ADAPTRONIC SYSTEM AND VIBRATION CONTROL WITH MR DAMPERS

Vasilije Vasić, PhD*, Mihailo P. Lazarević[1]*, Taško Maneski

Summary: *The ‘adaptronics’ is the comprehensive generic term, which is known internationally known as the »smart material« or »smart system« and in our case utilizing adapive (MR) dampers. The advantageous feature of adaptronic devices, like the adaptive (MR) dampers, is possibility upon the control algorithm and defined limits (e.g. vibration limit) to fulfill comprehensive goals. Above all this means dynamic stable system in wide frequency range for various working (load) profiles. The experimental setup includes pair of MR Dampers (type LORD RD-1005-3), which replaces the classical viscous-friction dampers. Adjusting the controlling current achieves changes of the damping ratio of overall system. The implementation of vibrations control ensures measurement of vibrations on all relevant places to achieve system tracking in the space (3D presentation). Another relevant criterion is the control the transient phenomena and evaluating the impact of certain working (speed) profiles as well as the (eccentricity) load on the overall system's dynamics. The experimental system shows applicability of adaptive dampers for various damping values and they could be correlated to the other working parameters (load, speed profile) as experimental verification for (theoretical) numerical multibody system model.*
Keywords: *adaptronics, MR damper, design of experiment (DoE), vibration control, washing machine*

INTRODUCTION

The concept of adaptornics as semi-active suspensions could be found in a wide range of application domains – as suspensions for various art of vehicles as well as appliances (e.g. washing machines), but also in civil engineering (bridges, etc.), bio-mechanical structures (e.g. artificial legs) etc. All applications have a common goal to suppress the sudden impacts or excessive vibrations in order to achieve stable technical system, which is consequently user friendly (e.g. low vibrations, noise).

This work will focus on application - the semi- active control of the suspension in a washing machine, with the purpose to validate various types of the suspension characteristics (hysteresis), influence the suspension degradation on the vibration level as well as the mutibody system simulation verification.

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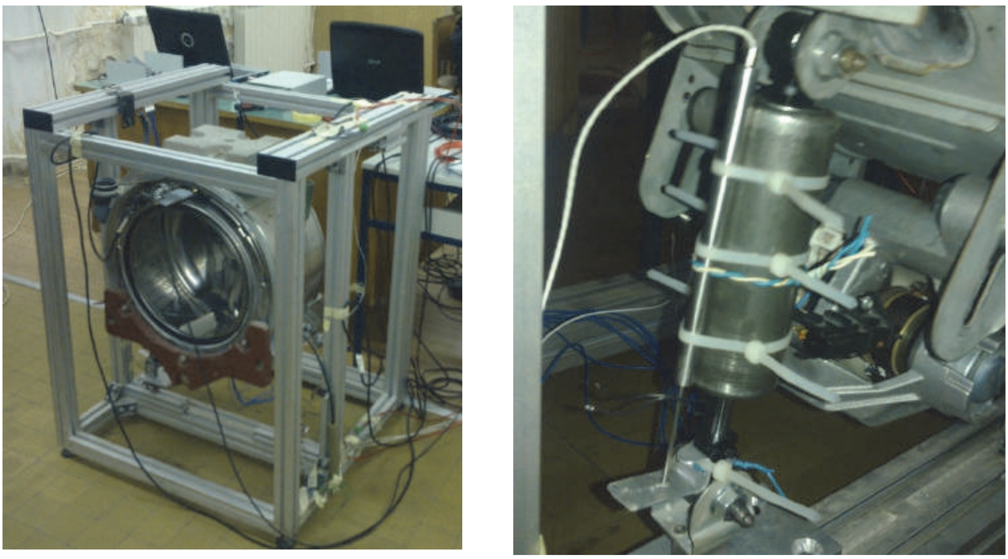
1. ADAPTRONIC SYSTEM WITH MR DAMPER

The adaptronic systems with MR dampers (magnetorheological damper or magnetorheological shock absorber) has proven itself as advantageous technical solution in terms of the vibration suppression. The pioneer work has been done by the Spencer, Dyke and Carlsoon (1996) described phenomenological model of a magnetorheological damper as well as with the adequate control strategy (*A Comparison of Semi-Active Control Strategies for the MR Damper*), but also presented one of the first applications in appliance industry (*Carlson (2001) – Controlling Vibration with Magnetorheological Fluid Damping*). In the following years there were many studies conducted by various researchers in order to achieve better performance of the appliance (*Spelta (2009) Control of magnetorheological dampers for vibration reduction in a washing machine), Nygårds/Berbyuk (2006-2012) – Vibration Control of Washing Machine with Magnetorheological Dampers*). All applications has a focus to find optimal damping solution (hysteresis) as well as control (sky hook, ground hook, SMC) for parametric evaluation working load on the system's stability and vibration.

1.1 Description of the experimental setup

The experimental setup is presented on the Figure 1a, where the adaptronic system (product) – washing machine without the cabinet with MR damper (LORD MR 1005-1).



a.) *Experimental setup* b.) *MR damper – LORD*

Fig. 1 *Adaptornic system – experimental setup and MR damper*

The tub assembly is fixed on the metal frame for proper evaluation the working profile – load (e.g. eccentricity of laundry) as well as the system excitation (e.g. speed of the drum) for given suspension properties (e.g. suspension fixation geometry, suspension damping properties).

The experimental setup consist on:

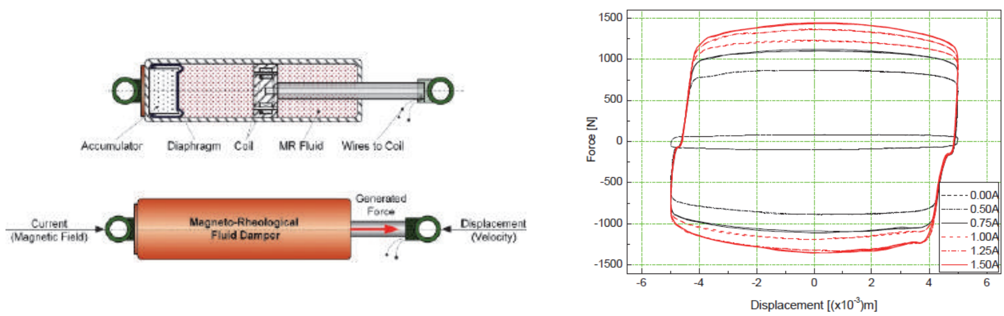
- system excitation – electronic controller for actuator;
- system measurement – displacement sensors (LVDT), acceleration (accelerometers), force (strain gauge)
- suspension control –control the adaptive – MR damper;

The experimental displacement sensors as well as accelerometers are placed on three horizontal and vertical levels in all directions. This is common approach, which has proven itself for valuable (*Lim,T.-H., etc:: Dynamic modeling and analysis of drum-type washing machine*). The force sensors are mounted on the suspension elements (springs, dampers) on the reference working plane and other are placed on outer planes (front, rear) to monitor eccentricity or nutation effect.

Novelty and special focus for the experimental validation has been given to the control the MR damper (Figure 1b), which is monitored with the displacement sensor.

1.2 Description of the MR damper

The MR damper used in experiment is adaptive damper (LORD RD 1005-3), which damping capability is controlled/changed by the current (Figure 2a). The MR damper has in the tube MR fluid contains 20-40% by volume of relatively pure, soft iron particles, e.g., carbonyl iron with consistency similar to that of motor oil. Due the presence of an applied magnetic field, the iron particles in suspension acquire a dipole moment aligned with the external field which causes particles to form linear chains parallel to the field. With solidification of the suspended iron particles is restricted the fluid movement, which could occur in few milliseconds.



a.) Hardware and working principle *b.) Response diagram*

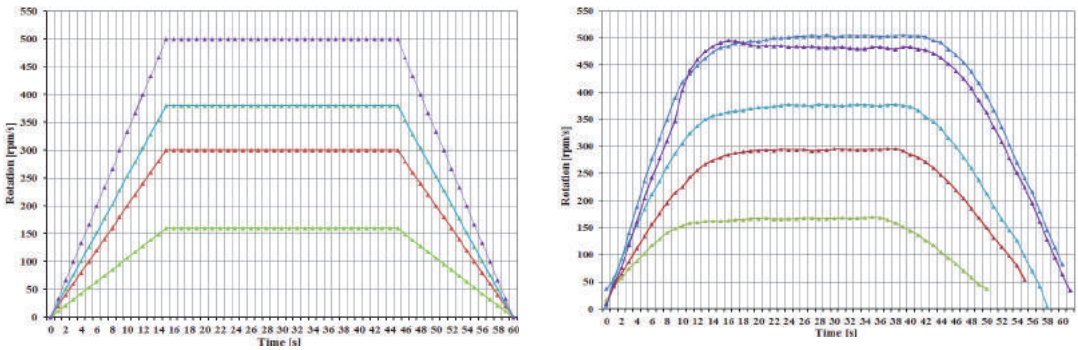
Fig. 2 *MR damper (LORD RD 1005-3) – description and response diagram*

The control of the damping properties are conducted with the control unit supplying the current (from 0 A up to the 2 A), which causes substantial difference in response (Figure 2b). The control unit could be done either with MR damper manufacturer’s control unit or (custom) industrial unit as it was in our case. The level of distance or vibration amplitude is the correlated with the level of supplied current to the damper.

1.3. Design of experiment

Prior the experimental activities, there has to be set the goal which would be achieved by the experiment. In our case, we would like to find out – what is the level of vibrations in the stationary (non-transient) art of working and what should be than the damping (current to the MR damper) to preserve allowed limit of vibration amplitude.

The vibration amplitudes are important for those excitation, which is common for the real life application and would serve as the reference value. In our case, this is excitation by the actuator with the certain number of (drum rotation) in rpm/sec (Figure 3a) – 150, 300, 400 and 500 rpm/s.



a.) *Actuator's command profile* **b.)** *Actuator's resulting profile*

Fig. 3 *Actuator's command resulting profile*

There is difference among the theoretical (command) profile set to the actuator and the real response (Figure 3b).

At each excitation level is the vibration amplitude, which should be determined and could be calculated in different ways (*Spelta,C.:Control of magnetorheological dampers for vibration reduction in a washing machine , Ghorbany,A.K.: Semi-active vibration control of a washing machine using magnetorheological dampers*) as non-dimensional evaluation criteria – peak-to-peak or RMS criteria. These criteria are correlated with the limited acceleration transmissibility and deflection, which are usually also normalized.

- Peak-to peak evaluation criteria

$$J_1 = \frac{\max_t |x_c(t)|}{\max_t |x_u(t)|} \text{ and } J_2 = \frac{\max_t |\ddot{x}_c(t)|}{\max_t |\ddot{x}_u(t)|} \qquad (1)$$

- or (normed) RMS value:

$$J_3 = \frac{\|x_c(t)\|}{\|x_u(t)\|} \text{ and } J_4 = \frac{\|\ddot{x}_c(t)\|}{\|\ddot{x}_u(t)\|} \qquad (2)$$

Where displacement time history of controlled system $x_c(t)$ and uncontrolled system $x_u(t)$ with the same approach to the acceleration.

These performance indexes have to be part of adaptronic system control (Washing machine multibody system – WM Multibody) unit as well as damper's control unit (Figure 4).

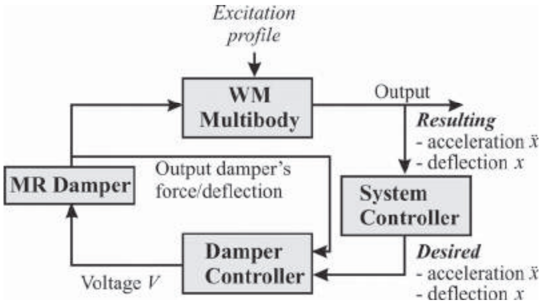
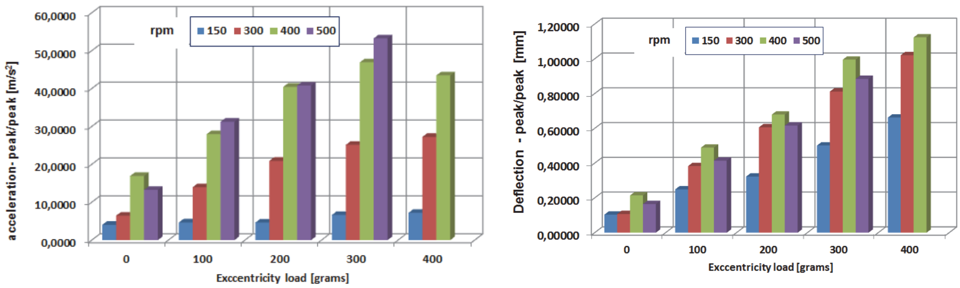


Fig. 4 *Semi-activecontrol scheme with MR damper for WM multibody*

2 EXPERIMENTAL RESULTS AND COMMENTS

On the first diagram (Figure 5a) is presented vertical acceleration and the deflection (peak/peak) (Figure 5b) in the vertical way of the adaptronic system (Figure 1a) upon the stationary excitation levels (Figure 3b) at profile's plateau.

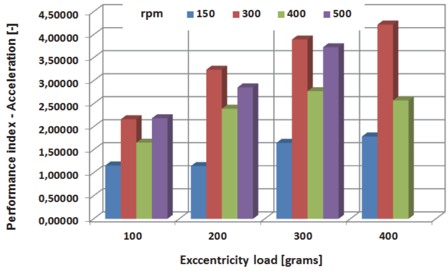


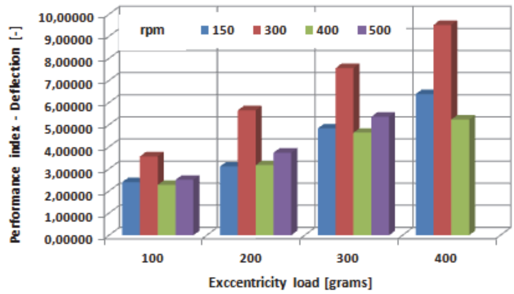
a.) Acceleration *b.) Deflection – peak/peak*

Fig. 5 *Resulting vertical accelerations and deflection for adaptronic system*

The measurement has been performed with NI acquisition system – NI 9233. It is a four-channel dynamic signal acquisition module for making high-accuracy measurements with the accelerometers, which incorporates integrated electronic piezoelectric (IEPE) signal conditioning with built-in antialiasing filters that automatically adjusts to the sampling rate. The distance is acquired with the NI acquisition system – NI 9205, which has 16 differential analog inputs with 16-bit resolution and a maximum sampling rate of 250 kS/s.

The performance indexes were performed with NI Labview software (Sound and vibration module) to benchmark the indexes among different excitations (Figure 6) upon reference (no load) for adequate the supplied voltage (V_{amp} =>c_{MR}) for the MR damper ($F_{MR} = c_{MR} \cdot \dot{x}$).





a.) Acceleration performance index *b.) Deflection performance index*

Fig. 6 *Resulting vertical accelerations and deflection for adaptronic system*

3 CONCLUSION

In this paper is presented a case study for the semi active controller parameter design for the fully automated adaptronic system – washing machine with MR damper. There were developed performance criteria upon conducted measurement – under load and free of load. This is important issue for the MR damper controller's algorithm.

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