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 \( \chi \) of paramagnetic material depends on its temperature, according to equation:
\[
\chi = C/(T - T_c)
\]
(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](image)

The force measured by a pull-force gauge is the sum of coercive and gravitational force, expressed as:
\[
F = F_{\text{coerc}} + G
\]
(2)
\[
F = F_{\text{coerc}} + (m_N + m_D)g
\]
(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 \( T_c \) 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 below 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 NEOXYMIUM 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:

\[ G > F_{\text{coerc}} \] (4)

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).
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.

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REFERENCES


