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Classification proposal for room temperature magnetic refrigerators

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ARTICLE INFO

Article history:
Received 11 August 2011
Received in revised form
3 September 2011
Accepted 24 September 2011
Available online 2 October 2011

Keywords:
Magnetic refrigerator
Regenerator
Refrigeration
Standardization

ABSTRACT

Magnetic refrigeration promises to be a breakthrough technology in the field of refrigeration at room temperature. Several magnetic refrigerator prototypes have been developed by research groups, with different embodiments and process thermodynamics. This short paper follows an idealized line connecting, from a conceptual rather than historical point of view, the different geometries, and proposes a classification based essentially on the type of magnetic source, the type of magnetocaloric material, and the relative motion of the active elements of the device. The proposed taxonomy is then applied to some prototype presented in literature, showing its potential to give a comprehensive description of magnetic refrigeration devices by means of a twelve digit string.

Proposition de classification des réfrigérateurs fonctionnant à la température ambiante

Mots clés : Froid magnétique ; Régénérateur ; Froid ; Normalization

1. Introduction

Since its early applications in the thirties (Debye, 1926 and Giacque, 1927), magnetic refrigeration systems evolved, according to both practical and theoretical constrains, to the various embodiments which characterize actual prototype scenery (see reviews by Gschneidner and Pecharsky, 2008; Yu et al., 2010; Tagliafico et al., 2010).

In view of an international standardization of room temperature magnetic refrigeration devices, it is of interest both to follow this evolution from a technical perspective and to structure it into a rational classification of actual magnetic refrigerators.

2. Active magnetic regenerative refrigerator evolution

The classification rationale will be based on a few concepts that characterize this kind of systems, that is; (i) type of

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0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2011.09.010

magnetic source, (ii) type of magnetocaloric material (MCM) and (iii) relative motion of the active material with respect to both the magnetic field and the heat transfer fluid flow.

In the following, an ideal typological evolution of active regenerated machines (AMR) is outlined, moving from the early work of Brown (1976).

Fig. 1 shows a sketch of a single effect AMR (still investigated for instance in Gao et al., 2006; Kawanami et al., 2006) based on three main components; the magnet, the active magnetocaloric material (MCM) and the intermediate fluid loop.

The four stages of the active regenerative cycle are performed moving the magnetic field up to embrace the MCM and by forcing a fluid through the regenerator with a proper synchronization with the magnetic field changes, thus achieving a refrigeration (or heat pump) effect.

The magnetization process can be accomplished in several ways, using a permanent magnet or an electromagnet, moving the magnet or the active material or, in absence of motion, by switching on and off the electromagnet.

Fig. 1 underlines these essential concepts: single effect, bi-directional (linear) field/MCM relative motion and bi-directional fluid/MCM relative motion.

Doubling the device of Fig. 1 as shown in step 1 of Fig. 2, and merging the resulting hydraulic loops (step 2), we obtain two different double effect machines having the advantage of a doubled refrigeration capacity, with the same magnetic structure and the same MCM mass, that is practically, double useful effect for the same weight and cost.

The two different devices, A and B, just realized are conceptually identical, but they can result in different systems when the relative motion between the magnetic field and the MCM is achieved by moving the MCM instead of the magnet. The actual directions of the fluid are shown to outline the need of a correct synchronization when the embodiments of Fig. 1 step 1 are merged to give the combined devices of Fig. 1 step 2. Moreover, Fig. 1 puts in evidence the temperature gradients inside the regenerators in the (pseudo) steady state regime, by means of short segments.

The synchronization criterion assures that when the MCM is subjected to the higher magnetic field it has a temperature distribution that increases inside the regenerator toward the hot side heat exchanger and the fluid moves through the AMR toward the same hot end. Conversely, changing the words "hot" and "increases" with "cold" and "decreases" respectively, the rule for MCM subjected to zero (lower) magnetic field is obtained.

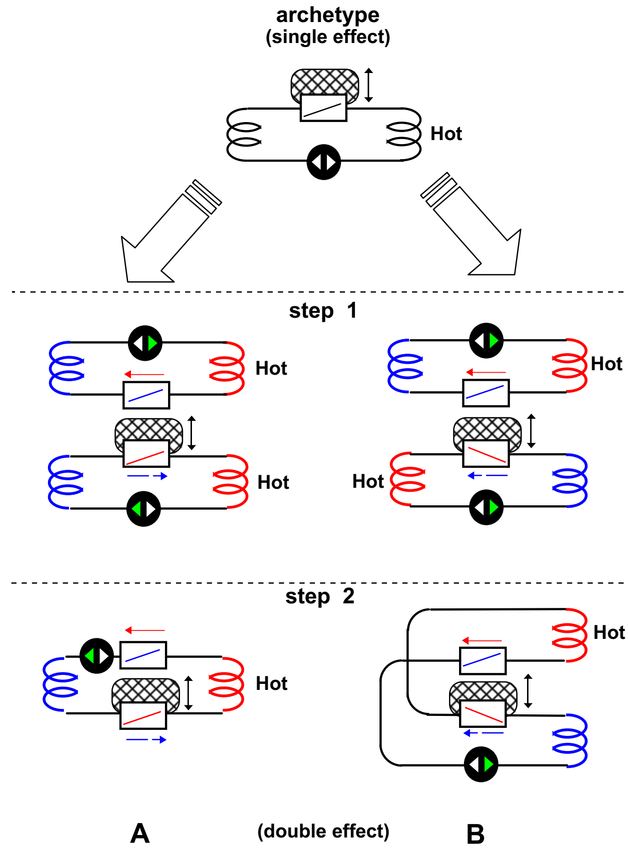

Fig. 2 – From the single to the double effect machines. Typologies A and B. The temperature distribution inside the MCM material is evidenced and the fluid flow directions are shown by arrows. Pumps with double arrows give an alternate fluid flow. A synchronization in bi-directional pulsating flow is necessary to allow the refrigerators to work properly.

Therefore as soon as the magnet moves from one MCM bed to the other (that is alternatively between the top and the bottom of each sketch), the flow inside the fluid loop must be reversed. In particular it can be noted that in the device marked "A" the temperature distributions in the two beds are "parallel", and the two MCM beds are crossed by fluid flowing in opposite directions. System "B" exhibits parallel flows, but has "non parallel" temperature distributions. These are the key aspects to understand the design developments when the

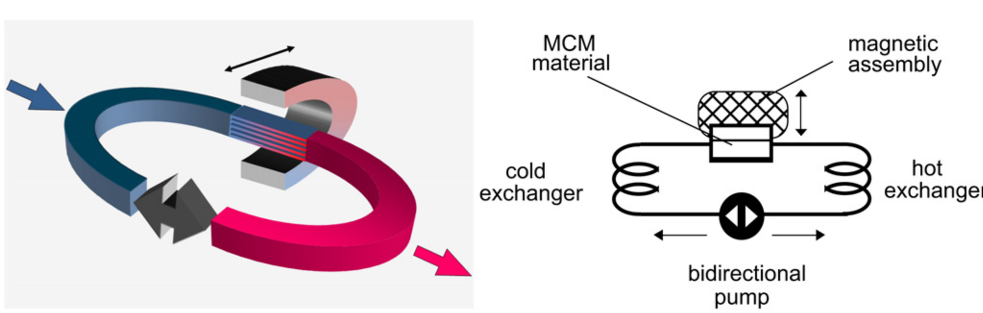

Fig. 1 – A pictorial view and a scheme of a simple single effect device with a linearly moving permanent magnet.