MAGNETOSTRICTIVE VIBROMOTORS USING TERFENOL-D ALLOY

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Abstract. This paper presents the use of Terfenol-D alloy in the development of unconventional motors, *i.e.* vibromotors. Choosing Terfenol-D alloy in the construction of these types of unconventional motors was determined by excellent magnetostrictive properties that this alloy holds. The basic principle in achieving these magnetostrictive vibromotors consists in achieving a vibrating system consisting of a coil wrapped around a Terfenol-D rod which acts on a disk-shaped rotor in the center of which is fitted a shaft. This paper presents three types of magnetostrictive vibromotors, one that uses two rotors, a vibromotor solution with the possibility of reversing the direction of rotation and a vibromotor solution with the possibility of adjusting the rotational speed.

Key words: vibromotors, Terfenol D alloy, magnetostrictive alloy, smart materials.

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1. Introduction

The vibromotors are unconventional motors that converts the movement of vibration in a continuous motion, linear or rotary. The transfer of electrical power absorbed from the source is achieved by friction, which requires direct contact between stator and rotor. Unlike conventional motors, based on the action of “remote” magnetic or electric fields, vibromotors functioning involves the transmission of power from the stator to the rotor through direct contact. In other words, there is a possibility of transmission by friction of a movement drive to the mobile part.

The magnetostrictive vibromotors develop high power, while keeping a low frequency power of about 16 to 22 kHz. A main characteristic of the magnetostrictive vibromotor is that presents a natural braking effect which manifests almost instantly, at the moment of switching off the power supply. Other features of magnetostrictive vibromotors are low supply voltage, no electrodes that could easily destroy, are insensitive to environmental factors, etc.

Magnetostriction is the property of a ferromagnetic material to alter its physical shape or size in response to the applied magnetic field. This effect was discovered by English physicist James Joule in the 19th century. He described this effect as a change in the physical quantity under the action of magnetic forces, using the term “magnetostriction” and calling it the “Joule effect”.

Terfenol-D alloy with Tb0.3Dy0.7Fe2 formula is a magnetostrictive material. The name comes from terbium (TER), iron (Fe), Naval Ordnance Laboratory (NOL) and D stands for dysprosium. It was made in 1970 by the Naval Ordnance Laboratory in North America, at the request of the United States Navy through a program for achieving sonar systems to equip warships, later used in applications such as sensors, actuators, ultrasonic transducers, magnetostrictive motors.

A.E. Clark, defines the phenomenon of magnetostriction mechanism at macroscopic level as the result of two distinct processes.

The first process is dominated by the migration of domain walls within the material in response to external magnetic fields. Second, is the rotation of the domains. These two mechanisms allow the material to change the domain orientation which in turn causes a dimensional change. Since the deformation is isochoric there is an opposite dimensional change in the orthogonal direction. Although there may be many mechanism to the reorientation of the domains, the basic idea, represented in the Fig. 1, remains that the rotation and movement of magnetic domains causes a physical length change in the material (Clark, 1980).
The highest known magnetostriction are those of rare earth elements Dysprosium, Dy, or Terbium, Tb; DyFe$_2$, and TbFe$_2$. However, these materials have tremendous magnetic anisotropy which necessitates a very large magnetic field to drive the magnetostriction. Noting that these materials have anisotropies in opposite directions, Clark and his co-workers at NSWC-Carderock, prepared alloys containing Fe, Dy, and Tb. These alloys are generally stochiometric, of the form Tb$_x$Dy$_{1-x}$Fe$_2$ and have been coined Terfenol-D. Terfenol-D, operated under a mechanical-bias, strains to about 2000 microstrain in a field of 2 kOe at room temperatures. For typical transducer, actuator applications and magnetostrictive motors, Terfenol-D is the most commonly used engineering magnetostrictive material (Clark, 1980).

In (Bujoreanu, 2002) are presented several characteristics of Terfenol-D, such as:

a) common magnetostrictive strains in the order of 0.15% (1500 m/m) obtained at relatively low magnetic fields (about 100 A/m);

b) faster response time, in the order of milliseconds;

c) possibility of developing forces of hundreds of N;

d) operating temperature lies between -50 and 710°C.
These characteristics listed above are considered average values and corresponding to “normal” external parameters (pressure, temperature, etc.). Thus, increasing the applied magnetic field up to approx. 200 kA/m (2500 Oe) we obtain a magnetostrictive strain of 0.2% (2000 m/m). Magnetostrictive strain increase with the applied magnetic field, but an influence in this aspect is the applied mechanical tension, as shown in Fig. 2.

2. Magnetostrictive Vibromotor with Two Rotors

The figure below presents a magnetostrictive vibromotor for converting vibratory motion produced by a magnetostrictive vibrator in a continuous motion.

The magnetostrictive vibromotor consists of two disc-shaped rotors, 1 and 1’, each one provided with a shaft 2 and 2’, supported through some bearings 3 and 3’, also 4 and 4’. On the surface of each rotor is attached a friction ring 5 and 5’, made from a suitable material and on the surface of which operates a friction spur 6 and 6’, each fitted with a metal armature 7 or 7’ to an end of the Terfenol-D rod 8, which is in turn under the action of a magnetic field generated from a coil 9 which is supplied from a AC power source 10.

Coil 9 is built on a housing 11, from insulating material, mounted on the Terfenol-D rod 8. The magnetization system of the Terfenol-D rod is provided, at one end, with a cup-shaped ferromagnetic armature 12, closed at the free end by a ferromagnetic cap 13, which at the bottom, through a holder 13’ is attached to a support surface 14.

![Magnetostrictive vibromotor with two rotors](image)

The operation and performance of the magnetostrictive vibromotor is due in the most part to the material from which it is made rod 8. Terfenol-D is a
magnetostrictive alloy to which the strains are from 2 to 4 orders greater compared with alloys of nickel.

When activating coil 9, the Terfenol-D rod, changes its length, generally with $\Delta L = 0.75 \pm 1 \, \mu m/m$. If an alternating current passes through the coil, the Terfenol-D rod, will perform a compression - dilatation movement, thus acting on the two friction spurs 7 and 7' which compresses them. Spurs 7 and 7' operates in a similar manner to the ratchet wheel, which moves the rotor in the same way as encountered in a “step by step” motor.

The rotor speed depends on the compression - dilatation movement of the Terfenol-D rod, as well as the frequency of the current flowing through the coil.

3. Magnetostrictive Vibromotor with Reversible Rotation

The magnetostrictive vibromotor with reversible rotation, presented in Fig. 4, consists of two identical magnetostrictive vibratory modules, positioned in diametrically opposite positions. The magnetostrictive vibratory modules are made from a Terfenol-D rod, each placed in the magnetic field of a coil supplied from a AC power source.

The free end of the Terfenol-D rod is completed with a metal fitting on which is attached a friction spur acting in one direction or in the opposite direction on the surface of a disk-shaped rotor.

Depending on the desired direction of rotation, one of the two vibratory modules is activated, one being associated with the rotational direction “to the right” and the other is associated with the rotational direction “to the left”.

Fig. 4 – Magnetostrictive vibromotor with reversible rotation (Romaniuc et al., 2011a).
The magnetostrictive vibromotor consists of a disc-shaped rotor 1, equipped with a vertical shaft 2, which slides on some bearings 2' and 2''. On the rotor surface is attached a friction ring 3, made from a suitable material. Also at the top of the rotor, there are two magnetostrictive vibratory modules M1 and M2.

Each of the two modules consists of a Terfenol-D rod 4 and 4', which is under the action of an alternating magnetic field produced by a coil 5 and 5', each supplied from an AC power source 6 and 6'. Terfenol-D upper ends 4 and 4', are embedded in a fixed holder 7 attached on a support surface 7', while the lower ends are firmly attached to a metal fitting 8 and 8'.

On the metal fittings are attached some friction spurs 9 and 9', each made from an elastic blade deflected in the direction corresponding to the direction of rotation.

The ends of the elastic blades 9 and 9', are supported on the surface of the rotor 1, through the friction ring 3.

4. Magnetostrictive Vibromotor with Adjustable Speed

The magnetostrictive vibromotor with adjustable speed, consists of a magnetostrictive vibratory module made from a Terfenol-D rod, placed in the magnetic field of a coil, which is supplied from an AC power source.

Fig. 5 – Magnetostrictive vibromotor with adjustable speed (Romaniuc et al., 2011b).
Terfenol-D free end is ended with a metal fitting on which is fixed a friction spur acting on the surface of a disc-shaped rotor. The vibratory module, which is provided with a threaded rod, will change the position by sliding on the surface of the rotor from the peripheral edge toward the center of the rotor according to the speed of rotation that we desire.

The magnetostrictive vibromotor with adjustable speed, consists of a disc-shaped rotor, equipped with a vertical shaft, which slides on some bearings. On the rotor surface is attached a friction ring, made from a suitable material.

At the upper part of the rotor is positioned a magnetostrictive vibratory module consisting of a Terfenol-D rod, which is under the action of an alternating magnetic field produced by a coil, supplied from a AC power source.

Terfenol-D upper end, is embedded in a fixed support, mounted on a drive holder, which slides on a guiding rod, and a threaded shaft, provided with a drive arm. Guide rod and the threaded shaft are placed on two support legs, attached to a support surface. Terfenol-D lower end is integral with a metal fitting, to which is attached a friction spur, made from an elastic blade deflected in the direction corresponding to the direction of rotation.

The speed of rotation can be controlled by operating the adjusting device, provided with the threaded rod and the guide rod, which support the vibratory module to the surface of the rotor.

Fig. 6 – Magnetostrictive vibromotor with adjustable speed (Romaniuc et al., 2011b).
For these magnetostrictive vibromotors, has been established the regular national filing to obtain the patent at OSIM.

3. Conclusions

New findings on magnetostrictive materials such as TERFENOL-D alloy appearance, led to extensive research on their applicability in achieving sensors and transducers, actuators and unconventional motors.

This paper presents several variants of vibromotors that uses the properties of magnetostrictive alloy TERFENOL-D, transforming into rotary motion the magnetostrictive strain.

The magnetostrictive vibromotor with two rotors, the magnetostrictive vibromotor with reversible rotation and the magnetostrictive vibromotor with adjustable speed, represents a few models of unconventional motors that we applied to obtain patent.

The magnetostrictive vibromotors are characterized by simplicity in construction, low noise, have a natural braking effect that manifests itself almost instantly at the moment of switching off the power supply.

An important detail is that for these types of unconventional motors miniaturization is possible, allowing their use in fields such as automotive, medicine, robotics, aerospace, etc.

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REFERENCES

VIBROMOTOARE ELECTROMAGNETICE CU ALIAJ TERFENOL-D

(Rezumat)

Vibromotoarele electromagnetice sunt sisteme electromecanice de conversie a vibrațiilor în mișcare de rotație sau mișcare liniară. Vibromotoarele prezentate în această lucrare au fost realizate pe principiul fenomenului de magnetostrictiune, utilizând proprietățile magnetostrictive ale aliajului Terfenol-D. Sunt prezentate trei variante constructive de vibromotoare magnetostrictive, un vibromotor cu două rotoare, un vibromotor cu posibilitatea inversării sensului de rotație și un vibromotor cu posibilitatea reglării vitezei de rotație. Lucrarea prezintă schemele de principiu ale acestora aducând explicații asupra modului de realizare și funcționare. Vibromotoarele magnetostrictive fac parte din categoria motoarelor neconvenționale și sunt caracterizate prin simplitate în construcție și zgomot redus.