

## Performance characteristics of prototype MR engine mounts containing LORD glycol MR fluids

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2009 J. Phys.: Conf. Ser. 149 012035

(<http://iopscience.iop.org/1742-6596/149/1/012035>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 38.107.179.212

The article was downloaded on 15/02/2012 at 01:40

Please note that [terms and conditions apply](#).

# Performance Characteristics of Prototype MR Engine Mounts Containing LORD Glycol MR Fluids

**Daniel E Barber and J David Carlson**

LORD Corporation, 406 Gregson Drive, Cary NC 27511

E-mail: daniel\_barber@lord.com

**Abstract.** LORD Corporation has recently developed glycol-based MR fluids for use in applications such as engine mounts and bushing, in which the MR fluid will contact rubber and other oil-sensitive elastomers. To demonstrate the performance characteristics of these fluids, prototype MR engine mounts were designed and their dynamic stiffness and damping were tested. In one configuration, the MR mount contained a simple MR valve and was filled with a glycol fluid containing 22% iron by volume. This mount had low dynamic stiffness and frequency-dependent damping in the off-state and higher dynamic stiffness with little damping in the on-state. The low-frequency stiffness and damping could be varied by adjusting the applied magnetic field. In a second mount configuration, the mount contained both an MR valve and an inertia track. Two such mounts were evaluated with MR fluids containing 22% and 36% iron, respectively. In the off-state, both mounts displayed low stiffness and damping as fluid flowed through the MR valve. In the on-state, the MR valve was closed and the inertia track was activated, giving characteristic frequency-dependent stiffness and damping that could be tuned by varying the strength of the magnetic field. These behaviors were observed at both low and high displacements of the mount.

## 1. Introduction

Over the past decade, commercial magnetorheological (MR) fluids and devices containing them have proven their value in providing dramatically improved ride comfort and performance in automotive applications [1]. There are presently more than 500,000 MR devices in use worldwide, and this number is expected to rise into the millions as more automotive platforms adopt MR fluid shock absorbers and other vibration-control technologies. Current commercial applications generally use oil-based MR fluids.

There is a growing commercial interest in applying MR technology to devices in which natural rubber or similar elastomers are a key structural component, particularly engine mounts and drive train or suspension bushings. Several US patents from LORD Corporation [2] and Delphi Technologies, Inc. [3] describe designs for MR fluid hydraulic mounts, and Choi et al. have described MR mounts for controlling vibration in passenger cars and other structures [4]. Paulstra Corporation has described the design and use of an MR suspension bushing in a twist-beam axle to give performance potentially comparable to a multi-link suspension [5]. MR fluids with either silicone oil [6] or glycol [7] as the carrier fluid have been described for use in natural rubber devices, since oil-based fluids would be incompatible with the elastomers in these devices.

Recently, LORD Corporation introduced glycol-based MR fluids for use in devices containing natural rubber or other elastomers, such as semi-active engine mounts, bushings, or similar vibration-

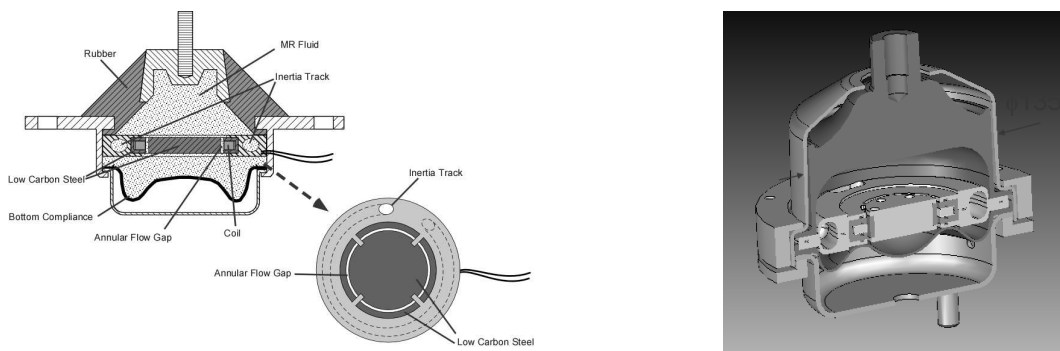
control devices [8]. To demonstrate the potential effectiveness of such devices, prototype MR engine mounts have been developed and their performance characteristics tested in both off-state and on-state conditions. This paper describes the dynamic stiffness and damping characteristics of the MR mounts.

## 2. Experimental Details

LORD MR fluids with predominantly glycol carrier liquid were prepared using proprietary formulations and processes. Iron content of the various fluids ranged from 22% to 36% iron by volume.

A standard LORD hydraulic mount with inertia track and membrane decoupler (part number FL-1002-13, outer diameter 135 mm) was used as both the performance control and the prototype from which the MR mounts were designed. One MR mount was built in which the decoupler and inertia track assembly was replaced with a simple MR valve, and a second MR mount was built which had both an MR valve and an inertia track (Figure 1). The magnetic valves in both mounts had an average diameter of 46 mm, a magnetic gap of 2 mm, and an active length of 8 mm. The inertia track volume of the second mount was approximately 58 cm<sup>3</sup>, and each mount contained approximately 500 cm<sup>3</sup> of the desired fluid. The elastomeric components were of the same type in all mounts.

Both types of MR mounts were filled with LORD MR fluid containing 22% iron using a vacuum-fill process. One mount with MR valve and inertia track was also filled with a LORD MR fluid containing 36% iron to assess the effect of higher fluid density, viscosity and magnetic strength. The dynamic stiffness and phase angle were measured at constant-amplitude sinusoidal displacements of either 0.1 mm or 1.0 mm and frequencies from 1-25 Hz with various applied magnetic field strengths.



**Figure 1:** Schematic diagram and CAD drawing of LORD mount with MR valve and inertia track

## 3. Results and Discussion

### 3.1. MR Mount Performance Characteristics

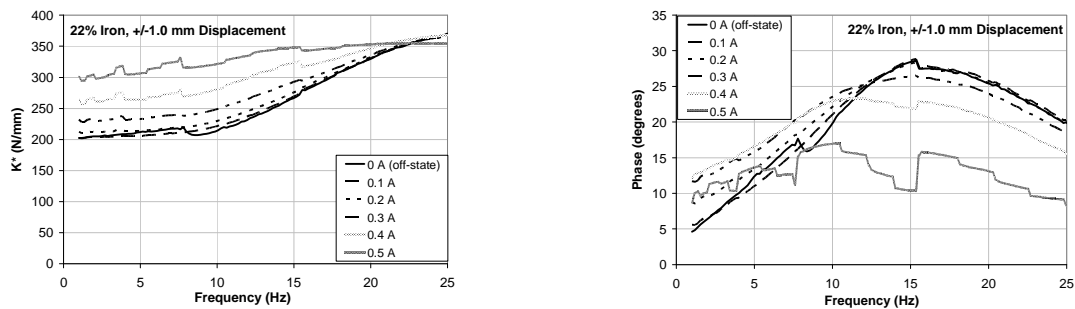
Engine mounts are typically characterized by measuring their dynamic stiffness,  $K_{dyn}$ , and the loss angle  $\theta$  as a function of vibration frequency. These parameters are related by equations (1) and (2),

$$K_{dyn} = \sqrt{(K')^2 + (K'')^2} \quad (1)$$

$$\theta = \tan^{-1}\left(\frac{K''}{K'}\right) \quad (2)$$

where  $K'$  is the elastic modulus and  $K''$  is the out-of-phase modulus associated with viscous damping [9]. High values of  $\theta$  correspond to high damping. Both mount configurations (MR valve only and MR valve plus inertia track) were tested at low (0.1 mm) and high (1.0 mm) displacements and various magnetic fields in the frequency range from 1 to 25 Hz.

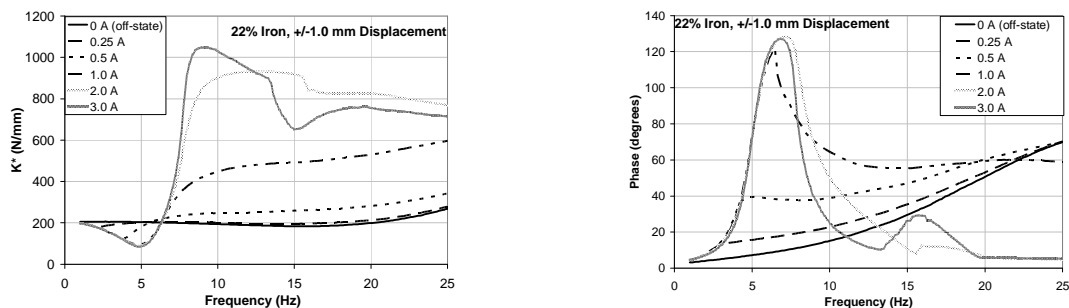
3.1.1. *MR Mount with MR Valve Only.* Figure 2 shows the dynamic stiffness and phase angle at high ( $\pm 1.0$  mm) displacement for the mount with an MR valve containing LORD MR fluid with 22% iron. Similar behavior was observed at low ( $\pm 0.1$  mm) displacement. In the off-state, the mount had a lower-stiffness condition at low frequencies up to about 15 Hz and a higher-stiffness condition above this frequency, with the maximum damping occurring at the transition from low to high stiffness. This behavior is similar to that of a standard hydraulic mount (non-MR) with a simple orifice [9], so in the off-state the open MR valve acts as a fluid orifice with the shear stiffness of the rubber dominating the low-frequency behavior.



**Figure 2:** Dynamic stiffness (left) and phase angle (right) at  $\pm 1.0$  mm displacement for mount with MR valve only and containing LORD MR fluid with 22% iron.

In the full on-state (0.5 A current), the MR valve is closed and no fluid flow occurs. The stiffness of the mount is now determined by the higher bulge stiffness of the rubber, and the mount behaves as a simple elastomeric mount with frequency-independent stiffness and low damping [9]. Variation in the low-frequency stiffness and damping was observed with varying magnetic field due to incomplete blocking of the MR valve. This behavior represents an opportunity for continuously tuning the low-frequency stiffness of such mounts. Similar behavior was observed for the multi-stage MR suspension bushing described by Piquet et al. [5].

3.1.2. *MR Mount with MR Valve and Inertia Track.* Two mounts with this configuration were tested, each containing LORD glycol MR fluid with either 22% or 36% iron by volume. Figure 3 shows the dynamic stiffness and phase angle results for the mount containing 22% iron fluid at high ( $\pm 1.0$  mm) displacement. Similar results were observed at low and high displacements for a given iron content.

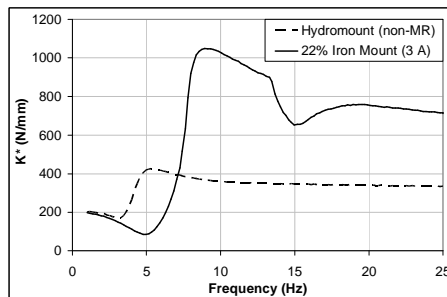


**Figure 3:** Dynamic stiffness (left) and phase angle (right) at high displacement ( $\pm 1.0$  mm) for mount with inertia track and MR valve containing LORD glycol MR fluid with 22% iron.

For 22% iron (Figure 3), the off-state stiffness was low throughout the tested frequency range and the phase angle increased gradually from  $10^\circ$  or less to about  $60^\circ$ . For 36% iron, similar changes occurred but at somewhat lower frequencies. The curves show some similarity to those for the MR

mount with valve only, although the features were somewhat broadened, possibly as a result of the additional orifice represented by the inertia track.

In the full on-state, the MR valve was essentially closed and classic inertia track behavior [9] was displayed by both mounts. The initial dynamic stiffness decreased to a minimum at a relatively low frequency (the low-stiffness “notch”) and the damping reached a maximum due to resonant oscillation of the fluid mass within the inertia track. At higher frequencies the mount had high stiffness and low damping much like a simple elastomeric mount due to blocking of the inertia track by the fluid at high frequencies. As compared to the non-MR mount (Figure 4), the low-stiffness notch was much softer and the high-stiffness condition was much stiffer for the MR mounts due to the high density and high solids loading of the MR fluid as compared to glycol. The mount with 22% iron fluid had a deeper notch than the one with 36% fluid, probably due to the lower viscosity of the 22% fluid, but the high-stiffness values at higher frequencies were nearly the same. Curiously, the mount with 22% fluid at the highest current showed a second decrease in stiffness and increase in damping at about 15 Hz.



**Figure 4:** Comparison of dynamic stiffness at high displacement ( $\pm 1.0$  mm) for standard LORD hydromount with inertia track (glycol-filled, non-MR) and MR mount with inertia track and MR valve in the on-state. MR mount was filled with 22% iron fluid.

At intermediate currents, more complex behaviors were observed due to incomplete blocking of the MR valve (Figure 3). This behavior allows some degree of tuning of the MR mount properties. For example, at currents above about 0.5 A, the low-stiffness notch was established and the higher-frequency stiffness varied over a relatively wide range.

#### 4. Conclusion

Prototype MR engine mounts utilizing recently introduced glycol-based LORD MR fluids have been shown to give a highly tunable response. Combined with the known rapid response of the MR effect, such mounts have the potential for a high degree of vibrational motion control.

#### References

- [1] J. D. Carlson, *Proceedings of the 10<sup>th</sup> International Conference on Electrorheological Fluids and Magnetorheological Suspensions*, World Scientific Publishing: Hackensack, NJ (2007), 389-395.
- [2] J. D. Carlson, M. J. Chrzan, F. O. James., US Patent 5,398,917, Mar. 21, 1995.
- [3] T. A. Baudendistel, S. G. Tewani, J. M. Shores, M. W. Long, R. E. Longhouse, C. S. Namuduri, A. A. Alexandridis, US 6,622,996 B2, September 23, 2003.  
P. N. Hopkins, M. W. Long, M. O. Bodie, US 7,063,191 B2, June 20, 2006.
- [4] S.-B. Choi, H.-H. Lee, H.-J. Song, J.-S. Park, *Proceedings of SPIE 2002*, 4701, 1-8.  
S.-R. Hong, S.-B. Choi, *J. Intelligent Material Systems and Structures 2005*, 16, 931-936.
- [5] B. Piquet, C. A. Maas, F. Capou, SAE 2007 World Congress, Detroit, MI, April 16-19, 2007, SAE Technical Paper 2007-01-0850.
- [6] V. R. Iyengar, P. N. Hopkins, M. E. Myers, US 7,070,708 B2, July 4, 2006.
- [7] V. R. Iyengar, T. J. Kacsandy, US 6,824,700 B2, November 30, 2004.
- [8] News release, <http://lord.com/Default.aspx?tabid=3879&Page=1&DocID=1134>, June 9, 2008.
- [9] W. C. Flower, *SAI Surface Vehicle Noise and Vibration Conference*, Traverse City, MI, May 15-17, 1985, SAE Paper 850975.