

## Implementation of Real Time Condition Monitoring of a Single Degree Freedom System Using Skyhook Control

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**ABSTRACT :** The suspension systems can be generally classified into passive systems, semi active systems and active systems. Passive suspension have fixed stiffness and damping properties and designed for general excitations. Semi-active dampers are a class of energy dissipating device for which the damping may be controlled in real-time. This is achieved by either altering the properties of the damping fluid, as is the case for electro- and magneto-rheological dampers, or by actuating mechanical components of the damper. The purpose of this chapter is to provide the necessary background for this research. This paper will first discuss the tradeoffs associated with typical passive single-degree of- freedom base-excited suspension systems. The conceptual basis for skyhook control will be developed, along with the anticipated improvements in performance. Next, a practical realization of the semi active skyhook control will be developed such that it can be implemented. The work also involves implementing the Skyhook control system in order to control the base excited system. The response of the base excited system with skyhook control was analyzed and found to be in agreement with existing literature. A preliminary study of the response time and output stability of skyhook control was performed and reported. The results have been discussed both qualitatively and quantitatively.

**Keywords:** Vibration control, suspension system, single degree freedom system, magneto rheological fluids, signal generation, DAQ, skyhook control,

### I. INTRODUCTION

In recent times, Magnetorheological devices are being looked into with newfound interest. This is because of their relatively simple construction and quick response. An existing damper is used in a suspended base excitation system excited by an electro dynamic shaker.

#### 1.1 Suspension system

The objective of any suspension system is to reduce and control the energy of the up and down motion performed by a vehicle's acceleration, braking, and cornering. During motion, the suspension system is designed to control the vertical energy transmitted by changes in the road surface or off-road terrain. Without suspending the vehicle separately from the frame, the vehicle would be absorbing the oscillating energy, causing the entire vehicle to accelerate this energy vertically, losing contact with the ground surface. [1]

#### 1.2 Skyhook Control of an SDOF System

This section will introduce the typical passive SDOF seat suspensions that are in common use on heavy vehicles. The concept of skyhook control will be introduced, along with the necessities that are required for practical implementation.

#### Passive Suspension for an SDOF Base-Excited System

The seat suspension system that is typically used on heavy vehicles is a passive single degree- of-freedom suspension system [2], which can be modeled as shown in Fig 1. We can derive the transmissibility of the passive seat suspension as

$$\frac{X_1}{X_2} = \frac{1 + j2\zeta_p\left(\frac{\omega}{\omega_n}\right)}{1 - \left(\frac{\omega}{\omega_n}\right)^2 + j2\zeta_p\left(\frac{\omega}{\omega_n}\right)} m \quad (1)$$

where  $\zeta_p$  is the passive damping ratio.

The transmissibility plot as a function of the quantity  $\frac{\omega}{\omega_n}$ , resulting in Fig. 2 for various damping ratios. Notice that at low passive damping ratios, the resonant transmissibility (around  $\omega = \omega_n$ ) is relatively large, while the transmissibility at frequencies above the resonant peak is quite low. The opposite is true for relatively high damping ratios. Fig 2 demonstrates the inherent tradeoff of passive seat suspension systems [3]. If a low

damping ratio then gain the superior high frequency isolation but poor resonant frequency control. However, as increase in the damping ratio, trade off the high frequency isolation for resonance control. Most seat manufacturers tend to favor resonance control over the high frequency isolation, and the resulting ride that the driver experiences are often deemed harsh. Some independent drivers remove the seat damper in favor of a smoother ride while risking the possibility that the seat will eventually hit the physical limits of suspension travel.

**Forced Sweep Sine Excitation with Different External voltage excitation**

In this case MR fluid was filled in the MRF damper with varying voltage corresponding to be given to the magnetic circuit in the damper. Due to the amount of magnetic field in the MR fluid results in the rheology of the viscous property lead to change in the damping effect of the MRF damper. There was change in the damping value with the applied magnetic field and a graph was plotted to ensure the effect of the magnetic field. Here voltage was varied from 0V to 9V [4] and it can be observed that there was a change in the damping value correspondingly.

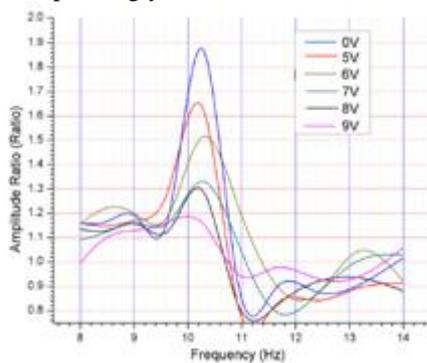


Fig 2 Amplitude ratio v/s exciting frequency

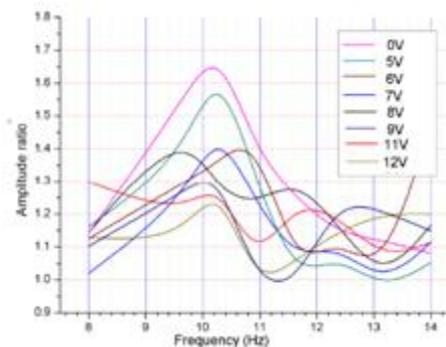


Fig 3 Amplitude ratio v/s exciting frequency

There was change in the damping value with the applied magnetic field and a graph was plotted to ensure the effect of the magnetic field. Here voltage was varied from 0V to 12V and it can be observed that there was a change in the damping value correspondingly to fig 3. It can be observed with all these plots MRF damper suits best for the low frequency base excited system. The minimum damping factor of the damper is 0.2139, in the dry friction damping case. When shearing effect (equivalent viscous damping) is introduced in the damper, the damping increases as expected. The average damping is found to be 0.277. The net increase in damping due to shearing effect is 0.06. In case 2, silicone oil is used as the fluid for the shearing effect. Silicone oil is chosen because it is also the base fluid of MRF. Further, magnetorheological fluid is filled in the damper. This shows the effect of the suspension iron particles on the behavior of the silicon oil. As can be expected, the shearing forces in MRF must be more than silicon oil because of the micron size iron suspensions. The experiment data validates this point. The average damping factor in the case of MRF without external excitation is 0.4054. The net increase of 0.1277 can be attributed to the effect of iron particles. Next, the rheology effect of MR fluid was taken into consideration. Theory suggests that as the external magnetic field is increased, the damping factor also increases. However, we found an anomaly in our experiment. The coil of the damper has 100 turns. This caused a net resistance of 4\_. Under the influence of an external voltage of 5V, this caused a current of 1.25A. The damping factor is found to be inconsistent for an excitation of 1.25A to 2A. However, from 2A, the damping factor steadily increases as predicted by the theory. The anomaly in the region of 1.25A-2A is inconsistent with theory and the reason for this anomaly is yet to be determined. The following graph shows the calibration chart for the damper. It shows the variation of damping factor against the product of excitation current and number of turns.

**2.1. Semi active control results using skyhook control**

The skyhook control system that has been discussed earlier has been applied to the damper. The damper is initially tested without application of magnetic field. Next, the damper is tested while applying 9V (2.25A) and without using skyhook control as shown [4] in fig 4 . The damper is then tested while applying the same voltage and with skyhook control. The results are seen in the figure that follows.

It can be seen that the contribution of skyhook control is rather minimal for this setup as the curve gives us values of amplitude ratio that are almost the same as the ones without skyhook. The above graph is

found to be in agreement in with existing literature. The same experiment is then repeated with 12V applied. It can be readily seen that the skyhook control system has a much greater contribution to the control of the system when the voltage is increased from 9V to 12 V. The amplitude ratio is lesser with skyhook control than its value otherwise for all values of frequency. For the purpose of studying the response time and stability of the skyhook control system, the setup has been operated at various frequencies with application of 9V (2.25A) without skyhook control. After the lapse of 10 seconds, skyhook control is turned on and the system is observed for a further 10 seconds. From this fig 5, it can be seen that while dropping the amplitude ratio from around 1.17 to 1.13, the skyhook system is quick to respond [5], doing so in about 0.75 seconds. It is also seen that the output still remains as stable as it started off implying that implementation of the skyhook control isn't detrimental to system stability. The test is repeated for various values of frequencies ranging from 9Hz to 14Hz as shown in fig6.

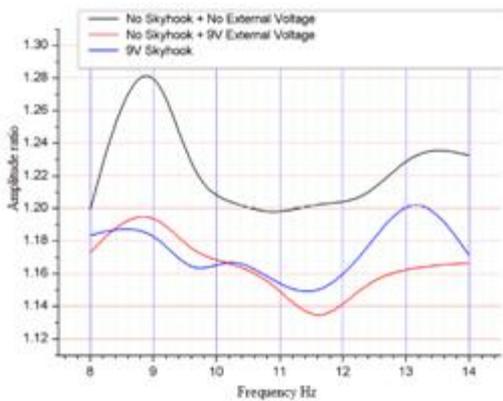


Fig 4 Comparison chart of skyhook control at various stages

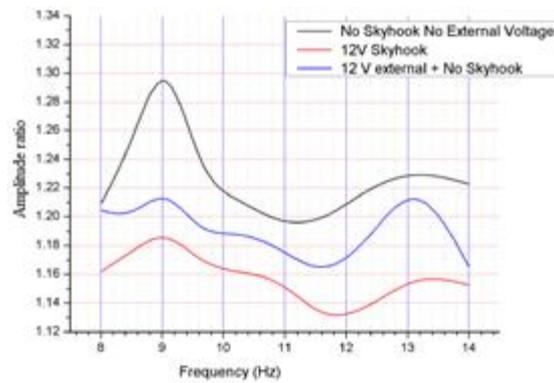


Fig 5 Comparison chart of skyhook control at various stages

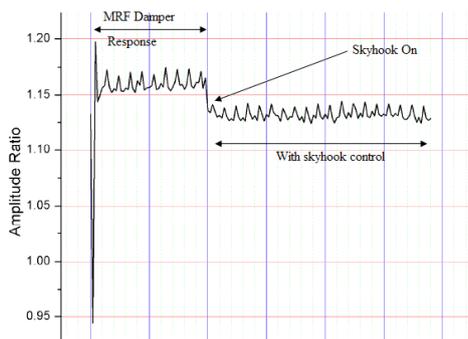


Fig 6 Amplitude ratio at 9v and 9 Hz frequency

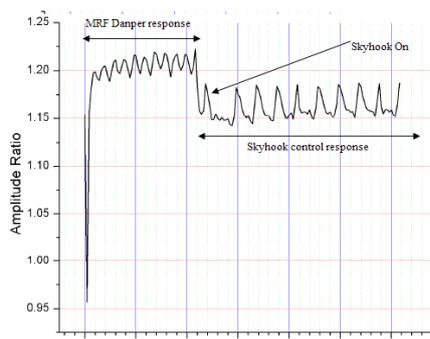


Fig 7 Amplitude ratio at 9v and 10.5 Hz frequency

From these graphs, it can be inferred that this property doesn't change significantly in the range of frequencies for which the experiment has been carried out. The characteristics of the system remain more or less constant with a similar decrease in amplitude ratio and retention of stability. The same experiment has been repeated for different values of frequencies while keeping the voltage in the circuit at 12V (3A) as shown in fig 7. It can be seen here that the amplitude ratio reduces from about 1.175 to 1.125. The system responds in about a second. Keeping the voltage at 12V, the experiment is repeated for different values of frequencies ranging from 9Hz to 14Hz. From the graphs fig 8, it can be inferred that this property [6] doesn't change significantly in the range of frequencies for which the experiment has been carried out. The characteristics of the system remain more or less constant with a similar decrease in amplitude ratio and retention of stability. The same experiment has been repeated for different values of frequencies while keeping the voltage in the circuit at 12V (3A) as shown in fig9.

It can be observed that as the frequency increases while maintaining 12 V, the amplitude ratio drops to a larger extent. The response time of the system shows no considerable change. However system stability tends to decrease a little under these conditions. As the frequency increases, it is observed that the control system switches on and off at a faster rate, as expected. However, the value of amplitude ratio also tends to fluctuate more about the mean value. In line with the findings of the literature survey, sky hook control varies in effectiveness with the value of applied current and also the applied frequency.

## **II. CONCLUSION**

For each of these inputs, it is observed the performance of skyhook and groundhook control as the best at controlling the sprung and unsprung masses respectively. It is observed the costly tradeoff inherent in skyhook and groundhook control. In that respect, this research has also highlighted the advantages of hybrid control for eliminating that compromise. Two alternatives to skyhook control have also been introduced and in some cases, the results are promising. Displacement skyhook and relative displacement skyhook demonstrate similar benefits observed in conventional skyhook. In particular, displacement skyhook can offer competitive results, and perhaps at less of a cost than conventional skyhook. Relative displacement skyhook indicated an ability to reduce the levels of sprung mass motion but not nearly to the extent of the other two skyhook controllers. The results of all tested inputs revealed that it was a weak contender next to skyhook and displacement skyhook.

## **REFERENCES**

- Mark R. Jolly, Jonathan W. Bender, and J. David Carlson, Properties and Applications of Commercial Magnetorheological Fluids” Thomas Lord Research Center, Lord Corporation, 110 Lord Drive
- Carlson, J.D. and Spencer Jr., B.F. (1996). “Magneto-Rheological Fluid Dampers for Semi-Active Seismic Control”, Proc., 3rd Int. Conf. on Motion and Vibration. Control, Vol.3, pp.35-40
- Fernando D. Goncalves, “Dynamic Analysis of Semi-Active Control Techniques for Vehicle Applications”. Master of Science in Mechanical Engineering thesis. Virginia Polytechnic Institute and State University Blacksburg, Virginia August 2001
- Shivaram AC, K V Gangadharan, “Design and Characterization of an MR device Subjected to annular Poiseuille flow”, of Master of Technology thesis, NITK Surathkal 2006
- Shivaram, KV Gangadharan, [Statistical modeling of a magneto-rheological fluid damper using the design of experiments approach](#), Smart materials and structures 16, 1310
- Harisha.S.R, K V Gangadharan, “Dynamic analysis of magnetorheological fluid damper for low frequency, semi active control applications”, Master of Technology thesis, NITK Surathkal 2010.