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Magnetic heat pumps – Configurable hydraulic distribution for a magnetic cooling system

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ABSTRACT

Magnetic cooling technology has experienced significant developments over the last five years. Most of the magneto-caloric prototypes use magneto-caloric alloys subject to variable magnetic field and coolant flow synchronized with the magnetisation/demagnetisation cycles. Hydraulic flow regulation has a major impact on the AMRR cycle and on the performance of the magnetic heat pump. This paper discloses a hydraulic solution implemented in a two stage linear prototype, where the volume, the flow rate and the coolant velocity can be controlled.

The dynamic sealing of the system is also described, as well as the performance of a two stage prototype integrating this hydraulic distribution solution to this first generation solution. A brief description of a third generation 'rotative' architecture is provided, with results obtained just after the last Thermag V conference.

Pompe à chaleur magnétiques – Distribution hydraulique configurable pour un système de froid magnétique

Mots clés : Pompe à chaleur magnétocalorique ; Distribution hydraulique ; Système linéaire ; Système rotatif ; Cycle magnétique régénérative actif (AMRR) ; Étanchéité dynamique

1. Introduction

A literature search reveals a large & diverse body of work available on topics such as general magneto-caloric systems (Tagliafico et al., 2011; Roudaut et al., 2011), magneto-caloric alloys (Gschneidner and Pecharsky, 1997; Tishin et al., 1999; Dan'kov et al., 1998), magneto-thermodynamic systems or related magnets (Egolf et al., 2012; Engelbrecht and Bahl, 2010) as well as various prototypes (Yu et al., 2010). It is a fact that, without this prior knowledge given through the results of numerical models (Nielsen et al., 2011; Risser et al., 2010; Tagliafico et al., 2010) as well as in experimental work (Engelbrecht et al., 2012; Tura and Rowe, 2007; Legait et al., 2014), the magneto-caloric systems could not be as advanced

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Nomenclature

Symbols

B	induction ($kg \cdot A^{-1} \cdot s^{-2}$)
b	height (m)
C	heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$)
f	frequency (Hz)
H	magnetic field ($A \cdot m^{-1}$)
h	heat exchange coefficient ($W \cdot m^{-2} \cdot K^{-1}$)
k	thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
L	AMR size (m)
M	magnetization ($A \cdot m^{-1}$)
P	Pressure (Pa)
RH	Relative humidity (%)
T	temperature (K)
u	fluid velocity ($m \cdot s^{-1}$)

Abbreviations

AMR	Active Magnetic Regenerator
AMRR	Active Magnetic Regenerative Refrigeration
COP	Coefficient of Performance
I	Inlet
MCE	Magnetocaloric Effect
MCM	Magnetocaloric Material
MHP	Magnetocaloric Heat Pump
O	Outlet

Greek symbols

Δ	difference
μ_0	vacuum magnetic permeability ($V \cdot s \cdot A^{-1} \cdot m^{-1}$)
ρ	density ($kg \cdot m^{-3}$)
μ	dynamic viscosity (Pa·s)
τ	torque (N.m)

Subscripts

C	Curie
c	consumption
p	pressure
u	useful

today. Due to the potential room for improvements, we decided to focus in our publication on the link between the elements cited above and the hydraulic flow regulation.

The impact of the hydraulic flow regulation is important in two senses; firstly, hydraulic flow is directly correlated with the cooling power level P_u, and secondly, hydraulic flow impacts on the power consumption required P_c.

Without an optimized hydraulic flow regulation and correctly managed coolant regulation, the AMRR of the Magneto-caloric Heat Pump (MHP) will not provide the expected default performance.

As efficient extraction of the cooling power from the magneto-caloric materials (MCM) is one of the key parameters of the MHPs, then the hydraulic flow regulation is equally the key to this sub-system on the MHPs.

2. Hydraulic flow regulation – principle

Hydraulic flow regulation has a critical impact on the overall MHP behaviour and performance, as the principle link between the resulting cooling and electrical power consumption. With respect to cooling power or span, this fluid link is the method used to manage the synchronised flow regulation in terms of the volume of the coolant transferred, the synchronisation determines how much of the potential energy from the magneto-caloric materials can be extracted and transferred to the heat exchangers.

Electrical power consumption is related to the internal fluid transfer; equally it affects both the MHP geometry and hydraulic circuit layout, which have significant effects on the overall performance.

It is usual to define the COP of a system as in Eq. (1):

$$COP = \frac{P_u}{P_c} \tag{1}$$

with P_u: the useful power to produce cooling or heating and,

P_c: the power consumption in the system.

This definition shows us that there are only two ways to improve the efficiency of a MHP.

One way is to increase the cooling power, and the other way is to minimize the power consumption.

In this paper we have focused especially on minimisation of the electric power consumption whatever the level of cooling power is. By minimizing the power consumption, the COP of the system will increase, for a constant value of cooling power, and this is the positive aspect, which can be use by all the scientific community interested on this emerging technology.

The main reasons conducting to electrical energy consumption are:

a) The magnetisation and the demagnetisation of the magnetocaloric materials (MCM). The energy is consumed for make the MCM getting in and getting out of the magnetic filed.
b) The heat transfer fluid flow. The energy is consumed to ensure the flow with a certain velocity in the materials and into the cold heat exchanger and hot heat exchanger.
c) The compensation of the mechanical friction force. The energy is consumed to overcome the loose by friction.

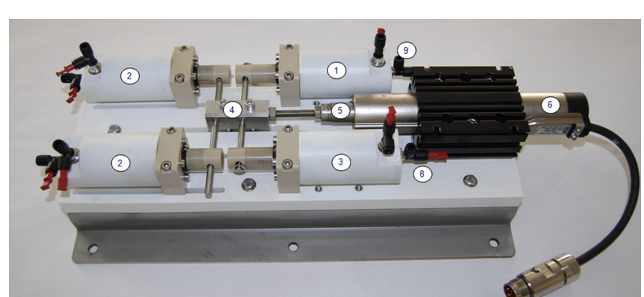

Fig. 1 – Hydraulic system with 2 × 2 pistons.