ANALYSIS OF ELECTROMAGNETIC REGENERATIVE SHOCK ABSORBER

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Automobiles have shock absorbers to damp out the vibrations experienced due to roughness of the road. In conventional shock absorbers energy gets dissipated as heat and is not used in anyway. Regenerative electromagnetic shock absorbers provide a means for recovering the energy dissipated in shock absorbers. The major objective of the present paper was the design, realised and analysis of the operation of a linear electromagnetic generator with main application - regenerative electromagnetic shock absorber . This type of electromagnetic generator isn't first realised in the field of regenerative electromagnetic shock absorber, based on specialized literature, but the authors of the paper have designed and built a prototype electromagnetic generator with design parameters described in this paper.

Keywords: electromagnetic, shock absorbers, regenerative damper, permanent magnet, generator

1. Introduction

In [1, 2, 4, 5] was studied the electromagnetic shock absorbers (EMSA) to transform the energy dissipated in shock absorbers for cars and trucks driven over various types of roads. An EMSA consists of a permanent magnet liniar synchronous generator, a spring and on electric energy accumulator.

2. Principle of EMSA

EMSA fabricated by INCDIE ICPE-CA consists of the three assemblies: the permanent magnet assembly, the coil assembly and the case assembly, as shown in Fig. 1.

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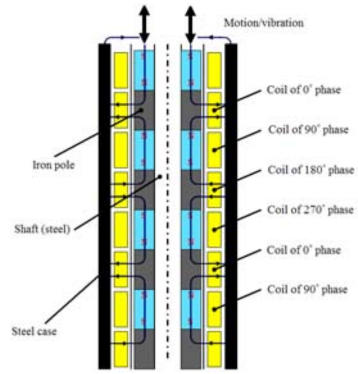


Fig. 1. Schematic view of EMSA

Voltage is induced in the windings when the magnet assembly moves relative to the coil assembly. The case assembly aligns and enables the piston-like motion between the coil and magnet assemblies.

The magnet assembly consists of an magnet stack compromises 12 layers of permanent magnet and 12 layers high permeability material and which are separated by permanent magnet respectively. A axial guide rod axially penetrates these permanent magnets and high magnetic conductive material layers to enhace their strength. Hard magnetic material NdFeB was chosen as permanent magnet and soft magnetic material having high permeability was chosen as magnetic conductive material.

The coil windings is fixed various coil windings group can be connected in parallel or in series or both ways. The coil group will be catting the radial magnetic induction lines, thus current occurs in the coil and in the mean time damping force occurs correspondingly.

3. Estimation of EMSA parameters

EMSA was designed and developed by authors of this paper inside of INCDIE ICPE-CA. The EMSA device isn't first prototype in the world, it based on specialized literature, but with input parameters below (see in paragraph §3) it hasn't been achieved.

A. Road data reference

It's known that mean roughness value of c-level road is about $1-6cm$ and the wavelength is about $10-100cm$, [3]. To simplify the calculation it's supposed that the waveform is half period is $z(x)=bx$, where $z(t)$ - the vertical displacement of the tire, b - the bump slope of the road (its range is $0.01-0.05$), V_z - vertical speed of the tire, V_x - the running speed of the vehicule.

B. Input data

The average power of the coil $P = 3W$.
The open-circuit voltage $V = 5V$.
The maximum running speed of the vehicle $V_{z\max} = 72Km/h = 20m/s$.
The frequency $f = 20Hz$.

Remarks:

Vertical speed of the tire is $V_{z\max} = \alpha V_{x\max}$; range of α is $0,01 \div 0,005$, [3]; for $\alpha = 0,025$ results $V_{z\max} = 0,5m/s$.

The mean relative velocity used to simplify the calculation is

$$V_z = \sqrt{\frac{1}{T}\int_0^T V_z^2(t)dt} = \sqrt{\frac{1}{T}\int_0^T a^2t^2dt} = V_{z\max}/\sqrt{3} \tag{1}$$

C. Electromagnetic parameters

The induced electromotive force (open-circuit voltage) $U_{\max}[V]$ is

$$U_{\max} = \pi D_m N V_z B_r \tag{2}$$

where: $D_m[m]$ - average diameter of coil, N - total turns of coil, $B_r[T]$ - radial magnetic flux density.

The current of the coil $I_{\max}[A]$ is

$$I_{\max} = \sigma \frac{\pi d^2}{4} V_z B_r \tag{3}$$

where: $\sigma[S/m]$ - electric conductivity of coil material (for Cu, $\sigma = 5 \cdot 10^7 S/m$), $d[m]$ - diameter of conductor.

The maximum electrical power (at match load) $P_{\max}[\mathrm{W}]$:

$$P_{\max} = U_{\max} I_{\max} / 4 \tag{4}$$

Using by (3), the $r.m.s.$ values are

$$U = U_{max} / 2\sqrt{3}\ ,\ I = I_{max} / 2\sqrt{3}\ ,\ P = UI = P_{max} / 12 \tag{5}$$

The maximum magnetic damping force $F_{d\,max}[N]$ is

$$F_{d\,max} = \sigma V_z B_r^2 V_c\ ;\ V_c = \pi D_m N \frac{\pi d^2}{4} \tag{6}$$

where: V_c - volume of coil.

For INCDIE ICPE-CA EMSA the parameters are:

$U_{max} = 17{,}3V$, $I_{max} = 2{,}1A$, $I = 0{,}6A$, $B_r = 0{,}7T$, wire diameter $d = 0{,}4mm$, $N = 1200 turns$, $24 wafers$, thickness of wafer $3{,}5mm$, inner diameter of wafer $15mm$, outer diameter $22mm$.

The manufacturing drawing is shown in fig. 2.

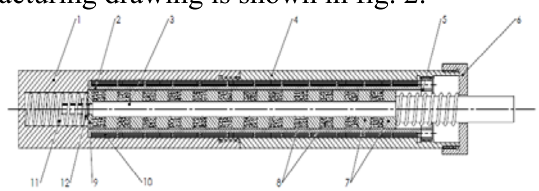
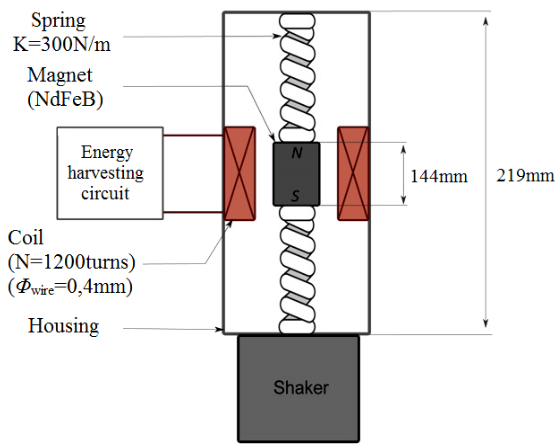


Fig. 2. Manufactoring drawing (1 - lower case; 2 - coil support; 3 - piston shaft; 4 - upper case; 5 - Special nut; 6 – casing cover; 7 – iron pole; 8 - permanent magnet; 9 – washer; 10 – coil; 11 – spring; 12 - M4 nut.

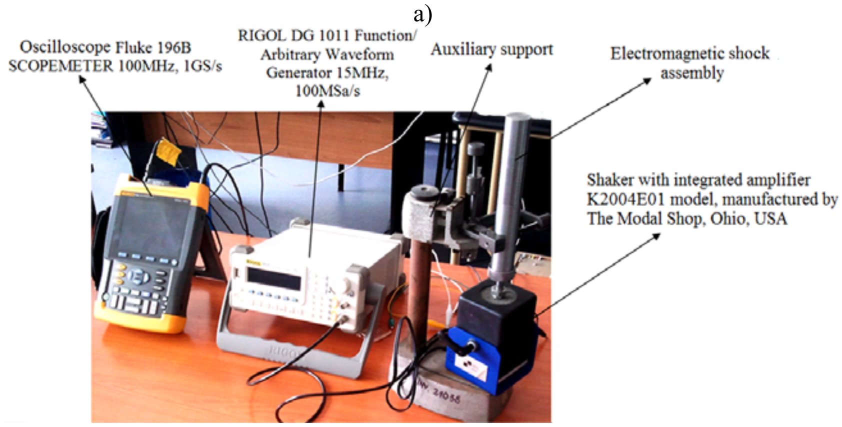
4. Experimental assessment

A. Experimental setup of EMSA

In the test for EMSA was used shaker with integrated amplifier K2004E01 model, manufactured by The Modal Shop, Ohio, USA (shown in fig. 3a), 3b)). Scanning the frequency $1 \div 100\text{Hz}$ and changing input signal amplitude shaker that gives him the arbitrary function generator Rigol DG 1011, the tension generated by electromagnetic shock is between $0{,}21 \div 14{,}8V_{rms}$. Voltage waveforms obtained from EMSA terminals was measured by digital oscilloscope Fluke 196B SCOPEMETER and electricity current on resistance load $R = 27\Omega$ was measured with a digital multimeter Meterman 30XR.



a)



b)

Fig. 3. a) Schematic of the experimental setup; b) test stand of EMSA

B. Experimental results

In fig. 4 you can see the voltage waveforms at different frequencies for an amplitude of $V_{pp} = 4V$ input signal shacker (resistance load $R = 27\Omega$). In fig. 5 and 6 may see the RMS voltage as a function of the frecuency domain and harvested power as a function of the frecuency domain for an amplitude of $V_{pp} = 4V$ input signal shacker (resistance load $R = 27\Omega$). In fig. 7 and 8 may see RMS voltage across the load resistance and harvested power as a function of the load resistance for the amplitude of $V_{pp} = 3V$ input signal shacker.

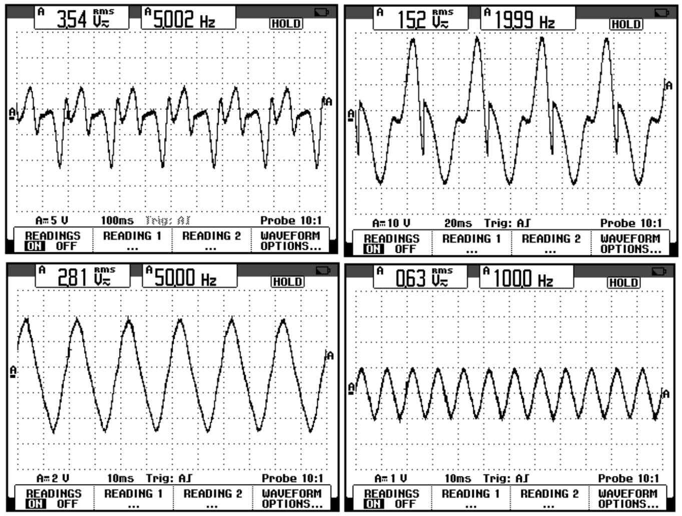


Fig. 4. Voltage waveforms for different frequency for an amplitude of $V_{pp} = 4V$ input signal shacker (resistance load $R = 27\Omega$)

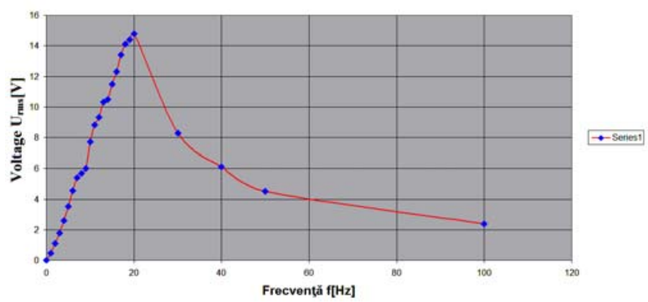


Fig. 5. Experimental RMS voltage as a function of the frecuency domain for an amplitude of $V_{pp} = 4V$ input signal shacker (resistance load $R = 27\Omega$)

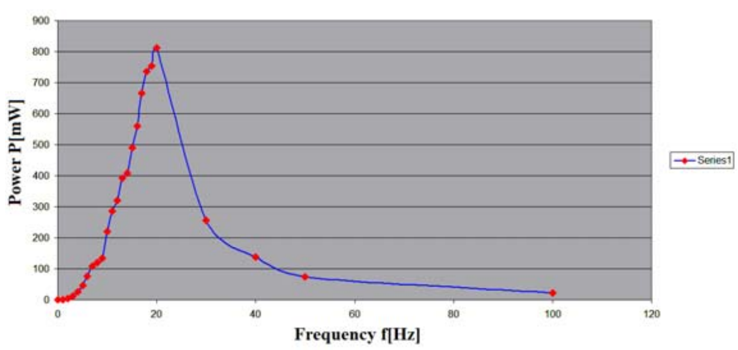


Fig. 6. Experimental harvested power as a function of the frecuency domain for an amplitude of $V_{pp} = 4V$ input signal shacker (resistance load $R = 27\Omega$)

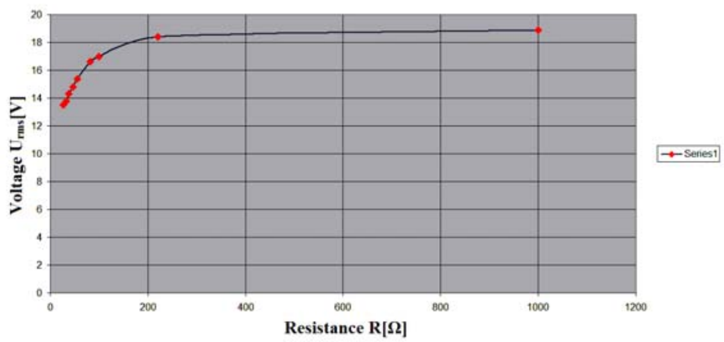


Fig. 7. Experimental RMS voltage across the load resistance R for an amplitude of $V_{pp} = 3V$ input signal shacker

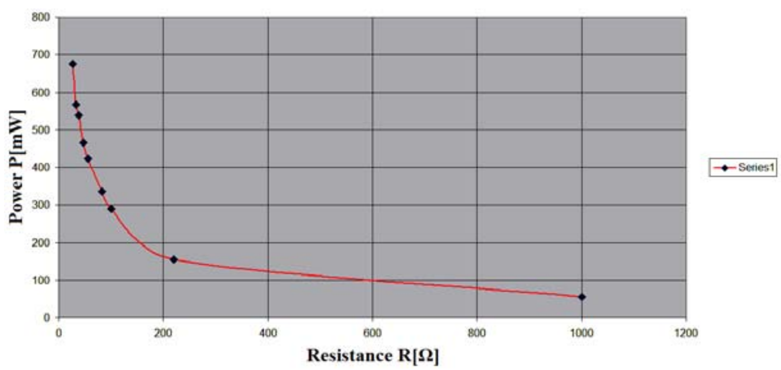


Fig. 8. Experimental harvested power as a function of the load resistance R for an amplitude of $V_{pp} = 3V$ input signal shacker

5. Conclusions

The fabricated EMSA performed as expected. A larger magnetic field will be necessary is more power needs to be generated. The resonance characteristics show an optim frequency of $20Hz$ which is specific for electromagnetic shock absorbers.

Other applications that can use the EMSA are: power energy wireless sensor networks for structural health monitoring, wireless monitoring of civil engineering structures such as bridges and overpasses, sensors used in military applications.

The main advantages of using EMSA are: alternative energy source to batteries, simple construction, low maintenance costs and installation costs, provide long-term solutions and reduce environmental impact.

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R E F E R E N C E S

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