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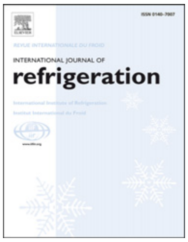

Improvement and application of a numerical model for optimizing the design of magnetic refrigerators

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ABSTRACT

Magnetocaloric systems are interesting from the point of view of energy efficiency and could be environment-friendly products. Numerous prototypes have demonstrated the feasibility of such systems for applications around room temperature, but there is still room for improvement. The research of an optimal configuration only by an experimental approach is a complex and difficult task due to numerous building parameters and driving parameters. Therefore we propose here a methodology based on a numerical approach. A numerical model calibrated with respect to experimental tests is used to make a parametric analysis of a magnetocaloric system. The design of the system is made according to given functional specifications, targeting different design strategies such as the power density, the energy efficiency, the maximizing of the temperature span, etc. This work is a step forward to the increase of the efficiency in the design of our future systems.

Amélioration et application d'un modèle numérique pour l'optimisation de la conception des réfrigérateurs magnétiques

Mots clés : Réfrigérateur magnétocalorique ; Modélisation ; Cycle thermodynamique ; Exergie ; Gadolinium

1. Introduction

Magnetic refrigeration is an innovative technology that could help to build refrigeration and heat pumping devices with high energy efficiency. This technology uses an environment-friendly coolant and could have an improved recyclability. The principle of magnetic refrigeration is based on the Magnetocaloric Effect (MCE). The MCE consists in an adiabatic temperature change (ΔT_{ad}) of the material under the effect of an applied magnetic field change. ΔT_{ad} is the highest in the vicinity of the Curie temperature (T_c) and is approximately proportional to the magnetic field change. The best Magnetocaloric Materials (MCM) currently

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Nomenclature

Symbols

B	induction (kg A^{-1} s^{-2})
C	heat capacity (J kg^{-1} K^{-1})
f	frequency (Hz)
H	magnetic field (A m^{-1})
k	thermal conductivity (W m^{-1} K^{-1})
L	AMR size (m)
M	magnetization (A m^{-1})
Q	energy density (J m^{-3})
R	ratio (–)
r	position in the space (m)
S	entropy (J kg^{-1} K^{-1})
T	temperature (K)
u	fluid velocity (m s^{-1})
x	position (m)

Abbreviations

AMR	Active Magnetic Regenerator
AMRR	Active Magnetic Regenerative Refrigeration
CHEx	Cold Heat Exchanger
COP	Coefficient of Performance
HHEx	Hot Heat Exchanger
MCE	Magnetocaloric Effect
MCM	Magnetocaloric Material

Greek symbols

Δ	difference
μ_0	vacuum magnetic permeability (V s A^{-1} m^{-1})
$\prod$	MARR cycle period (t)
ρ	density (kg m^{-3})

Subscripts

ad	adiabatic
amb	ambient
c	Curie
cold	on the cold side
d	demagnetizing
e	external
exp	experimental
f	fluid
H	magnetic field
hot	on the hot side
HT	heat transfer
i	internal
leak	leakage
MC	magnetocaloric
out	at the channels output
p	pressure
s	solid
simu	simulated
span	span between cold and hot side
visco	viscosity
vol	volumetric
x	on the *x* direction

available present a maximum adiabatic temperature change of no more than 4 [K/T] (Tishin, 2007; Dan'kov et al., 1998) that is not enough for conventional application at room temperature with magnetic field that can be obtained in industrial devices. Thus, a magnetic refrigeration device must use a regenerative process in order to increase the temperature span up to the required one for conventional applications. An Active Magnetic Regenerator (AMR) consists of a porous matrix of magnetocaloric material that is crossed by a coolant. The reciprocating motion of the fluid synchronously with the magnetic field change will create a thermal gradient covering a temperature span (ΔT_{span}) of several orders of magnitude above ΔT_{ad} (Barclay and Steyert, 1982).

Many configurations for the magnet, for the coolant circuits and the channels, and various thermodynamic cycles have been studied over the last thirty years. The most recent devices are moving towards thermodynamic cycles of Brayton over a wide temperature range in an AMR to achieve maximum performance (Gschneidner Jr. and Pecharsky, 2008) even if several designs of systems are still studied and need to be classified (Scarpa et al., 2012).

As T_c varies with the MCM, the use of giant magnetocaloric materials with different Curie temperatures adapted to the thermal gradient in an active magnetic regenerator is a key to achieve a high temperature span (Pecharsky and Gschneidner, 2006; Richard et al., 2004; Rowe and Tura, 2006). Several prototypes have demonstrated the feasibility and validity of the concept of room temperature magnetic refrigerator (Yu et al., 2010). Using Active Magnetic Regenerative Refrigeration (AMRR) cycle in a rotating system with permanent magnets seems to be a good compromise in terms of cost, feasibility and space requirement (Chen et al., 1992; Bahl et al., 2011). The research of an optimal configuration only by an experimental approach is a complex and difficult task due to numerous building parameters and driving parameters. For this purpose, several numerical models increasingly detailed have been designed to enhance our understanding of the behaviour of an AMR device. They have the drawback of requiring an increasing computational time with their complexity. A recent and extensive literature review on AMR numerical models is given by Nielsen et al. (2011). However, some analytical one-dimensional models like the one of Tagliafico et al. (2010) or most recently with Rowe (2012) or Vuarnoz and Kawanami (2012) allow to obtain a global and reliable overview of the systems behaviour in a fast and simplified manner. Moreover Engelbrecht and Bahl (2010) have also studied the effect of different magnetocaloric properties on the performances of a system through a 1D model. In this paper we present a methodology based on a numerical approach for the simulating of magnetocaloric system behaviour. This numerical model is used to make a parametric analysis of a magnetocaloric system in order to optimize its design.

2. The numerical model

2.1. Presentation

We are using our numerical model previously presented in Risser et al. (2010). This model is based on a one-dimensional