Contributions to the Development of a Low-Speed Gadolinium Actuator System

V E Toader¹*, C Ungureanu¹, L D Miliți¹
¹Faculty of Electrical Engineering and Computer Science, Ștefan cel Mare University of Suceava, RO

*E-mails: eusebiu.toader@gmail.com; costel@eed.usv.ro; dam@eed.usv.ro

Abstract. Within the EMAD Research Centre of the USV, a low-speed actuator system has been developed which is based on the properties of the intelligent material gadolinium, i.e. the modification of the magnetic properties of the material according to temperature, magnetic at a temperature of less than 22.5 degrees and paramagnetic at a temperature greater than 22.5 degrees. The speed adjustment is made by the temperature variation (cold - warm). The paper presents the constructive solution, experimental data from which the characteristics of the equipment designed, carried out and tested and the general conclusions on its implementation in industrial actuator systems.

1. Introduction
Gadolinium was discovered in 1880 by Jean Charles de Marignac, who detected his oxide using spectroscopy. Gadolinium is a chemical element with the symbol Gd and atomic number 64. Complex organic and gadolini compound solutions are used as an intravenous MRI contrast agent to improve imaging in medical nuclear magnetic resonance imaging and magnetic resonance angiography (MRA) procedures. Gadolini compounds are also used to make green phosphorus for color TV tubes. Gadolinium is used in many quality assurance applications, such as line sources and calibration ghosts, to ensure that nuclear medicine imaging systems work correctly and produce useful images of radioisotope distribution in the patient's body. It is also used as a source of gamma rays in X-ray absorption measurements or in bone density assessment for osteoporosis screening, as well as in the portable lixiscope X-ray imaging system [1].

The realization of the first engines based on the conversion of helio-thermo-magneto-motors, became a reality, only in the second half of the 20th century [2] and was favored, as already mentioned, by the enhancement of magnetic materials, with Curie temperature, possible to reach even at ambient temperature (gadolinium). This advantage, combined with the possibilities of investigation in theory, opened by the theory of the finished element and the use of the calculation technique, made it possible to obtain promising results [3, 4].

The fact that gadolinium is ferromagnetic with a Curie temperature of only 294 K (21 °C) has been used to develop simple thermomagnetic motors for laboratory demonstrations [4]. They can be operated by an electric lamp or sunlight and will not work on a warm day as the material would always be above Curie temperature. Today there is a great interest in the development of non-conventional thermomagnetic systems that can use considerable heat from the exhaust gases of the internal combustion engine to generate energy. They use materials with curia temperatures much higher than gadolinium, such as iron-nickel-chrome alloys [5]. In the case of the model studied, the
A ferromagnetic material is a rotor in the form of a ring or cylinder, which moves in a magnetic field created by permanent magnets. It is heated at a time so that it passes into the state of paramagnetism when the magnetic field decreases. There is, therefore, a constant torque on the rotor that causes it to rotate. The rotor is then cooled and regains its ferromagnetism before re-entering the magnetic field [4]. In Figure 1a is presented the operating principle of an engine that can generate mechanical power 100W at 1.5 rpm.

![Figure 1](image1.jpg)

**Figure 1.** (a) Experimental model of a thermomagnetic motor; (b) Power and torque for thermomagnetic motor [4].

The problems that occur with this variant are related to the speed of heating and cooling as it cannot vary very quickly so that the speed of rotation is low (Figure 1b), usually from 0.5 to 1.5 speeds per second [4].

### 2. Description of the experimental stand

The operation of this gadolinium engine (Figure 2) is possible thanks to the system made of an assembly of two permanent magnets 6 placed in front of each other, among which passes the disc with gadolinium pills, mounted in a fixed position on the support of the aluminum radiator 1.

![Figure 2](image2.jpg)

**Figure 2.** Engine with gadolinium1 - aluminum radiator; 2 - pinion that transmits engine movements; 3 - disc of electroisolating material; 4 - gadolinium pills; 5 - the motor body; 6 - permanent magnets; 7 - permanent magnet support; 8 - electrical resistors.
The rotor, in the form of disc 3 (Figure 3), made of electro-isolating material, presents on its circumference the pills of gadolinium 4, arranged equidistantly and which are located in the magnetic field of the permanent magnets 6. The disc rotor begins to rotate when a temperature difference occurs between the cold source and the warm source, a temperature range that will include the Curie temperature of the gadolin. We will notice an increase in the speed of the gadolinium disc when the temperature varies to one of the outer or inner environments. Once the engine disc starts to rotate, the gadolinium pills enter the cooled enclosure and become ferromagnetic. From the rotational inertia of the disc and under the action of the magnetic field of the permanent magnets that attract the ferromagnetic gadolinium pills, the pills then reach the area heated by the two electrical resistors 8, which causes the pills to become paramagnetic, at which point the disc is printed a rotational impulse produced by the following gadolinium pills that have transited the cold source, making his movement continuous.

Figure 3. Experimental model of the experimental stand for the gadolinium engine: a) the rotor with gadolinium pills; b) the refrigeration system; c) general view.

For the designed, made and tested version of the gadolinium engine, an experimental stand has been developed that allows the transition of gadolinium pills on the rotor between a cold source made with a freon aggregate (refrigerator) and a warm source made with resistance powered by an adjustable source of continuous voltage.

The engine rotor (figure 3a) has gadolinium pills distributed on the circumference of the rotor to reduce the time required for the thermal exchange in the active material by decreasing the amount of heat needed to switch between the magnetic and paramagnetic states of the gadolinium pills depending on the temperature of the two media [7].

The stand produced highlights the principle of operation of engines based on thermo-magneto-mechanical conversion. It consists of the basic elements necessary for the operation of an engine in this category: the cold source, represented by the cooling system (Figure 3b), the hot source and the magnetic field source.

3. Experimental data
The built gadolinium engine was tested on the stand designed to identify the main characteristics related to speed and active mechanical torque [8].

The temperature of the environment of the two heat sources as well as the gadolinium pills on the rotor was carried out with contactless, infrared thermometers, the speed was recorded with a non-contact numerical tachogenerator and the engine torque with a torque sensor. The hot source was controlled by a variable voltage that powers electrical resistors.

Here are some experimental data relevant to the operation and operation of the gadolinium engine as follows:
• If both the cold and warm sources change their temperatures in order to widen the difference between them, a variation is obtained within wide limits of the speed, with a small slope in the first part after which the slope changes until a maximum value of 520 rpm is reached, a value which can no longer be exceeded by the change in the temperatures of the two sources (Figure 4);

• If the temperature of the hot source is the temperature of the medium (24 °C), the engine speed value has been measured at the change in the temperature of the cold source between 18 and -16 °C, with a significant increase in speed followed by a landing (Figure 5);

![Figure 4](image1.png)

**Figure 4.** Change in speed when the temperature of the cold and hot source changes.

![Figure 5](image2.png)

**Figure 5.** Change in speed when the temperature of the cold source changes.
Figure 6. Change in speed when the temperature of the hot source changes.

If the temperature of the cold source is kept constant at 18 °C and the temperature of the hot source varies in the range (24 ÷ 56) °C, a slow variation in speed tends asymptotically towards a maximum value (Figure 6).

4. Conclusions
The gadolinium drive system designed, developed and tested can be used successfully in low-speed electrical operations where two optimal heat sources are available for operation, the warm source allowing heat recovery from combustion gases or technological steam.

The adjustment of the engine speed achieved can be done by changing the temperature of one of the heat sources and ensuring an optimal transfer of heat to the rotor. The speed increase can be done by changing the temperature of the heat sources or by increasing the transfer of heat by ventilating the environment at their level.

The engine has a small size, which allows its use in narrow, high thermal flux spaces to facilitate heat transfer.

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