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Analysis of Power Dissipation from Multi-State Switchable Damper

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ABSTRACT:

A considerable amount of vibration energy in automotive is worth of being harvested through power dissipation using regenerative suspension systems. In this study, the vehicle dynamics and energy dissipated from a Multi-State Switchable Damper (MSSD) based suspension for various vibration dynamic modes are assessed. Quantification of the energy dissipated in a MSSD is achieved through an experimental test at laboratory environment. The test results showed a linear relationship between the dissipated power and the damping modes.

KEYWORDS:

Multi-state switchable-damper; power dissipation; Vehicle dynamics; Regenerative suspension system

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1. Introduction

Hydraulic shock absorbers come into widespread use in vehicle suspensions since decades ago to effectively reduce the acceleration of auto bodies and maintain good contact between tires and ground under road irregularities. Although energy efficiency has been a serious concern within the automotive industry, researchers realized that the energy dissipated in traditional hydraulic shock absorbers are recovered only within the middle of 1990s. Since then, many different types of energy harvesting based shock absorbers were conceptualized and prototyped. Unlike traditional suspension systems which suppress the vibrations by dissipating the vibration energy into waste heat, the regenerative suspension with energy harvesting shock absorbers can convert the traditionally wasted energy into harvested electricity [1]. A comparison of the overall energy harvesting methods states that the energy source of machine vibration has a substantial overall efficiency between 20-40% compared to other energy sources such as solar, wind and thermal energy sources [2]. One amongst the promising energy harvesting suspension systems is the hydraulic transmission-based energy harvester despite its relatively high cost compared to other systems [3].

Passive suspensions were considered in automobiles since 1990 for maintaining a sufficient contact performance between the wheels and ground. The ride quality is another function of auto suspension systems resulting in the driver’s fatigue which is associated with the accidents. Passive suspensions are still utilized in a sizable amount of cars. This makes the suspension element as an area of interest to the researchers and vehicle manufacturers. Essentially, the suspension acts as a vibration isolator to suppress the disturbance from the road irregularity by dissipating the up and down vibration energy into heat waste [4]. In recent century, the energy saving directions witnessed an excellent development and prosperity [5]. Achieving better ride quality and road handling responses with good manoeuvrability through lesser energy consumption is a critical issue for the passive suspension design. Hence, regenerative suspension systems [6-9] are becoming a necessity. The suspension regenerative systems are supported with linear and rotary electromagnetic damper mechanisms [9-14]. In this work, the damper characteristics caused by the vibration and therefore the damping force behaviour under sinusoidal excitation were investigated experimentally to work out the energy dissipated from the Multi-State Switchable Damper (MSSD) based regenerative suspension system.

2. Test rig and experimental setup

The test rig for damper characteristics is designed and developed at Vehicle Dynamic Lab, Automotive and Tractor Dept. at Minia University [2]. The outline of the test rig and its instrumentation is shown in Fig. 1. The damper is allowed to move vertical direction only. The test rig is meant to permit the force to be applied to at least one end of the damper by a variable cam while the opposite end is fixed. The frame of the test rig was made up of steel channel sections are welded together. A calibrated load cell is employed to monitor the force transmitted through the damper. A linear variable displacement transducer (LVDT) is mounted between the 2 ends of the damper to monitor the damper displacement. A constant amplitude input is applied by a reciprocating mechanism that is driven by an electrical motor (7.5 HP, 50 Hz, 220/380 V, 1430 rpm, and cos (Φ) = 0.75). The frequency is adjusted by using variable speed gear box.

Fig. 1: Damper characteristics test rig

Both the compressive and tensile force can be applied to the damper and the displacement stroke of the piston rod is measured using load cell and LVDT displacement transducer. Load cell and LVDT output signals are recorded using interface card [2].The tests are performed by exciting the suspension system by a sinusoidal input consistent with chosen frequencies with amplitude of 20 mm. The output data from the load cell and therefore the LVDT were converted to digital signals through (A/D) card. A load cell with a measurement range of ±1000N is employed to measure the damper force. The force measurement signal produced by the load cell is supplied to the test computer through an HBM MVD255 amplifier. The A/D convertor is shown in Fig. 2. The load cell transducer is used to measure the dynamic forces generated between the damper and the fixed jaw of the damper characteristics test rig. The particular values of the dynamic forces were obtained in force units by the load cell calibration curve as shown in Fig. 3. The voltage signal from HBM W100 (D.S.1362) LVDT with a sensitivity of 80 mV/mm is fed to the PC through an interface card as shown in Fig. 4. The relative motion between the top of damper are measured using the LVDT calibration curve as shown in Fig. 5.

Fig. 2: Load cell with amplifier

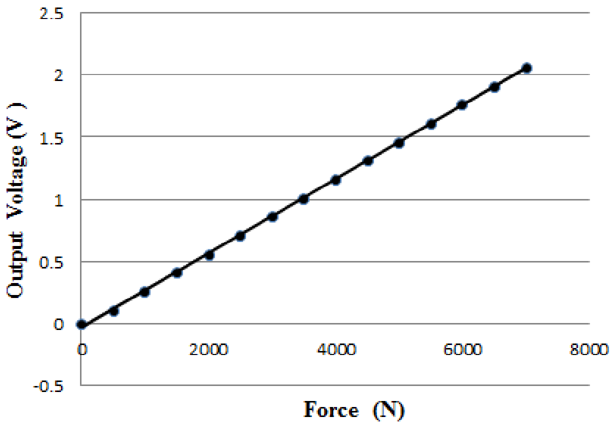


Fig. 3: Load cell calibration curve

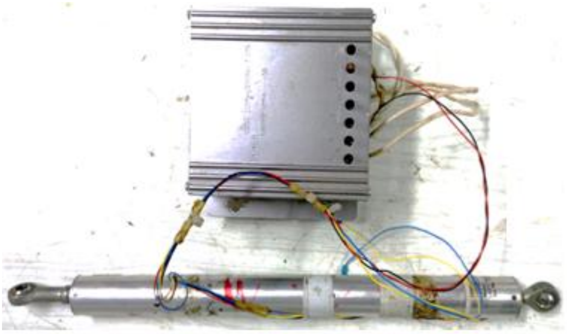


Fig. 4: Linear variable differential transducer

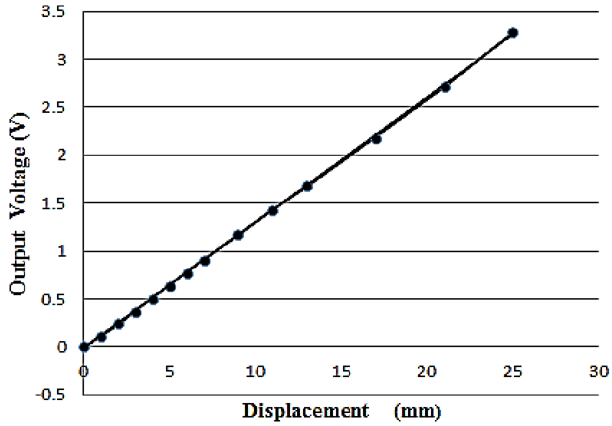


Fig. 5: LVDT calibration curve

3. Results and discussions

After installing the shock absorber to the test rig and checking the correctness of the assembly process, the damper is adjusted to third damping position to measure its performance characteristics. The tests are conducted by exciting the hydraulic cylinder by a sinusoidal input adequate to excite a frequency of 0.617, 1.13, 1.37, 1.87, 2.5 and 4 Hz with 20 mm amplitude. The measured displacement and force are obtained after filtration. Then, the displacement is differentiated to get the velocity response. The power dissipation response is obtained from the multiple of the force and velocity. Fig. 6 shows the displacement, velocity, force and dissipation power responses in the time domain at constant frequency of 4 Hz and the damping coefficient of 2500 Ns/m. Fig. 7 shows the power dissipation from the MSSD with constant damping coefficient of 2500 Ns/m for the variations in excitation frequencies.

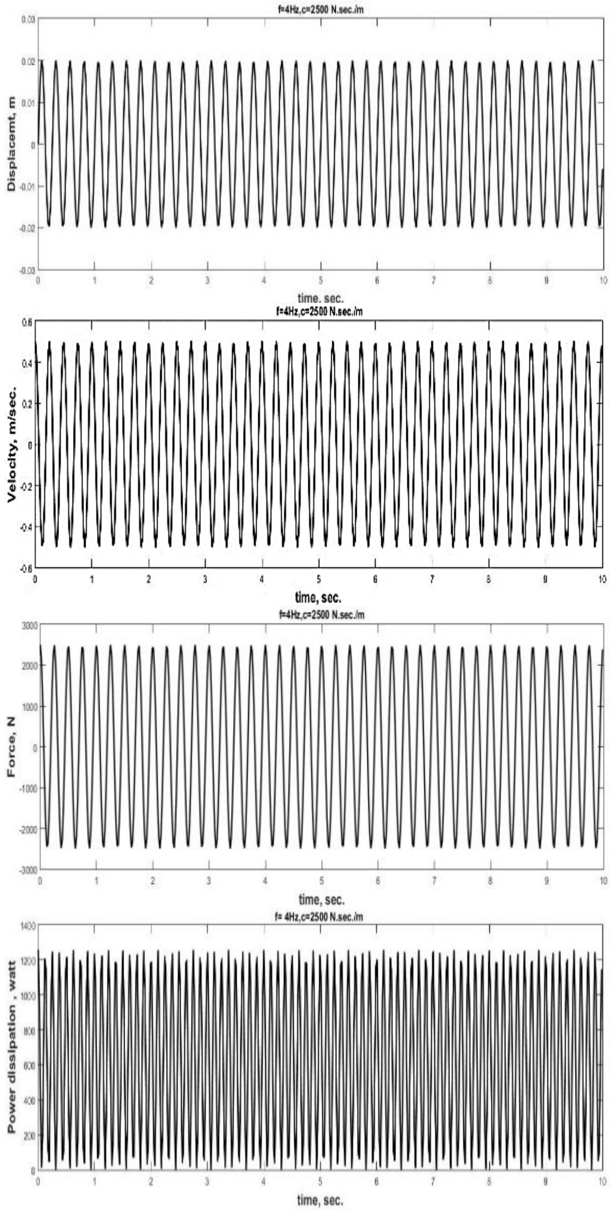
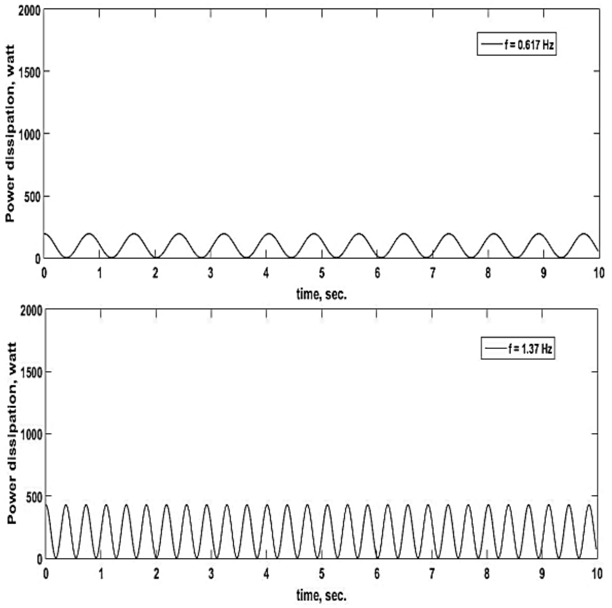


Fig. 6: Displacement, velocity, force and power dissipation responses in time domain at 4 Hz



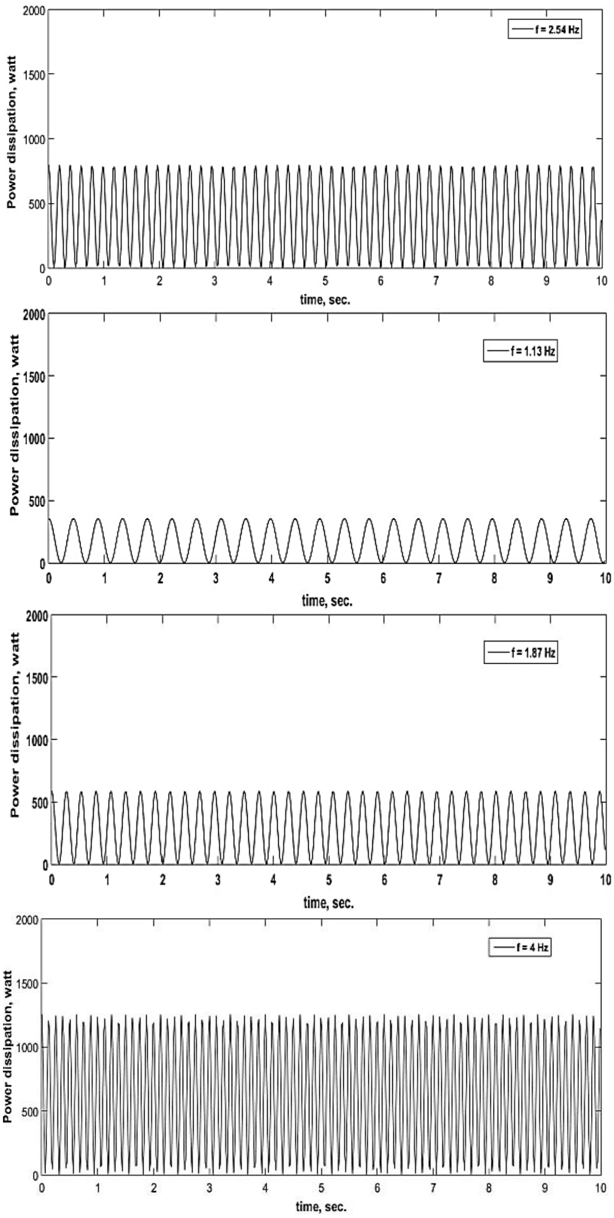


Fig. 7: Power dissipation responses from the MSSD at damping coefficient of 2500 Ns/m for different frequencies

Fig. 8 shows the power dissipation from the MSSD for different damping modes at constant frequency of 4 Hz. Table 1 gives a summary of RMS of the power dissipation for these output responses. From these results, it can be noticed that the power dissipation from the MSSD is increasing when the damping force is increased. Also, the first the four damping modes have significant influence on the power dissipation.

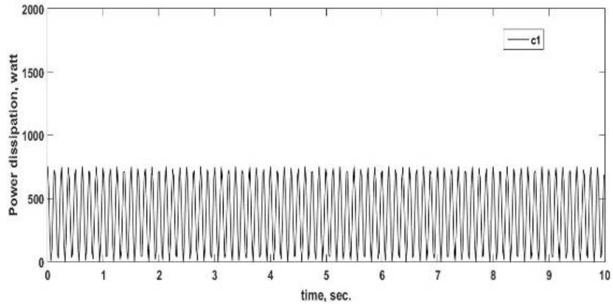


Fig. 8(a): Power dissipation from the MSSD for damping coefficient of 2500 Ns/m at 4 Hz

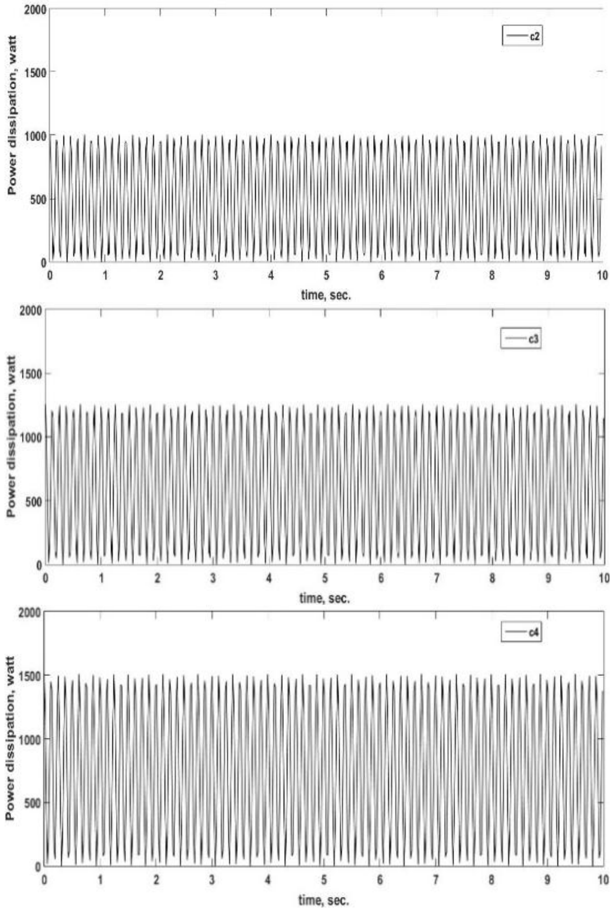


Fig. 8(b): Power dissipation from the MSSD for second to fourth damping modes at 4 Hz

Table 1: RMS of power dissipation responses

Frequency, Hz	RMS of power dissipation at 2500 Ns/m, W	Damping coefficient, Ns/m	RMS of power dissipation at 4 Hz, W
0.67	119.6	1500	462.2
1.13	217.2	2000	616.3
1.37	264.4	2500	770.3
1.87	360.7	3000	924.4
2.54	488.2		
4.00	770.3		

4. Conclusion

This paper detailed the power dissipation from multi state switchable damper measured using a damper characteristics test rig in laboratory environment. Power dissipation from MSSD was assessed for the variations in frequency at a constant damping coefficient of 2500 Ns/m and also for the variations in the damping coefficients of the first four modes with fixed frequency of 4 Hz. Power dissipation from the MSSD is directly proportional (depicted a linear relationship) to the damping coefficient and velocity.

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