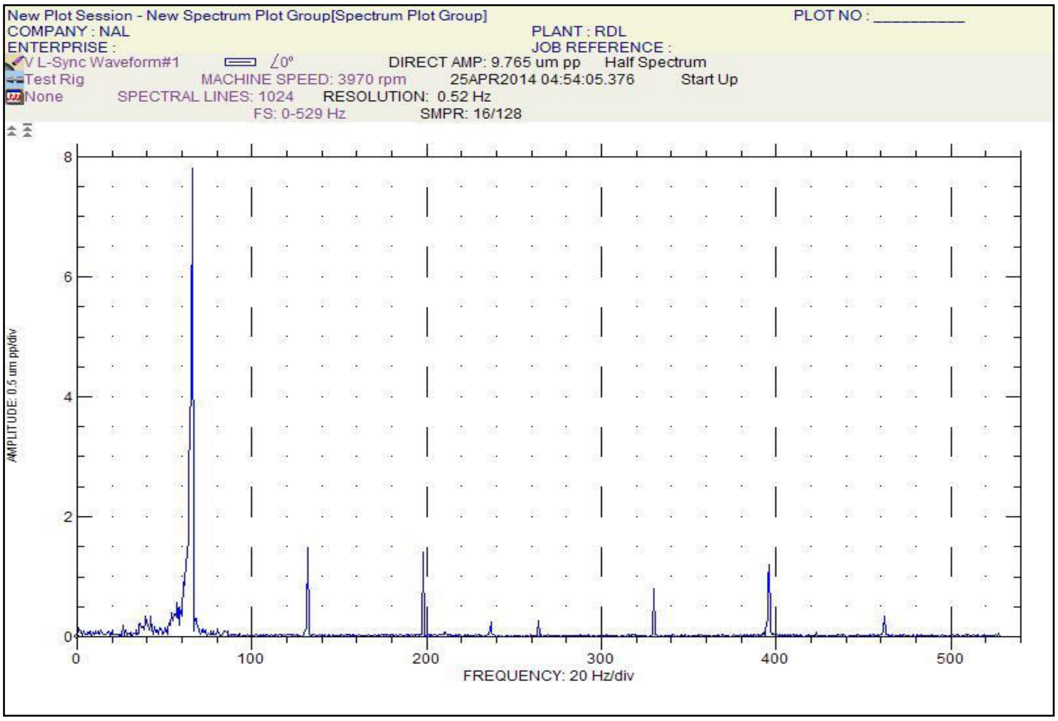

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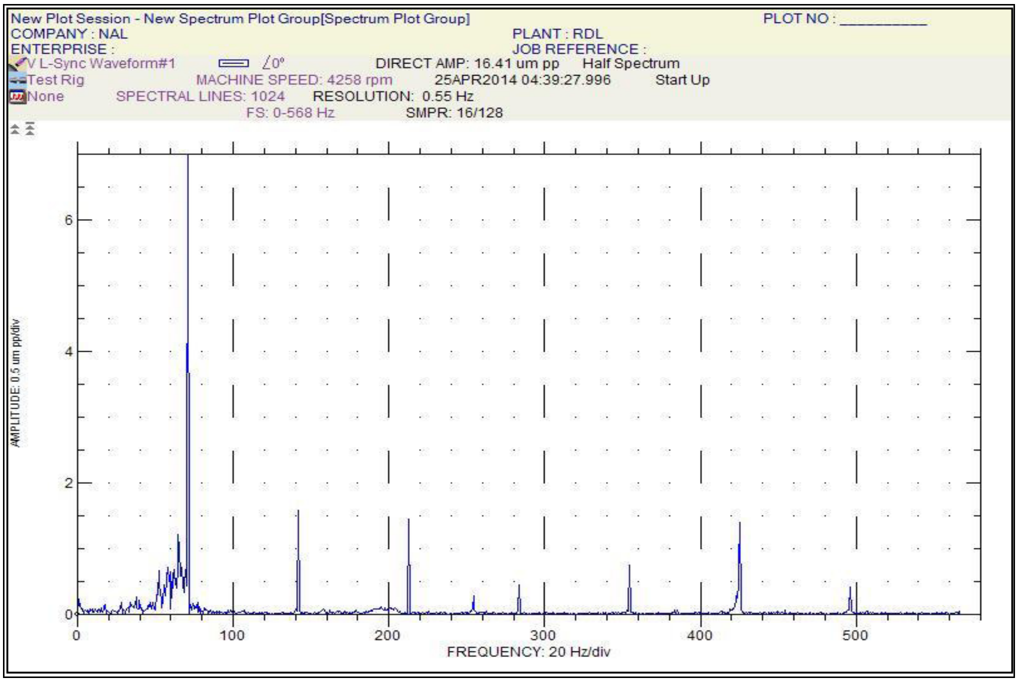
(c) With MR-SFD & 0.1A Current; (d) With MR-SFD & 0.2A Current.



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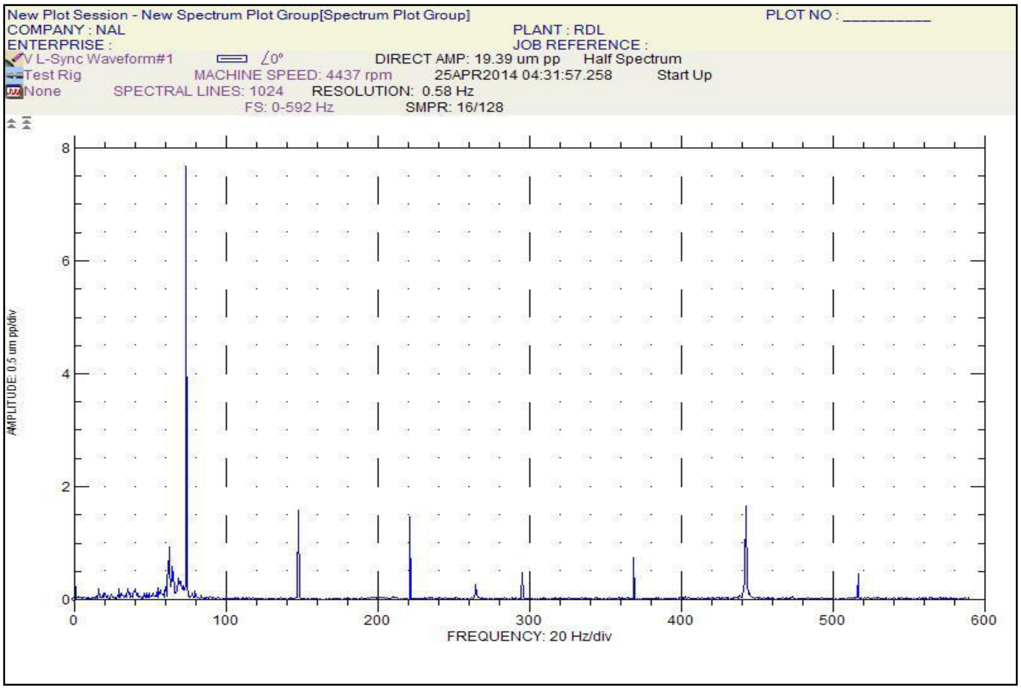

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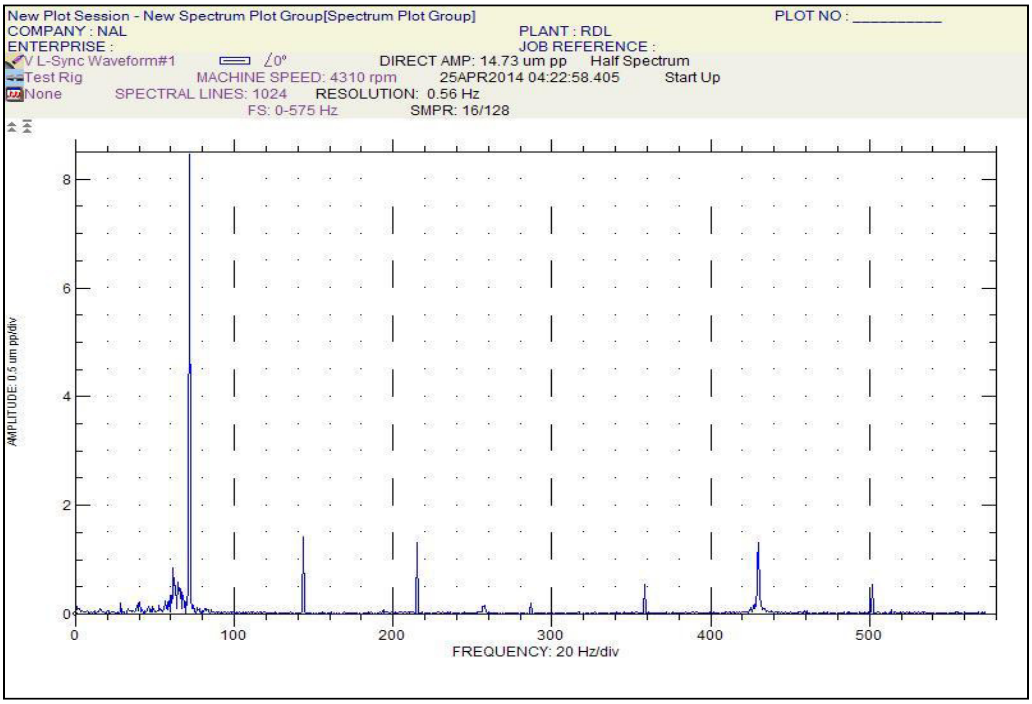
(e) With MR-SFD & 0.3A Current; (f) With MR-SFD & 0.4A Current.

g 

(g) With MR-SFD & 0.5A Current.

Fig. 5. FFT Plot of rotor system with MR-SFD.

5. Conclusion

The result shows that the damping of the system increases with the introduction of MR-Fluid in the system and it can be controlled to the desired level by varying the magnetic field. The observed reduction in overall vibration and 1X amplitude is 70% and 71.9% respectively. It is also observed that the overall vibration of the system also reduced when the damper is active throughout the working range simulating the conventional SFD system. Hence, it can be concluded the active squeeze film dampers can be designed with the help of MR fluid and the rotor response at critical speeds can be controlled with a caution of excessive force transmissibility at higher damping [5].

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