CALIBRATION OF A SYSTEM CAPABLE TO RECOVER THE DISSIPATED ENERGY INTO AN AUTOMOBILE SUSPENSION

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The purpose of this paper is the characterization of the system used to recover the oscillation damping energy from an automobile suspension, in terms of the Effort – Displacement and Effort – Speed and to appreciate the energy dissipated by the suspension dampers. The evaluation for this system is necessary to guarantee that the suspension dynamics not will be changed, compared to a classic damper. The test is performed on the hydraulic stand which measures the effort, strokes and generates the excitation signals. The tested system opposites the effort and recovers the energy, using an electric generator and a mechanical system that transforms translation in rotational movement.

Keywords: effort, stroke, electric generator, signals, characteristics.

1. Introduction

Car suspension is a potential source of energy supply continuously due to its operating condition as long as the car is in motion. The energy dissipated by the suspension dampers can be transformed into electric energy, using an electric generator instead of a damper.

The purpose of this paper is the characterization of the system used to recover the oscillation damping energy from an automobile suspension, in terms of the Effort – Displacement and Effort – Speed and to appreciate the energy dissipated by the suspension dampers. The evaluation for this system is necessary to guarantee that the suspension dynamics not will be changed, compared to a classic damper. Fundamental research into the feasibility of using a dissipative energy recovery system in suspension dampers began in the 1980's, [1].

In paper [2] is presented the operating principle of the power dissipation system of the PGSA suspension (Power-Generating Shock Absorber), which transforms the automobile suspended mass oscillations energy into electricity using a linear electric generator. The lower part contains the magnets and the upper part contains the coil. In the compression and rebound strokes, alternative voltage is supplied, who will be rectified and stored into battery.

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Fig. 1. PGSA Suspension Energy Recovery System, [2]
a) presentation of the system; b) system detail

Test speeds were achieved at 32km/h and 48km/h. The electrical power supplied on all suspensions is maximum 67.5W and average of 19.2W, [2].

In paper [3] it is presented the operating principle of the recovery energy system in the suspension of automobiles, by means of a pinion and rack-electric gear, which transforms the oscillation motion of the automobile mass into generator rotation. At a speed of 96km/h on high road category in terms of irregularities [4], the system produces total power on all suspensions between 100W and 400W. For the road irregularities $\pm$ 100mm, with vehicle speed at 100 km/h, the system produces maximum 980W.
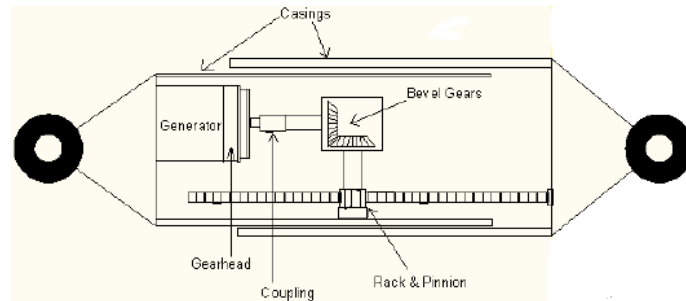

Fig. 2. Energy recovery system with pinion and rack-electric gear, [3]

In paper [5] is presented the energy dissipation system in the vehicle suspension eROT (electromechanical rotary), proposed by the Audi automobile manufacturer.
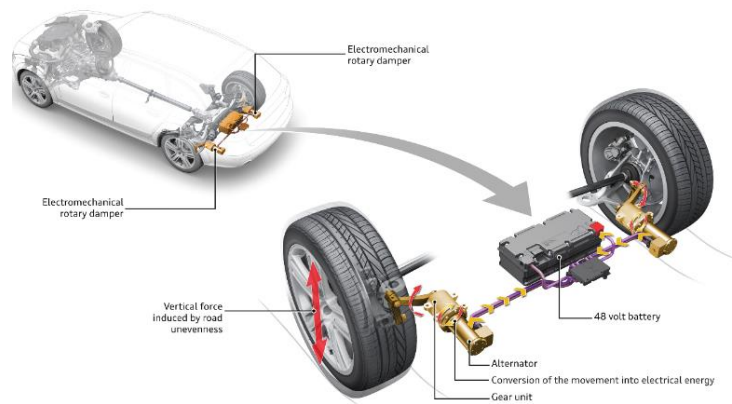
Fig. 3. Energy recovery system eROT, [5]

Audi wants to avoid the loss of energy by replacing the hydraulic damper with an electromechanical system. The system tested on the high road category [4] showed an average power from all suspensions 3W and from the lowest road category 613W, according with [5].

2. System presentation

The system used for recover the energy contains three category of components: the element who replaces the damper suspension, the speed amplifier and the electrical components.
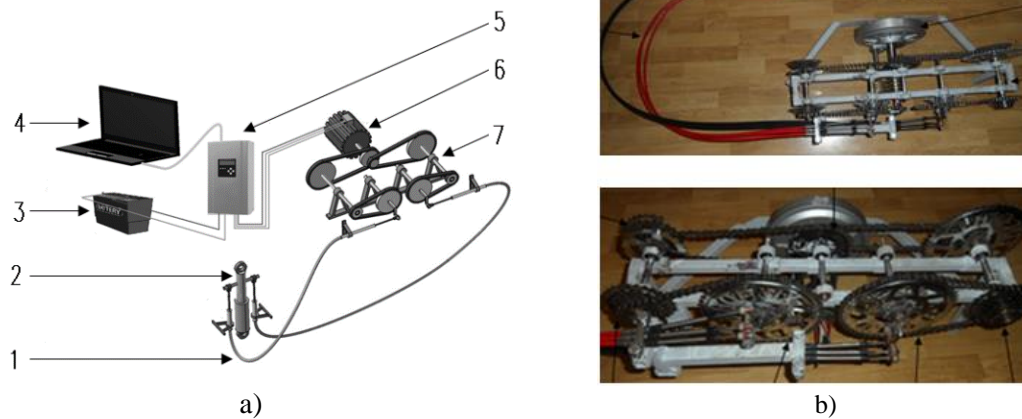

a)   b)
Fig. 4. The recovery energy system
a) The principle scheme; b) The real system
1 – push pull cables, 2 - slider, 3 – battery, 4 – laptop, 5 – electronic control system,
6 – electric generator, 7 – speed amplifier system

In Fig. 4. are presented the system subcomponents. The suspension slider (2) is a system that provides the sliding function, with the role of taking over the

translational movement of the suspension. It includes an upper part which is fixed to the suspended mass and a lower part which engages the non-suspended mass.

Cables (1) are push-pull cables needed to take up the suspension movement on both directions, the compression and the rebound. The technical solution to recover the energy dissipated by the suspension uses transmission through cables for reasons of favorable location on the car, [6].

The speed amplifier system (7) contains the one way gears to assure the unidirectional generator shaft rotation and the other gears to achieve the speed amplifier.

The electric generator (6) is a DC generator, with permanent magnets and three phases, for use in wind turbines for household use. The main reason for choosing this type of generator is that it offers relatively high voltage, relative to the 12V electric car system, from low speeds, using an electronic control system. It can be used in both 12V and 24V circuits, [7].

The measurement and data acquisition system is represented by a MPPT (Maximum Power Point Tracking) controller (5). It is the most important element of the entire energy recovery system as it can ensure the charging of the 12V battery, even the generator supply 4V, [8].

The battery (3) is an automobile battery and the laptop (4) is used to represent the electrical signals.

3. The test bench

The experimental model of the shock absorbers testing platform HIDROPULS is presented in figure 5, [9].
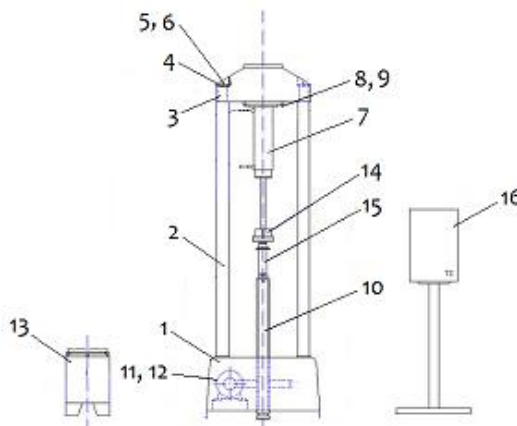

Fig. 5. The general scheme of a platform for dampers test (stand)

1 - cradle; 2 - guide column; 3 - upper upright; 4 - end washer; 5 - screw M24x85; 6 - Gr.N24 washer; 7-cylinder hydraulic; 8 - screw M16x50; 9 - washer; 10 - leading screw; 11 - electric motor; 12 - drive group; 13 - hydraulic group; 14 - the tensometric dose; 15 - damper; 16 - control panel

The shock absorbers testing platform offers the possibility of simultaneous endurance dynamic testing of more shock absorbers, thus reducing both the time and cost of a test and it could be used in the future for testing other machine parts. Likewise, static strength tests of shock absorbers can be performed as well as dynamic tests to obtain the elastic characteristics. The equipment can reproduce different reference signals for actuating the shock absorbers, under different forms and with different frequencies and amplitudes, thus reproducing the entire range of vibrations and loads at which the shock absorbers are subjected by daily use and the strains at which they have to be subjected for testing, stipulated in standards and other regulations, [9].

a)   b)

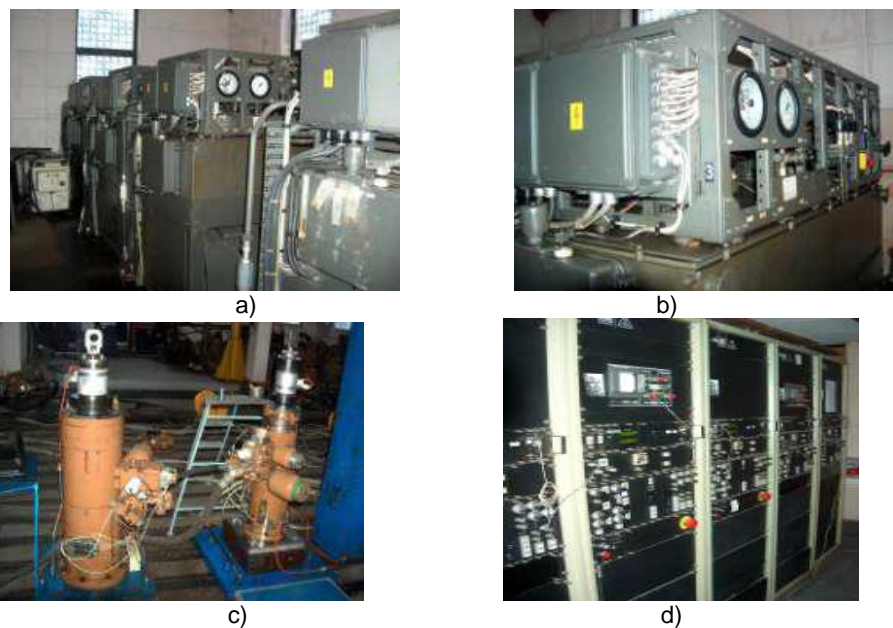c)   d)

Fig. 6. The components of a platform for dampers test (stand), [9]
a) pumping aggregates, b) monitoring pumping aggregates
c) vertical hydraulic cylinders d) control panel

Fig. 7. The system on testing bench

The equipment was tested using a hydraulic testing bench, in the followings conditions, who simulate the running on the medium road category, with the speed which assures the comfort of the passengers, [10]:

- the signal form: sinusoidal
- the signal frequency: 1.5Hz, 2Hz, 3Hz
- the signal amplitude: ± 25mm.

4. Results

The test described the reaction force from the hydraulic system according with the suspension displacement and speed excitation, applied to the recovery energy system. 16 measurements for the frequency of 1.5Hz, 13 measurements for 2Hz and 17 measurement for 3Hz frequency were performed. After data processing for elimination of errors, the average of all the tests was calculated and the results are presented in the graphs below.
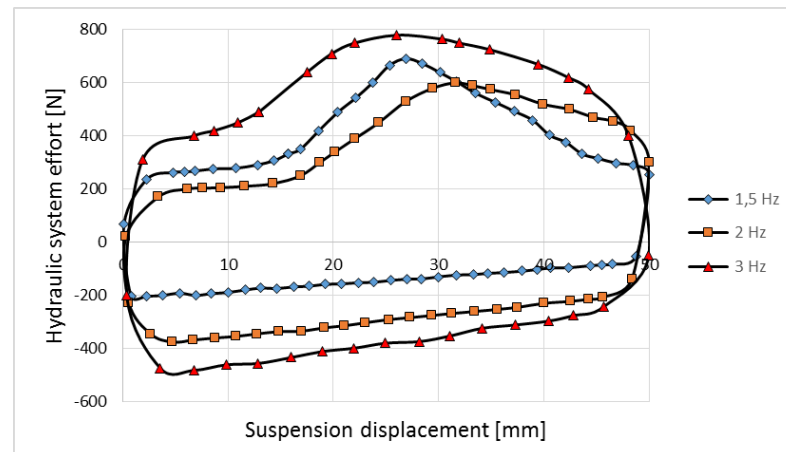

Fig. 8. The Effort - Stroke characteristics

The graphs of Fig. 8 show that the 1.5 Hz test frequency generates a force-displacement graph on the test system, which follows the form of the sine wave signal of the system. At 2Hz, the sinusoidal shape can be tracked only at half of the detour stroke, and at 3Hz the F-d graph no longer follows the form of the excitation signal.
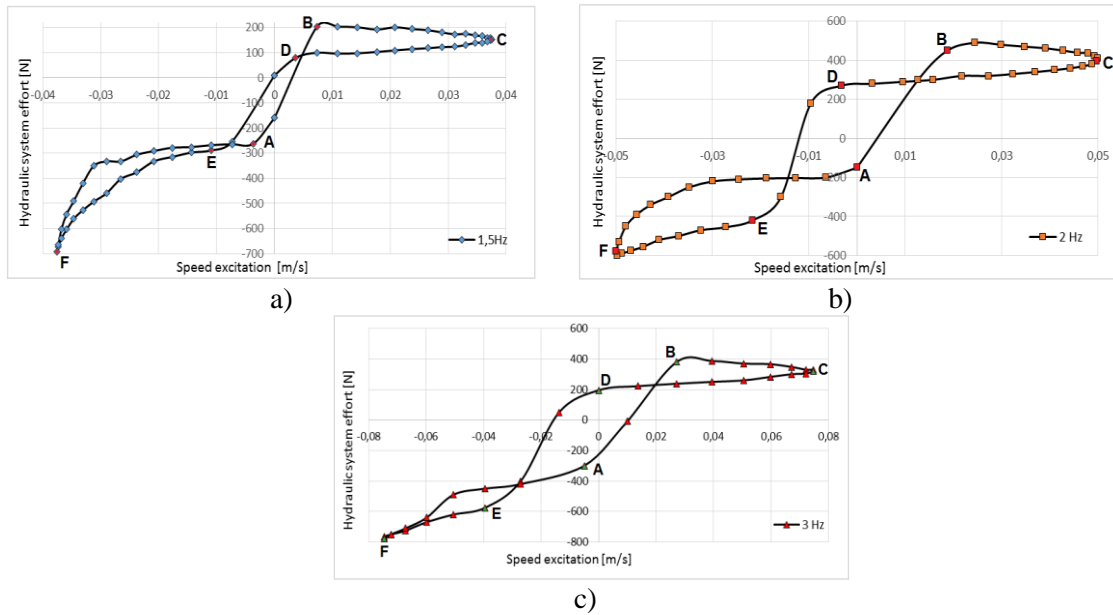
a)

b)

c)

Fig. 9. The Speed – Effort characteristic
a)   1.5Hz testing frequency; b) 2 Hz testing frequency; c) 3 Hz testing frequency

Regardless of the frequency at which the system was tested, the damping feature comprises of several distinct areas. On the compression stroke the following areas are distinguished, fig. 9:
- • A-B: progressive damping feature
- • B-C: regressive damping feature until mid-stroke
- • C-D: regressive feature until the end of the compression stroke

On the rebound strokes there are the following areas:
- • D-E: progressive damping feature
- • E-F: regressive damping feature until mid-stroke
- • F-A: regressive feature until the end of the compression stroke

On both strokes of compression and rebound, the succession of progressive and regressive features is naturally achieved without any intervention in the damping effort. This causes the system to behave as a regular shock absorber, to which the discharge valves open when the critical piston drive speed is reached.

The progressive feature is due to the inertia of the generator and the mechanical speed-boosting system. Once the whole system reaches the maximum speed to which it was trained, the regressive feature is due to the strong torque of system friction and power generation. For an increased transmission ratio, the progressive feature will be steeper. At the same time, the acceleration of the generator will lead to the production of a higher power, and the regressive characteristic will become a progressive one.

The damping characteristics comprise several distinct areas. The compression and rebound strokes are progressives on the beginning and regressive until the end. The hysteresis of the system is inversed around the zero point because of system inertia.
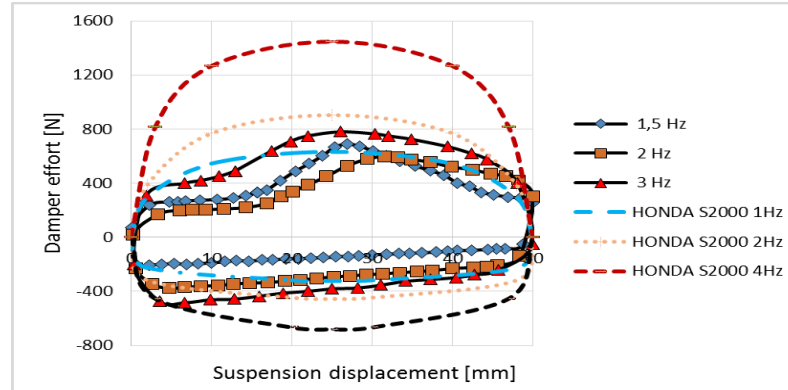

Fig. 10. The Effort – Stroke characteristics comparation, [11]

Compared to the similar model Honda S2000, it is noted that the system tried to stay at the 1.5 Hz and 2 Hz frequencies as the compression stroke reaches a peak at the middle of the suspension stroke. At the same test frequencies, the similar model reaches about the same maximum strength value, but on a much longer stroke.

In the case of the 3Hz test frequency of the system, the effort has a characteristic that is found under the effort curve of the similar model of the Honda S2000. In all test situations, the system may be considered to have a lower damping constant than a regular damping. To change the feature, in order to increase the resistance force opposed by the system, it is necessary for the system to produce more electric power. This can be done by increasing the speed at which the shock absorber is driven, namely an increase in the speed boost ratios.

As far as the characteristics of the generator are concerned, the evolution of the speed, voltage, current and electrical power that loads the accumulator battery according to the frequency of the test is shown in fig. 11. The evolution of measured values is performed over 10 seconds and the values are recorded at a sampling frequency of 1 record / second.

a)   b)

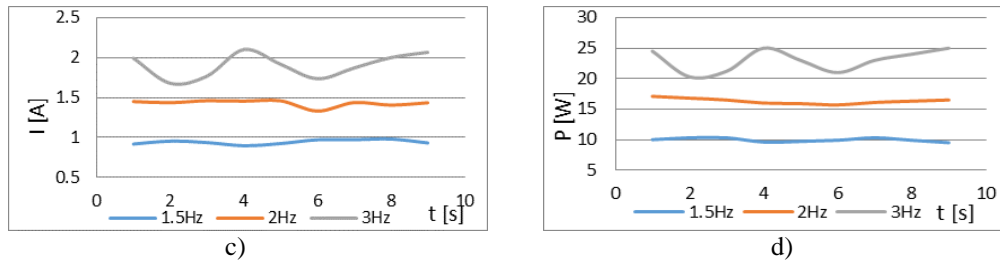c)   d)
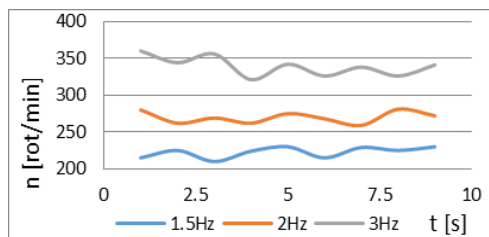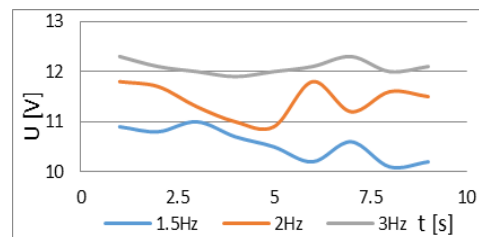
Fig. 11. Generating energy parameters - a) generator speed; b) voltage; c) current; d) power

In the case of the test at 3 Hz frequency, the voltages at the output from the controller are limited to 12.5V, when the maximum rotational speed slightly exceeds the value 350 rpm. At the same time, the battery charge current reaches a maximum of 2A, with a greater variation than the 1.5Hz and 2Hz frequencies. The electrical power has a uniform characteristic with an almost constant evolution around 10W at the 1.5Hz test frequency. For tests at 2Hz frequency, the average power increases to about 17W. At 3Hz, the power provided by the system shows significant variations in data acquisition, ranging from 25W to 30W. This is explained by the variation in speed at which the generator was subjected. The evolution of speed is explained by the elasticity of the mechanical components subjected to the stresses and position deviations of the pinions that generated the peaks of the effort during the tests.

To ensure that the battery pack is fully charged and that the system operates at the highest possible efficiency, it is necessary that the power management on the car ensures a voltage at the battery terminals below the one produced by the generator at any speed. In the absence of such a management, when the battery reaches a maximum voltage and can no longer be charged from the generator, the electrical power supplied by the system will be dissipated on an internal resistor of the controller, [8].

5. Conclusions

Bench calibration of the energy recovery system available from a car suspension reveals some differences between a regular shock absorber and the presented system.

The effort-stroke characteristic feature on the stand is inferior to the features of the two similarly analyzed models. This shows that the friction in the system and the electrical power that opposes the movement cannot have the same mechanical resistance as a regular shock absorber.

From the Force-Speed feature it is noted that the system under review is approaching a shock absorber belonging to an average-sized car, and, compared to the second similar model, the characteristic is inferior. The stress curve shows a progressive and second regressive part, simulating the operation of a shock absorber with discharge valves operating at critical speed of the normal damping. The distribution of these characteristics is related to inertia, efficiency and power

generation of the system. Both of the above features have peak and average values, proportional to the transmission ratios of the system, on compression and rebound strokes. Following the comparison of the system characteristics with similar model in the same class, it is noted that the system can also increase its rigidity by increasing the transmission ratios by using a generator that produces energy from lower or rated power larger, necessary to increase the capacity of the system to produce and store electricity.

The author's contributions were related to the possibility of a convenient system placement on the car and maximizing the recovered power.

Regarding the possibility of the system being conveniently placed on the car, the systems analyzed so far required their placement in the immediate nearness of the suspension. In this working environment, the mechanical and electrical equipment must be made taking into account several factors, such as: ensuring the necessary sealing, especially of the electrical equipment, the increased mechanical strength in case of contact with the various obstacles over which the car passes, access difficult to change subcomponents due to positioning under the car.

By using pushing and pulling cables, it was possible to separate the body translation acquisition area from the power generation area. To use a future power recovery system equipped with such transmission cables, it is recommended to use robust cables to increase their reliability. At the same time, the personal contributions on the experimental part have highlighted the use of electronic equipment, which has the role of maximizing the recovered electric power at all times, but also of charging a 12V accumulator battery starting from the voltages provided by the 4V generator, thus increasing the energy recovery area, relative to running conditions.

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