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Use of neodymium in passive temperature sensors

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ABSTRACT

The paper suggests the possibility of utilizing the principle of the Curie temperature for identification of increased temperatures resulting from a developing fire. The proposed temperature sensor can complement the existing fire protection system and increase its effectiveness.

Keywords - Curie temperature, neodymium, temperature sensor

I. INTRODUCTION

Neodymium magnets are currently the most powerful magnets with excellent magnetic properties, such as remanence and energy product [4]. Neodymium magnets are based on rare earth elements (lanthanides), their main components are iron (Fe), neodymium (Nd) and boron (B). Other elements are added into the final alloy, especially cobalt (Co) and dysprosium (Dy), to improve magnetic parameters (remanence, coercivity) and thermal stability (maximum working temperature) of the alloy. The working temperature of neodymium magnets is between +80 and +240°C, depending on material grade. Neodymium magnets have excellent resistance to external magnetic fields and in normal conditions retain permanent magnetic properties [2].

II. TESTING THE INFLUENCE OF TEMPERATURE ON THE MAGNETIC PROPERTIES OF NEODYMIUM MAGNETS

Prior to testing, it is important to mention the Curie-Weiss law, which says that magnetic susceptibility χ of paramagnetic material depends on its temperature, according to equation:

$$\chi = C/(T - T_c) \tag{1}$$

The test was conducted on an anisotropic neodymium block magnetized through thickness H (axially) with maximum working temperature of +80°C. The coercive force of the magnet specified by the manufacturer is determined at room temperature (20°C) in contact with a polished plate made of mild steel with a thickness of 10 mm by pulling the magnet vertically from the surface (1kg≈10N) [2].

The aim of the experiment was to verify the influence of temperature on the coercive force of a neodymium magnet. Individual test samples were gradually exposed to various temperatures ranging from +20 to +350°C and their coercive force was measured by a pull-force gauge. The measurement was performed using a test stand pictured in Fig. 2, where N is the neodymium magnet being measured and D is the contact plate.

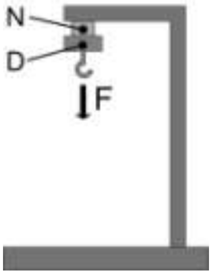

Fig.2 Measurement of coercive force of neodymium magnets

The force measured by a pull-force gauge is the sum of coercive and gravitational force, expressed as:

$$F = F_{coerc} + G \tag{2}$$

$$F = F_{coerc} + (m_N + m_D)g \tag{3}$$

It is apparent from the experiment that the coercive force of the neodymium sample decreases in proportion to the increased temperature. When the material temperature increases, each atom oscillates around its equilibrium position in the crystal lattice. The oscillation disrupts the alignment of magnetic moments' spins [1]. This implies that with increasing temperature of ferromagnetic material its magnetization decreases, as shown in Fig. 3.

The decline continues until the temperature reaches the Tc value, known as the Curie temperature, when parallel (collinear) orientation of magnetic moments is lost and they align randomly. Above the Curie temperature, the magnetic dipole moments are oriented at random, chaotically, without a preferred direction. After the ferromagnetic cools bellow the Curie temperature, its moments spontaneously align in one direction. It is a spontaneous distortion of symmetry, because the non-magnetic phase has a higher symmetry (all directions are equivalent and the field is isotropic), than magnetic (with a preferred direction of spontaneous magnetization).

Figure 3 shows the dependency of the coercive force on respective temperatures affecting the tested neodymium sample. The change in the magnetic properties of samples caused by the increased temperatures is permanent.

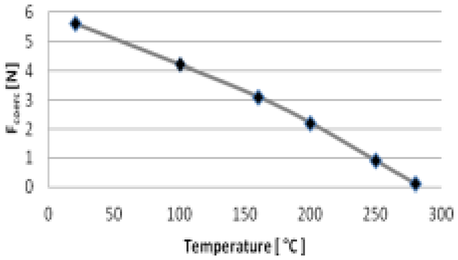

Fig. 3 Measured dependency of coercive force on the temperature of the tested neodymium sample

After verifying the magnetic properties of neodymium magnets, a solution based on the Curie temperature and Earth's gravitational field was proposed.

III. DESIGN CONCEPT OF THE TEMPERATURE SENSOR BASED ON NEODYMIUM MAGNET

The change in the magnetic properties of neodymium magnets after reaching the Curie temperature can be utilized in the design of the proposed sensor. The sensor detects the increased temperature and reacts to it by a step change, i.e., depending on the sensor structure, it will either switch the electric circuit on (Fig. 4a) or off (Fig. 4b).

The condition required for switching the electric circuit on/off is:

$$G > F_{coerc} \tag{4}$$

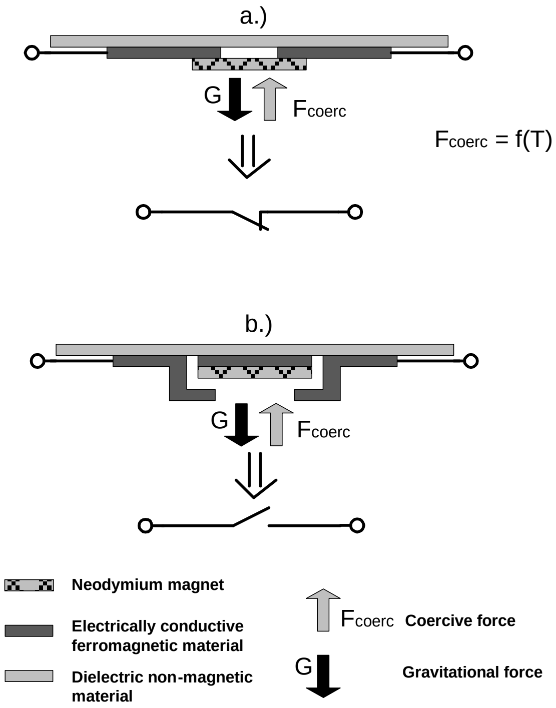

Fig. 4 Design concept of the magnetic temperature sensor

This change in the state is permanent, which means the sensor has a memory effect. The neodymium magnet of the switch has to be replaced in order to restore the function of the sensor. The value of the temperature to be detected is determined by the material properties of the neodymium magnet being used. Should the detectors of increased temperatures be used in large objects and line constructions, such as tunnels, sensors containing a higher number of neodymium magnets can be constructed (Fig. 5).

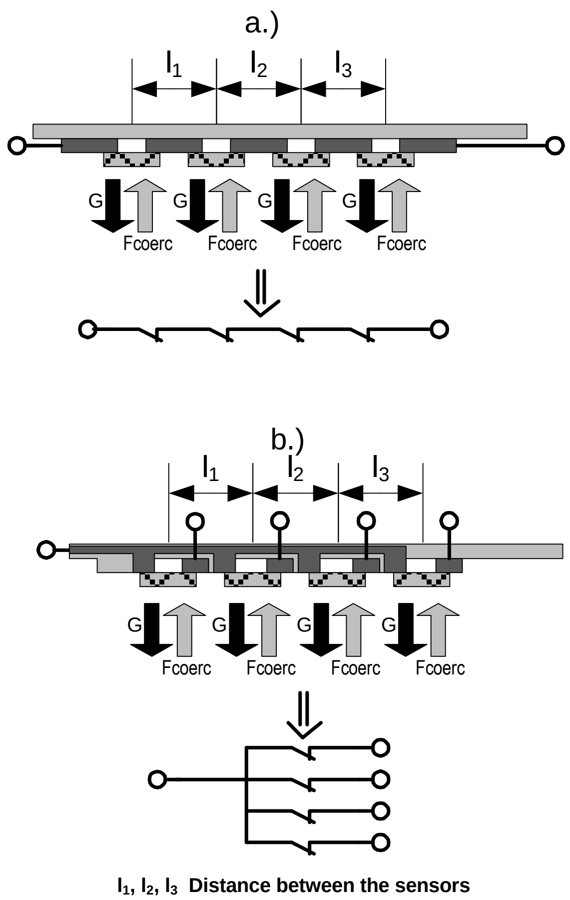

Fig. 5 Concept of the serial (a.) and parallel (b.) linear magnetic temperature sensor

IV. CONCLUSION

The paper suggests the possibility of utilizing the principle of the Curie temperature for identification of changing temperatures caused by fire. The proposed temperature sensor is based on the fact that the magnetic properties of neodymium magnets change after the Curie temperature has been reached. The sensor reacts to the increased temperature by a step change; i.e., depending on the sensor structure, it either switches the electric circuit on or off. This change in the state of the sensor is permanent, hence bringing a memory effect.

V. Acknowledgements

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