CORRELATION BETWEEN THE CONTROL CURRENT AND THE DAMPING EFFECT FOR MAGNETO RHEOLOGICAL SHOCK ABSORBERS

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The paper presents the researches carried out by the authors on the structure, basic computational elements, and real dynamic behaviour of the last generation of the magneto rheological shock absorbers used in automotive suspensions. This technology, called "MagneRide", uses magneto rheological fluids. They normally behave like a usual liquid but when a magnetic field is applied on them the particles begin make up the chains and the fluid becomes highly viscous. The authors have designed and built a complex test bench in order to establish the correlation between the control current and the magnetic damping effect, taking as reference a classical shock absorbers with the same external geometry. The experimental results can be used in the synthesis of controllers needed by the modern car suspensions.

Keywords: magneto rheological damper, magnetic field, test bench, damping force – current correlation.

1. Introduction

The MagneRide damping system [1], developed by the Delphi Automotive Corporation consists of four monotube dampers, a sensor set and an Electronic Control Unit (ECU). The magneto-rheological (MR) fluid used in the dampers is a suspension of magnetically soft iron particles, easily, but temporarily magnetized, in a synthetic hydrocarbon base. The damper piston contains a coil that can generate a variable magnetic flux across the fluid passages. When the coil current is off, the MR fluid is not magnetized, the iron particles are randomly dispersed within the fluid, and the fluid behaves like conventional hydraulic oil. When the coil is energized, the magnetic field causes the particles to align into fibrous

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structures in the direction of the magnetic flux. The strength of the bond between the particles in the structures is proportional to the strength of the magnetic field, so changing the current provides real-time variable damping with a very large range of force variation. The result is a system that outperforms conventional variable damping systems, without using electrohydraulic servo valves. Compared to other, valve-based technologies, MagneRide achieves a much broader damping force range and responds much more rapidly without generating noise. The following qualities recommend this technology: continuously variable digressive damping; fast and linear response to control input; wide dynamic range; high authority at low piston velocities; symmetric forces (compression vs. extension).

A few years ago the passive dampers equipped the majority of vehicles. Today the use of adaptive shock absorbers begins to increase due to the better comfort and a better vehicle dynamics they are offering [1].

The principle scheme for a magneto rheological shock absorber is shown in figure 1. Into the MR shock absorber the piston contain coils capable to offer a magnetic field in the orifices.
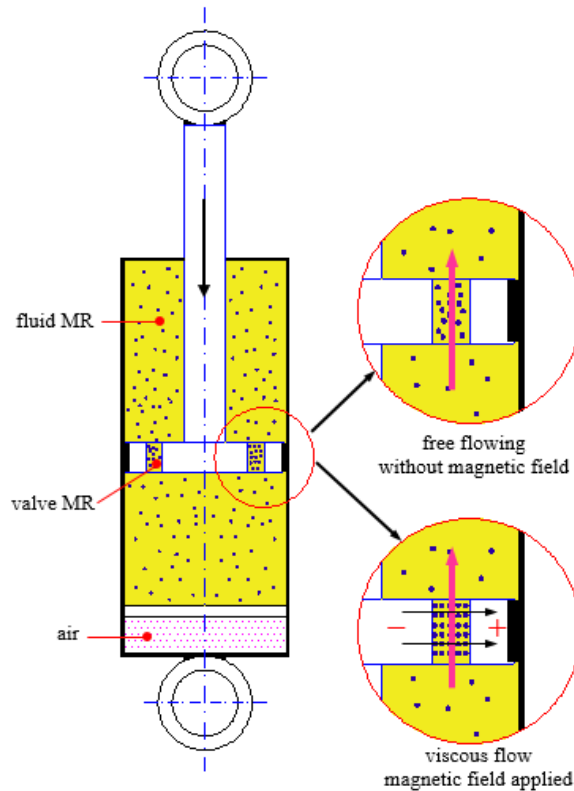

Fig. 1. The principle scheme for a magneto rheological shock absorber

Accordingly, the piston can be regarded as a MR valve and the damping is the result of the friction that occurs between MR fluid and orifices (fig. 1).

When an electric current is applied to the coil, a magnetic field appears and produces the alignment of the magnetic particles in the magnetic flux direction. When the coil is not powered, the magneto rheological fluid is not magnetized, and the iron particles are randomly dispersed into the fluid, hence the liquid behaves as a conventional hydraulic oil. The strength of the link between particles is proportional with the intensity of the magnetic field. These are positioned transversely on the oil flow direction, thereby limiting the flow rate of the fluid through the channels of the piston.

The magneto rheological (MR) damper can combine the comfort with the dynamic driving, because allows the adjustment of the damping characteristic according to the road profile. The piston of the damper doesn't contain conventional oil, but an especially smart fluid called magneto rheological.

Usually, the magneto rheological fluids are composed from ferromagnetic and light paramagnetic particles with the diameter included in the 0.03 ... 10 µm range dispersed in a carrier liquid [2]. Particles with larger diameters than 100µm can cause jamming irreversible and accelerated wears, while those with diameters less than 1µm can generate the changes of the yield point, making them useless for use in adaptive dampers [3].

The viscosity depending on the magnetic field, for a MR damper is presented in figure 2. Can observe that the viscosity is kept below 50 Pa·s.
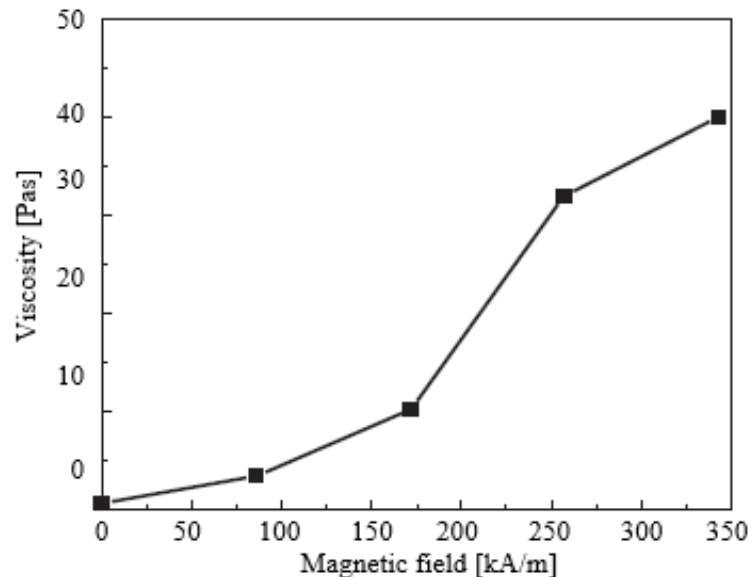

Fig. 2. The viscosity depending on the magnetic field in a MR damper [2, 4]

Usually, the yield stress of the magneto rheological fluid has exponentially proportional relation to the magnetic field. This equation is known as the Bingham plastic model and can be governed by the equation [2, 5]:

$$\tau_y = \alpha \cdot H^{\beta} \tag{1}$$

Where: τ_y represents the yield stress of the MR;

H - Magnetic field;
α, β - are calculated.

The experimentally determined Bingham model [2] is described as:

$$\tau_y = 0.1367 \cdot H^{1.213} \tag{2}$$

Using the relation (2) one can determine the variation of the yield shear stress depending on the magnetic field, presented in the figure 3. The yield shear stress increases exponentially with the growth of the magnetic field.
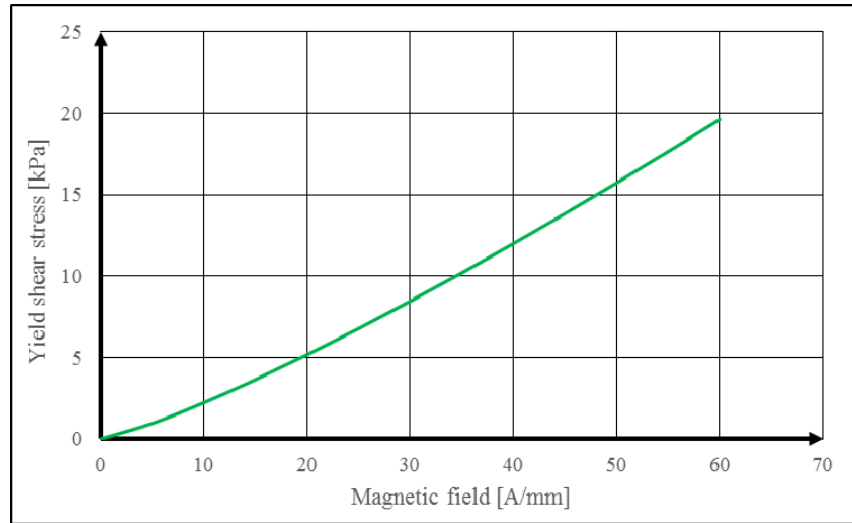

Fig. 3. The yield shear stress depending on the magnetic field, for a MR damper

The scientific literature [6-9] presents different studies regarding the magneto rheological fluids which contain particles of micron sizes and nano sizes particles. For example, Rosenfeld and Wereley [6] studied a mixture of micro particles with a mass participation of 20% nanoparticles. This composition has led

to a substantial reduction of the sedimentation rate (with an order of magnitude) and the increase of the dynamic yield point by more than 15 percent in a high magnetic field [7]. For comparison, Foister in [10] has developed a bimodal suspension of micron size, which have a mixture of big particles (greater than 10 µm) and the smaller particles. The ratio from the big and small particles was 5: 1. The blend led to the significant improvement of the yield point without any increase in viscosity; reported improvement was 2.7 times over the mono size suspension.

2. The test bench design

The test bench used by the authors consists from a shock resistance frame, which is provided at the upper part with a space for mounting the damper, and in the lower part - with a space for mounting an electrohydraulic servomechanism. This includes a hydraulic cylinder and a servo valve. A position inductive transducer attached to the piston lower road supply the external servo controller with the position feedback. The damping force was measured by a high speed piezo ceramic force transducer. The velocity of the piston was measured with a velocity inductive transducer (fig. 4 and 5). In the figure 4 is presented the block diagram of the system for testing magneto rheological dampers.
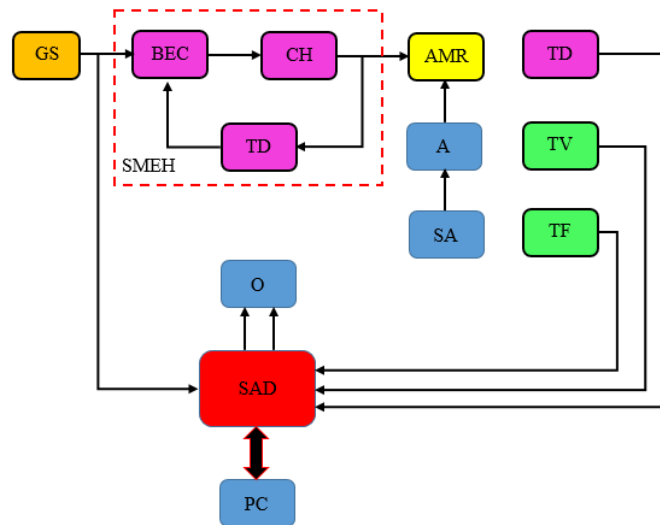

Fig. 4. The block diagram of the testing magneto rheological dampers:
GS – signal generator of; BEC – servo controller; CH – hydraulic cylinder with servo valve; TD - displacement transducer; SMEH – electro hydraulic servomechanism; AMR – magneto rheological shock absorber; A – digital multimeter; SA – power source; TV – velocity transducer; TF – force transducer; SAD – data acquisition system; PC – computer; O – memory oscilloscope
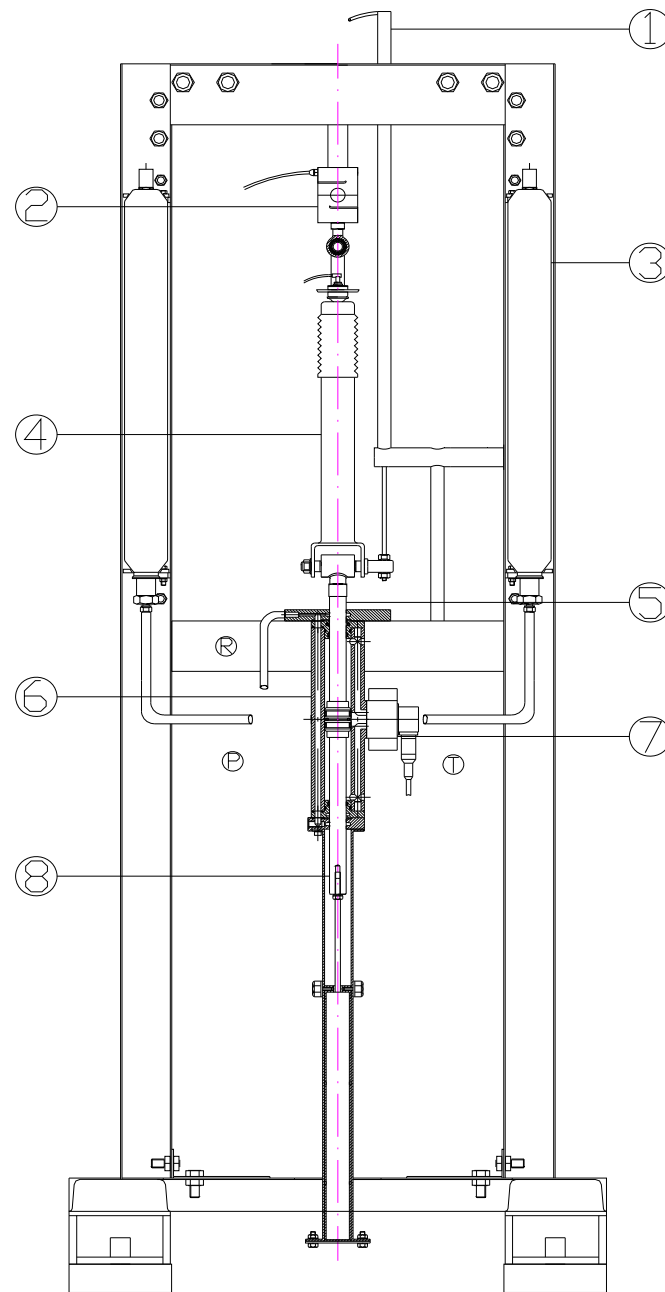
Fig. 5. Main section of the test bench for testing the MR dampers: 1 – velocity transducer;
2 – force transducer; 3 – hydraulic accumulator; 4 – MR damper; 5 – driving rod with elastic joint;
6 – hydraulic cylinder with hydrostatic bearings; 7 – servo valve; 8 – position transducer

A PXI industrial controller provided with two data acquisition boards, both produced by NATIONAL INSTRUMENTS Corporation was used for the control of the servomechanism and for data acquisition. The excitation of the shock absorber was done with a position signal, similar to the real exploitation situations. The input signal can be: sine, triangular or compound. The test bench output is the damping force developed by the shock absorber for different velocity. A partial view of the test bench is presented in the figure 6.

Fig. 6. Partial view of the test bench for testing the MR dampers

3. Experimental results

The figure 7 shows the influence of the electric current on the velocity of the piston of a magneto rheological shock absorber for a sine input signal with 0.5 Hz frequency.
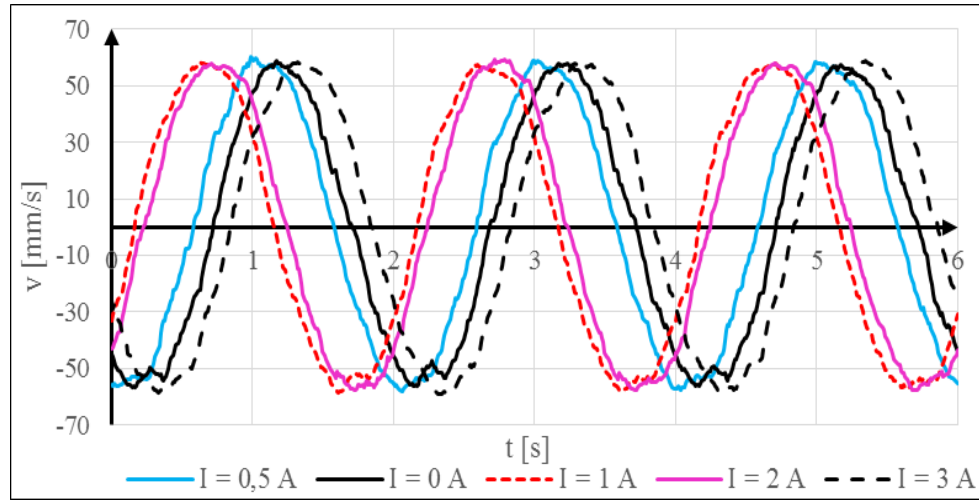
Fig. 7. The velocity of the piston depending on the time, for a MR damper for different values of the electric current

The figures 8, 9 and 10 show the variation in time of the damping force, respectively of the piston velocity for a magneto rheological damper piston speed for different input signals.
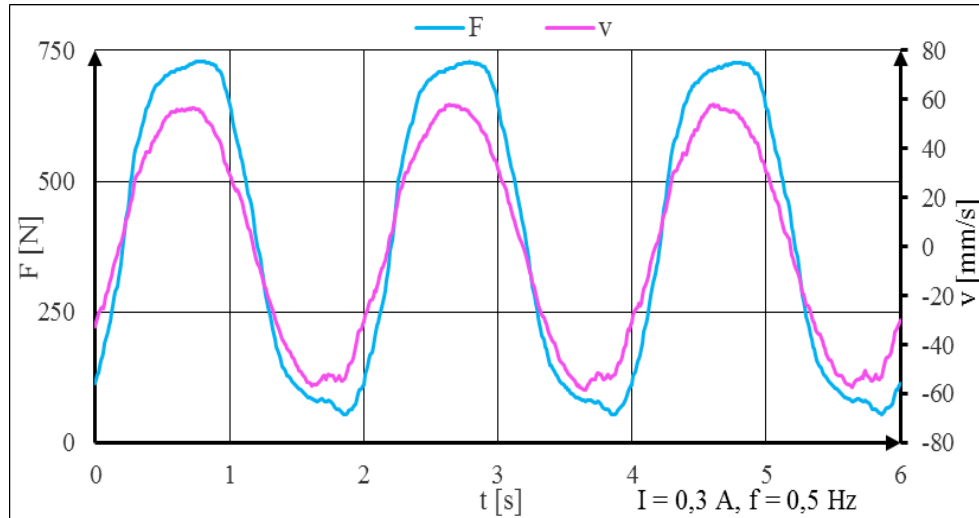

Fig. 8. The damping force and velocity of the piston depending on the time, for a MR damper for an electric current of 0.3 A and a frequency of 0.5 Hz
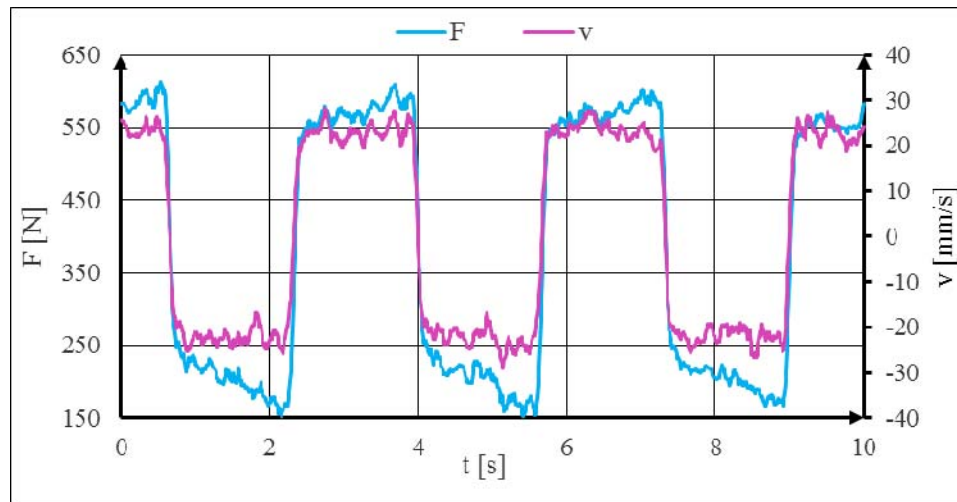
Fig. 9. The damping force and the velocity of the piston depending on the time, for a MR damper supplied with an electric current of 0.5 A at a frequency of 0.3 Hz
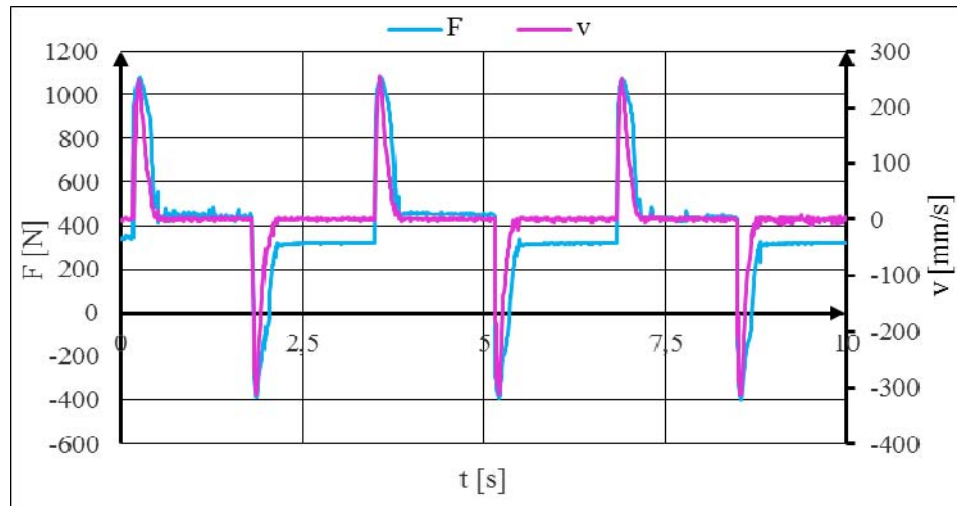

Fig. 10. The damping force and velocity of the piston depending on the time, for a MR damper for an electric current of 0.5 A and a frequency of 0.3 Hz

In the figures 11 and 12 is presented the influence of the frequency on the damping characteristics, for an intensity electric current of 0.5 A, and a sinusoidal input signal. We notice that the increasing of the frequency signal increases the hysteresis loop and the damping force records a consistent growth for a magneto rheological damper (the force increases 1.24 times).
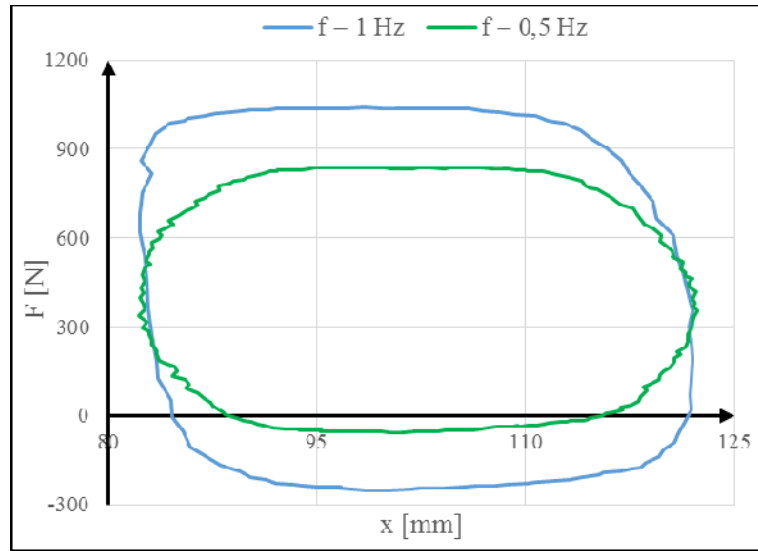
Fig. 11. The damping characteristic in coordinates force-displacement, for a magneto rheological shock absorber for different frequencies
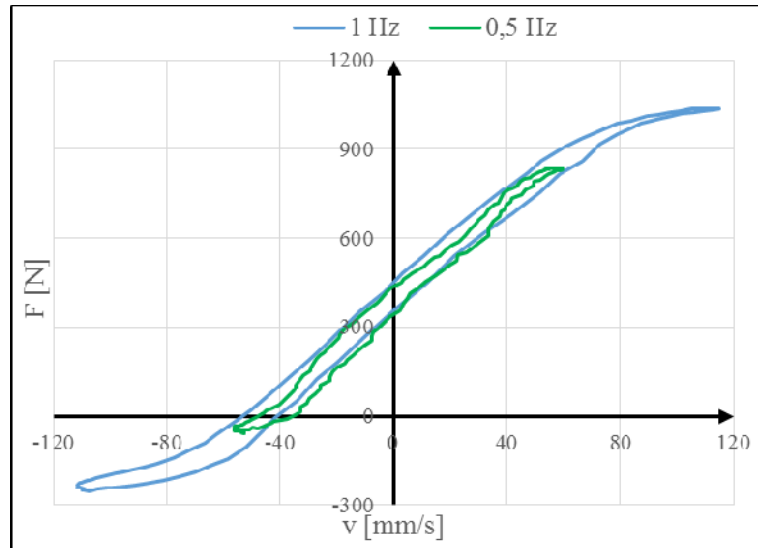

Fig. 12. The damping characteristic in coordinates force-velocity, for a magneto rheological shock absorber for different frequencies

The figure 13 shows the variation of the maximum damping force versus the electric current for a piston velocity of about 60 mm/s. One can observe that

the maximum damping force has a polynomial variation and increases once with the increasing of the electric current intensity. This characteristic is typical for all the shock absorbers made with a single coil located in the piston. Normally, for 1A the damping force becomes double in comparison with the case "unpowered" [11].
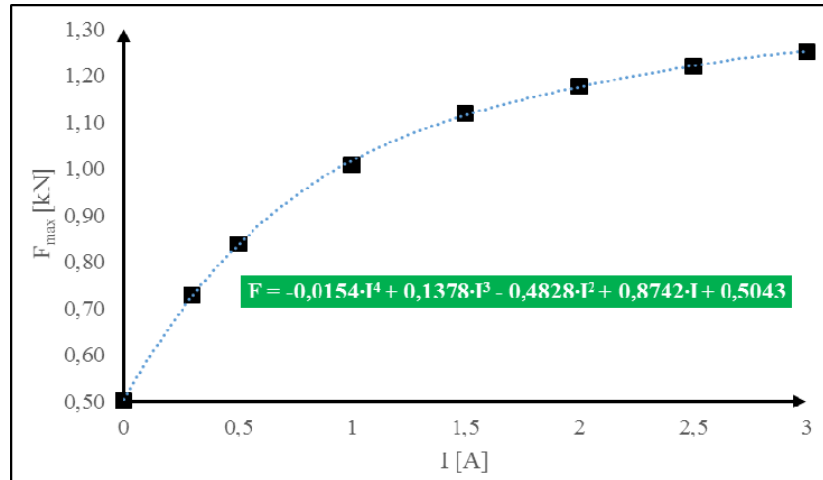

Fig. 13. The maximum damping force depending on the electric current intensity

4. Conclusions

The control of the damping force is obtained sin a simple manner, by changing the electric current intensity value. For small control current, the rate of the damping force reaches the biggest value. For a current control without PWM, the damping force saturates around 3A. The maximum damping force has a polynomial variation. The maximum damping force for an electric current of 3A is about 1250N. The magneto rheological shock absorber offers a substantial improving of the comfort due to the control of the damping force. Unhappily, the price of the controller remains great enough for limiting the scale of the applications.

5. Acknowledgement

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