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ELECTROMECHANICAL CONVERTOR WITH MAGNETS - THEORETICAL ASPECTS -

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ABSTRACT
The paper presents a novel electromechanical device using two magnets, a ferrofluid and a coil, that comprises a damped vibratory ensemble for which a theoretical model of the dynamic behaviour is described. The device is intended to be designed to function as a current to displacement converter, a vibrator, a displacement transducer or a vibration sensor.
Keywords: *electromechanical device, ferrofluid, displacement converter.*

1. INTRODUCTION
Small power electromechanical devices (actuators) of various types are currently used to convert an electrical signal into a mechanical action (force, torque, displacement or vibration). At the same time there is a large number of other electromechanical devices, sensors and transducers which are being used in order to measure electrically the forementioned mechanical parameters. Sensors and transducers are usually based on a totally different principle as that by the devices that generate mechanical actions.
Technological progress and the large variety of industrial applications require the development of new accurate, robust, light and small devices. Some of these are based on new physical principles and materials, such being the case of the MEMS (MicroElectroMechanical Systems) sensors and actuators. MEMS is a class of systems that are physically very small. These systems have both electrical and mechanical components. MEMS originally used modified integrated circuit (computer chip) fabrication techniques and materials to create these very small mechanical devices. Today are many more fabrication techniques and materials available [1], [2].
Many non-conventional devices such as actuators and sensors, with macro- or micro- structure (MEMS), some of which are in the design stage, others being already produced and sold, are based on new materials, magnetic or non-magnetic, some of them being considered "intelligent" materials. Some of these new materials are: shape memory alloys, amorphous alloys, materials with giant magneto-impedance and giant magneto-resistance, piezoelectric materials, magnetostrictive alloys, rare earth-iron alloys for high-energy magnets, ferrofluids, electrorheological fluids and magnetorheological suspensions.
In the next sections a preliminary analysis of an original device based on magnets and ferrofluid (magnetic fluid) is presented. The device may be designed to function as a current to displacement converter, a vibrator, a displacement transducer or a vibration transducer.

2. DEVICE PRINCIPLE
The schematic diagram of electromechanical device with magnets is shown in Figure 1. It consists of a non-metallic cylindrical carcass mounted on a support and having attached to it a flange at the top. A non-metallic diaphragm is fixed to this flange by means of another flange. A non-magnetic rod is fixed at the centre of the diaphragm and a disc shaped magnet with a central channel is fixed at the other end of the rod. The magnet is surrounded by a ferrofluid layer, strongly adherent to the magnet surface, that prevents it to touch the carcass walls. This magnetic piston is suspended in the magnetic field created by

itself and an inferior magnet fixed on the device support. The rod inner channel links the air bulks below and above the magnetic piston. The coil mounted on the carcass has two identical windings that can be used in an additional or differential connection, depending on the device destination.
When the movable magnet is displaced in the radial direction in the gap, a restoring force is obtained by ferrofluid, which is proportional to the displacement. Although this force is a fraction of that provided by suspension, it is still enough to influence the centering of the moving magnet. This force constant is given by [3]:

$$k = 2M_s H_m ht / r \quad (1)$$

where:

- k = force constant in Newtons/meter
- M_s = saturation magnetization of the ferroflui in tesla
- H_m = maximum field strength in the gap in ampere meter
- h = height of fluid in the gap in meter
- t = width og the gap in meter
- r = radius of the gap in meter

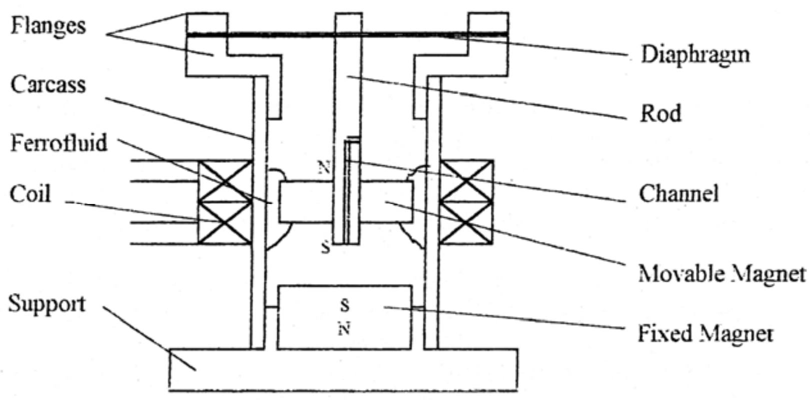


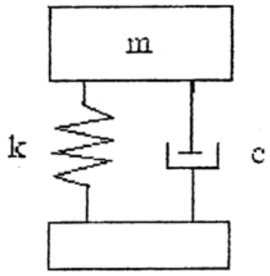
Figure 1. schematic diagram of electromechanical convertor.

Ferrofluid in the gap provides a mechanical resistance to the moving magnet. The amount of damping is proportional to the viscosity of the ferrofluid.
In Figure 1 mobile ensemble formed by movable magnet, ferrofluid and rod is elastic suspended by means of the diaphragm and the magnetic field that produces repelling forces between the two magnets placed with identical poles facing each other. At equilibrium, with zero coil current and no external force, the weight of the mobile pails is compensated only by the magnetic force generated by the magnets and the friction between the magnetic fluid and the carcass. An elastic force exerted by the diaphragm also appears while the device is operating.
If the coil is fed with d.c. or a.c. current a supplementary magnetic force appeals resulting in a continuous or alternative movement of the mobile part. A reversible behaviour is also to be expected i.e. if the mobile part move linearly or vibrate an electric signal is obtained in the coil.
The first step toward the design of devices and more complex analyses of specific applications is the theory of single degree-of-freedom dynamic system.

3. SINGLE DEGREE-OF-FREEDOM DYNAMIC SYSTEM

Figure 2 shows the "classical" spring, mass, damper depiction of a single degree-freedom dynamic system. This figure and related equations are well known and serve as a useful basis for beginning the analysis of a behaviour problem. However, classical vibration theory is based on one assumption that requires understanding in the applications of the theory. That assumption is that the properties of the elements of the system behave in a linear, constant manner.

The equations of motion for the above model system are familiar to many. For review purposes, they are presented here.



m – Mass – Stores kinetic energy
k – Spring – Stores potential energy, supports load
c – Damper – Dissipate energy, cannot support load

Figure 2. Elements of vibratory system

The differential equation of motion is:

$$m\ddot{y}+c\dot{y}+ky=F(t) \quad (2)$$

in which it be seen that the forces due to the dynamic input (which varies as a function of time) are balanced by the inertial force of the accelerating mass and the spring force. From the solution of this equation, comes the equation defining the natural frequency:

$$f_n = \frac{1}{2\pi}\sqrt{k/m} \quad (3)$$

In reality, the freedom oscillating frequency does vary slightly with the amount of damping in the system. The damping factor is given the symbol "ζ". The equation for the natural frequency of a damped system, as related to the for an undamped system, is:

$$f_{nd} = f_n\sqrt{1-\xi^2} \quad (4)$$

The damping ratio ζ, is defined as:

$$\zeta = c/c_c \quad (5)$$

where, the "critkal" damping level for a damped vibratory system is defined as:

$$c_c = 2\sqrt{km} \quad (6)$$

For a oscillating input force, $F(t) = F_0\cos\omega t$ the vibrator system shows the following equation of amplitude vs. frequency characteristic:

$$A(\omega) = \frac{A_0}{\sqrt{(1-r^2)^2 + 4\xi^2 r^2}} \quad (7)$$

where, $A_0 = F_0 / k$ is the static deformation of the spring that have elastic constant k, because the action of force F_0, and $r = f/f_n$ is the command frequency related to natural frequency of system.
Amount of amplification A(ω) is maximum at resonance while accomplished the condition $\xi < 1/\sqrt{2}$, and in this case the maximum point coordinates of the A(ω) are:

$$r_r = \sqrt{1-2\xi^2} < 1, \qquad A_{\max} = \frac{A_0}{2\xi\sqrt{1-\xi^2}}, \quad (8)$$

The following relationship may be established between the three forementioned frequencies:

$$f_r < f_{nd} < f_n$$

In the real world of practical systems, the elements are not linear and the actual system response does not follow the above analysis rigorously. In the case of the system in Figure 1. the elasticity constant k is ensured for low amplitude vibrations mostly by the magnetic field which behave as an elastic force field; thus the small displacements may be considered harmonic. The amortization constant c is ensured by the magnetic fluid viscosity and by the hydrodynamic configuration of the device. The ferrofluid viscosity may be modified by concentrating or diluting the fluid or by producing a constant magnetic field. The equation that describes more accurately the system in Figure 1, taking into account the friction force F_f between the magnetic fluid and the carcass is:

$$m\ddot{y} + c\acute{y} + ky + F_f = F(t) \tag{10}$$

Eqn. (10) is non-linear because the coefficients c, k and F_f are not constant during operations.

4. CONCLUSION

The electromechanical convenor proposed in this paper is based on magnets and a ferrofluid that substitute the elastic springs in classical devices, thus forming a stable oscillating electromagnetic system with one degree of freedom. The design of the device together with its Theoretical model fonns the basis of more complex analysis and of future applications. One may anticipate that static and dynamic performances as well as the small dimensions of die device depend largely on die magnet characteristics that must be made of high-energy materials.

5. REFERENCES

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