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DYNAMIC ANALYSIS AND COMFORT EVALUATION OF A FULL SUSPENSION BICYCLE EQUIPPED WITH A MR DAMPER

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Abstract. *Typical vehicle suspension systems are based on passive energy dissipation devices. This type of systems have proven to be a reliable and economic approach, however they are not capable to modify its behavior in accordance with the road conditions. On the other hand, active systems allow a continuous control of the suspension response although requiring sensors, actuators and controllers which represents a more complex and expensive system, usually demanding high power requirements. A middle-term vibration control approach is to use the so-called semi-active systems with the adaptability of active systems and lower energy consumption. This paper aims to evaluate the comfort ridding of a full suspension bicycle equipped with semi-active open loop controlled suspension system using a magneto-rheological (MR) damper. The assessment was carried out based on the analysis of real data, extracted from the instrumented bicycle prototype. The experimental tests were made in a smooth indoor pavement and a cobblestone road. Finally, the results obtained with the proposed semi-active suspension control system are presented and discussed.*

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1 Introduction

In several engineering applications there is frequently the need to control and/or attenuate the vibrations of different mechanical systems, in order to promote the comfort increase of its users. Bicycles are typical mechanical systems, in which it is essential to control the vibrations that are transmitted to the passenger, while driving.

There are three main groups of control systems applied to attenuate the effects caused by unwanted vibrations, the passive, active and semi-active. The passive systems are the simpler and the more economical, since it is not necessary to use external power sources, actuating directly with the physical properties of the system. The main drawback of this systems is that they are not able to adapt to different road conditions and only actuate in a limited frequency bandwidth. The downsides of passive control systems can be avoided by using active control systems, but this systems require sensors, actuators, feedback control and external power source, making it complexer, more expensive to prototype and to produce and less economic while using. The solution for this problem is the use of semi-active control systems, that combine the characteristics of both passive and active control systems [1][2][3]. As in the passive control systems the control force is generated trough the energy dissipation of the system, yet, this force can be controlled. The force control implies power consumption, but much lower values when compared with the active control systems.

This paper aims to discuss the assessment of the comfort evaluation of an semi-active open controlled suspension system of a bicycle, that is equipped with a magneto-rheological damper [4][5][6][7]. The evaluation was carried based on the analysis of real data extracted from an instrumented bicycle prototype. The paper is structured as follows, initially the bicycle prototyping and its instrumentation are described, then the data extracted data is analyzed and discussed for several road and finally some conclusions and future work are pointed out.

2 Bicycle Prototyping and Instrumentation

The presented prototype was adapted from a standard commercial bicycle, that was originally equipped with a passive suspension system, being modified to use a MR damper instead of a typical shock absorber. These semi-active devices use MR fluid whose behavior can be controlled by a magnetic field in order to change the damping characteristics of the damper. This allows a passive or semi-active operation of the suspension controlled by keeping constant or varying the power of the electromagnet within the damper, respectively. Besides, they have as small power requirement, reliability and inexpensiveness to manufacture. These unique features makes them particularly appropriate to design advanced suspensions that can adapt the damping force according with the vehicle body motion (monitored through sensors in the vehicle) and road conditions. The bicycle prototype was equipped with accelerometers and with incremental encoders based on the Hall effect (applied to estimate displacement and velocity). The referred sensors provide valuable information in order to evaluate the ride comfort. The data was acquired at a 100 Hz rate using an Arduino Mega Board and the data was sent to a laptop through a Serial Port connexion. The instrumented bicycle prototype can be observed in Figure 1.

3 Bicycle Comfort Analysis

Comfort is, in the cycling world, one of the topics that is subject to continuous research over the years [8][9]. In this case, acceleration measurements of the handlebar, seat and pedals are monitored and later applied in the performance evaluation for two input voltages 0.78 V

Figure 1: Bicycle Prototype

(0.35 A) and 1.56 V (0.70 A). To ensure that there are no differences between the experimental conditions, the velocity is kept constant during each test. The experimental tests were carried out in two types of horizontal road profiles: a smooth indoor pavement and a cobblestone road. The measurements taken during the tests, for each combination of voltage input and road profile, can be observed in Figures 2 to 5. A lower peak and RMS value signifies better performance or handling comfort.

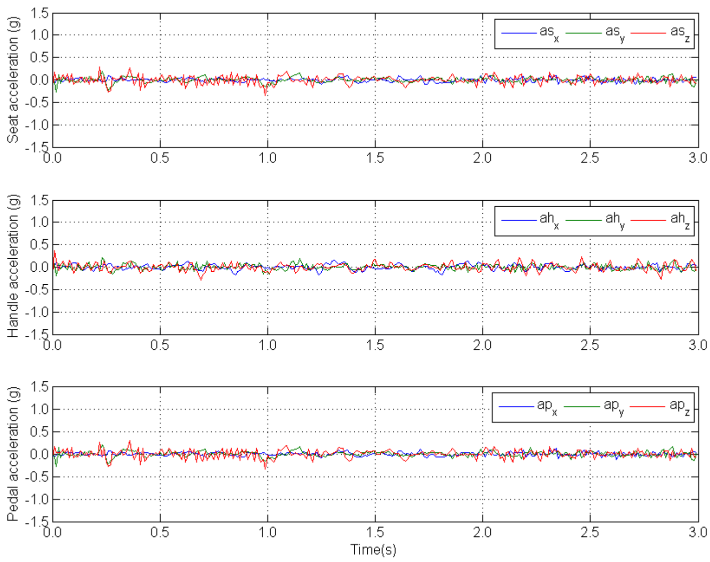

Figure 2: Indoor Pavement (0.78 V).

The damping properties or damping level of MR dampers can be modified using a voltage or a current based controller. The usual approach is to use a voltage signal created by a microcontroller or DAQ card to feed a voltage-to-current linear converter (WonderBox by Lord Co., USA) that is responsible to generate the operating current for the electromagnet within the device in order to change the magnetic field applied to the MR fluid. According with the

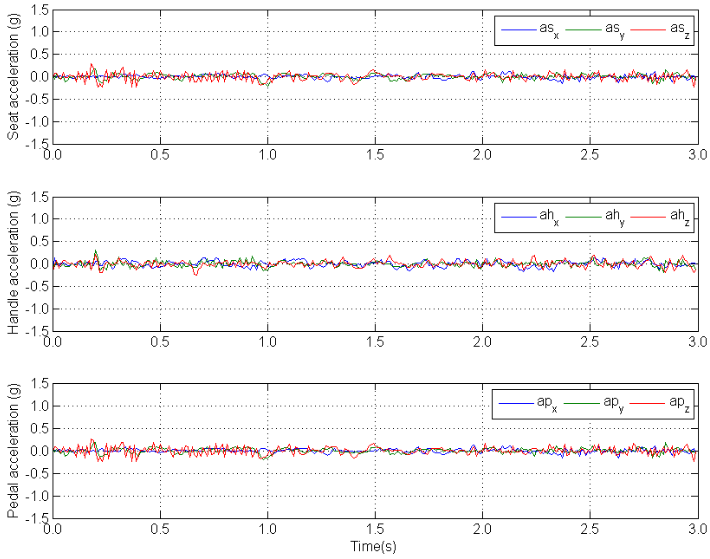

Figure 3: Indoor Pavement (1.56 V).

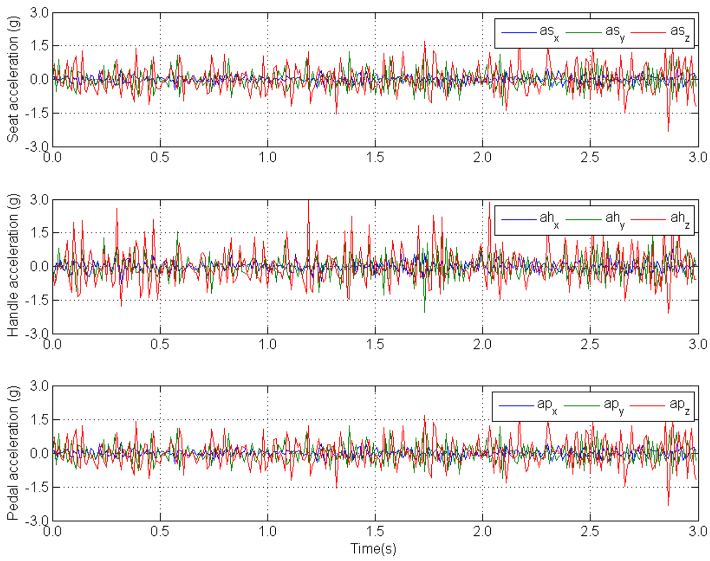

Figure 4: Cobblestone Pavement (0.78 V).

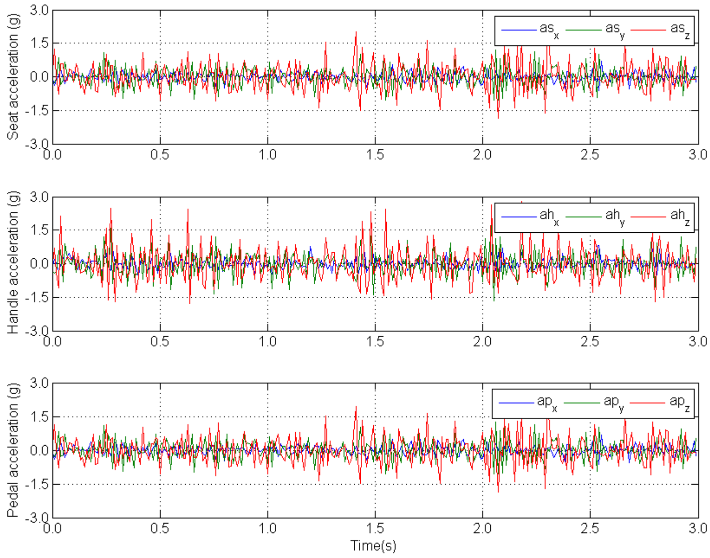

Figure 5: Cobblestone Pavement (1.56 V).

Table 1: Maximum Relative Accelerations

		Maximum Z-axis Acceleration (g)			Velocity m/s
Pavement	Input (V)	Handlebar	Pedals	Seat	
Indoor	0.781	0.589	0.302	0.289	3.859
	1.56	0.207	0.259	0.291	3.683
Cobblestone	0.781	3.077	1.747	1.766	4.034
	1.56	2.801	2.251	2.219	3.869

device specifications, the RD-1005-3 series can operate within a current range from 0.0 A up to 2.0 A with a maximum recommended input value of 1.0 A for continuous operation. Thus, the microcontroller generates a voltage input and the WonderBox provides the corresponding operating current for the electromagnet. As already has been specified, the operating current increases linearly with the voltage input.

The evaluation criteria are based on a comparison of the peak responses and also the root mean square (RMS) values for the z-axis acceleration. The results of this analysis are summarized in Tables 1 and 2.

As can be seen, the peak vertical acceleration in the handlebar for both road profiles is reduced as the voltage input or damping level increases. This mean that the vibration level

Table 2: Root Mean Square Relative Accelerations

		RMS Z-axis Acceleration (g)		
Pavement	Input (V)	Handlebar	Pedals	Seat
Indoor	0.781	1.261	1.252	0.089
	1.56	1.260	1.244	0.085
Cobblestone	0.781	1.505	1.384	0.629
	1.56	1.475	1.380	0.653

transmitted to the rider arms has been reduced and therefore the rider comfort and handling are improved. On the other hand, the peak values measured in the seat and pedals with a high voltage input are increased, which means that the damping effect provided by the MR damper is essentially focused on the bicycle handlebar. The results of the RMS values are consistent with the ones encountered for the peak accelerations, i.e., the higher the damping mode the lower the handlebar vibration level, although in this case there has been an improvement in almost all performance indexes indicating that the high voltage input or damping level is better for the rider comfort than the low voltage signal.

4 Conclusions and Future Work

Overall, it was verified that the MR damper is capable to improve the behavior of the bicycle suspension system providing a better riding experience. What particularly stands out from this analysis is that there is a large potential application of MR dampers to control the vibration level of a bicycle suspension system in order to improve the rider comfort and handling. It is recommended a further analysis using a closed-loop control system for different road profiles to demonstrate the effectiveness and robustness of the proposed controllable suspension system.

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