A CONCEPT OF THE TEST STAND FOR MAGNETOCALORIC EFFECT INVESTIGATIONS

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1. Introduction

Magnetic cooling is a modern method of decreasing temperature using magnetocaloric effect. Compared with traditional methods, the magnetocaloric cooling is highly efficient and more environmentally friendly, hence the interest in this technology in recent years has significantly increased.

The magnetocaloric effect was first observed in 1881 by E. Warburg. He noticed that the iron sample placed in a magnetic field for a short time is warming up and after removing the magnetic field its temperature decreases [1]. Magnetocaloric effect was initially used in cryogenics for liquefaction of hydrogen and helium. The opportunity to apply this effect in refrigerators operating at room temperature occurred in 1976, when G. V. Brown built the first device. The very first magnetic refrigerator attracted great attention due to the fact that it was not using the chlorofluorocarbon gases and in consequence caused less damage to the ozone layer. A cooling material employed in the process was gadolinium. The first magnetic refrigerator enabled obtaining a temperature difference of 47 K in magnetic field induction of 7 T [2].

The magnetocaloric effect is a thermodynamic phenomenon which consist in material temperature alternations due to a cyclically variable magnetic field. An application of the magnetic field causes magnetization of the material. In the process, magnetic dipoles arrange themselves parallel to the direction of the field, the entropy of the material decreases (Fig. 1a) and the temperature rises. When the field is removed, the material is demagnetized, a disorder of the magnetic dipoles occurs, the entropy increases (Fig. 1b) and the temperature decreases. The magnetocaloric effect reaches maximum in the ferromagnetic transition temperature, the so-called Curie temperature ($T_c$).

![Fig. 1: The entropy of the material in magnetic field (a) and after removing the magnetic field (b)](image)

This paper presents the concept of the test stand to study the magnetocaloric effect in materials with a transition temperature close to room temperature (~294 K). The stand is currently under construction.

2. Test bed design

Cooling systems which operate based on the magnetocaloric effect are built out of several elementary parts: magnetic bed filled with a magnetocaloric material, magnet, heat transfer fluid system and control system. Figure 2 presents a model of the laboratory test stand. This system is modular, so any configuration...
and optimization can be easily applied. The magnetic bed is cylindrical with a diameter of 25.4 mm and is 25 mm in length. It has been filled with a magnetocaloric material – gadolinium in the form of particles with dimensions ranging from 2 to 5 mm (Fig. 3). Because of the transition temperature of 294 K and a relatively large change in entropy, gadolinium is the material most commonly used by the designers of magnetic refrigerators.

Fig. 3: Particles of gadolinium

Preliminary tests confirmed the existence of magnetocaloric effect in the employed material. Figure 4 presents images from a thermal imaging camera, when gadolinium is in the magnetic field (a) and after removing the magnetic field (b). Achieved temperature difference amounted to 2 K in the case of 0.5 T magnetic field and 3 K when the field was about 1 T.

Fig. 4: Gadolinium in the magnetic field (a) and after removing the magnetic field (b). Images from a thermal imaging camera

The so-called Halbach array [3] was used to generate a magnetic field of 1 T. This array is composed of permanent magnets that concentrate and homogenize the magnetic field entirely within the cylinder while cancelling the field on the outer side.

Heat transfer medium usually appears in the form of liquid or gas. The laboratory test stand will use a liquid medium. The system, composed of pistons connected by flexible pipes to a magnetic bed, will be employed to transfer heat. These pistons will also fulfill the function of heat exchangers – Cold Heat EXchanger (HEX) and Hot HEX.

The system will work in the AMR (Active Magnetic Regenerator) cycle. In this cycle a magnetocaloric material is not only a refrigerant, but also a regenerator. AMR refrigerator cycle consists of 4 stages [4]:

(a) Adiabatic magnetization of the magnetocaloric material, causing an increase in the temperature of magnetic bed,

(b) Isofield process in which the magnetic bed is cooled by a heat transfer fluid (blown from the Cold HEX) which absorbs heat from magnetocaloric material and expels this heat to the Hot HEX,

(c) Adiabatic demagnetization of the magnetocaloric material – magnetic bed is cooling,

(d) Isofield process in the absence of the field, when the heat transfer fluid is blown from the Hot HEX, expels heat to the magnetic bed and absorbs heat from Cold HEX.

3. Summary

In this paper a laboratory test stand to investigate the magnetocaloric effect has been described. This stand allows one to measure temperature differences in various magnetocaloric materials, regardless of their form.

4. References


