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► **To cite this version:**

Morgan Almanza, W Cherief, A. Kedous-Lebouc. Dynamic Temperature Measurement for Magnetocaloric Materials. 7th International Conference on Magnetic Refrigeration at Room Temperature (Thermag VII), Sep 2016, Turin, Italy. pp.11 - 14. hal-01674289

**HAL Id: hal-01674289**

**<https://hal.science/hal-01674289>**

Submitted on 2 Jan 2018

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# DYNAMIC TEMPERATURE MEASUREMENT FOR MAGNETOCALORIC MATERIALS

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## ABSTRACT

A device to measure the dynamic response of magnetocaloric effect in terms of temperature change at different speed and up to  $1 T.ms^{-1}$  has been developed. The magnetic source is based on rotating magnets and the temperature measurement on thermocouple. This prototype will be able to explore the dynamic response of magnetocaloric effect under controlled temperature for different type of material: first order and second order phase transition material.

**Keywords:** dynamic response, magnetocaloric effect, temperature measurement, thermocouple, magnetic source.

## 1. INTRODUCTION

Assuming that heat exchange can be improved, increasing the operating frequency is a key solution to achieve high cooling power density. Because at each cycle the heat  $Q_{cold}$  [J] is taken at the cold reservoir, when the number of cycle per second, i.e. the frequency, increases, the cold power linearly increases with the frequency [1]. Currently, almost devices run around few Hertz, some prototypes [2] were designed to go up to 10 Hz but higher frequency could be investigated in the future and therefore a better knowledge of the magnetocaloric material (MCM) behavior under dynamic excitation will be required.

At G2Elab, a dedicated characterization device is under development to measure the adiabatic temperature change  $\Delta T_{adia}$  as a function of the field level  $H_a$ , its rate of time variation  $dH_a/dt$  and temperature  $T$ . It will be also used to study the time relaxation and hysteresis of the transition [3], [6] and to cycle the material in order to study its ageing. It is designed to explore dynamics up to  $1 T.ms^{-1}$  and cycling up to 300 Hz. In this paper, we describe the system and preliminary measurements obtained for second order phase transition (MCM). Section 2 describes the experimental set up used to produce a rotating magnetic field. The methodology for temperature measurement and the first results obtained are provided in section 3. While 4 presents the conclusions and future works.

## 2. MAGNETIC SOURCE

The magnetic source is based on spinning magnets where a tunable air gap controls the applied field applied from 0.2 T to 1.2 T, as shown in Figure 1 and Figure 2. The rotational angle defines the magnetic field, as illustrated in the Figure 1, therefore by controlling the rotational speed from 0 to 10000 rpm the magnetic field sweep rate is controlled from 0 to  $1 T.ms^{-1}$ . Systems as [4], [5] used linear configuration but the field rising time is smaller compared to the  $1 T.ms^{-1}$  reached by this device. However recent work [6] using superconductors reaches  $1.5 T.ms^{-1}$  for a field of 10 T. To minimize the effect of the demagnetizing field the samples are elongated, being 10 mm long and 1 mm wide. In this study we consider a 2 mm thick Gadolinium sample. This leads to a demagnetizing factor of around 0.05. In this study the fixed air gap is 15 mm and the applied field is 0.9 T.

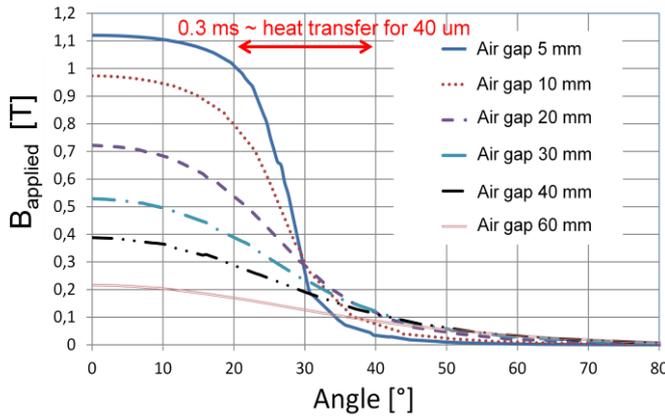


Figure 1 Experimental setup and magnetic field level evaluated with simulation in the air gap for different configurations as a function of the rotation angle

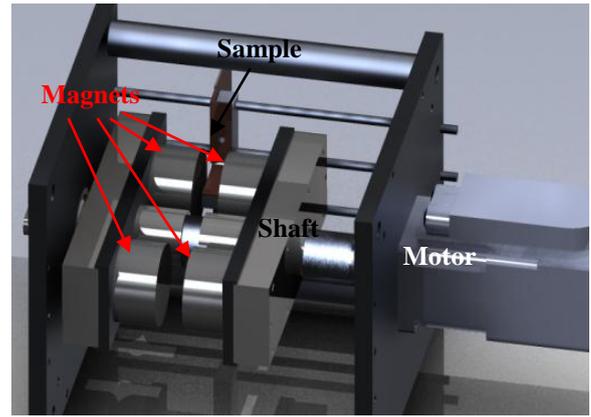


Figure 2 Magnetic field source with the magnets, the motor, the sample holder

### 3. TEMPERATURE MEASUREMENT

The main difficulty is to measure the temperature at high field sweep rates of up to 10 kHz and sufficiently high precision of 0.1 K. Conventional approaches involve gluing or welding the Copper/Constantan junction [2] or the thermistor [3] on to the sample (MCM). Here, this is accomplished using a thermocouple junction that closes via its mechanical contact with the MCM sample itself (Figure 3, Figure 4).

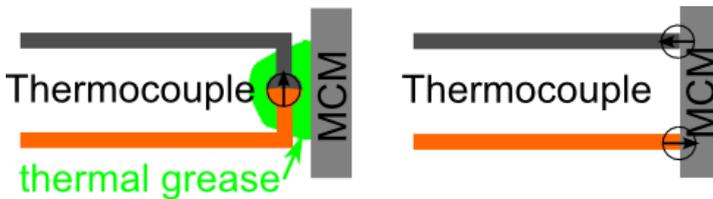


Figure 3 Connection of the thermocouple: Left) with thermal grease, Right) mechanical contact.

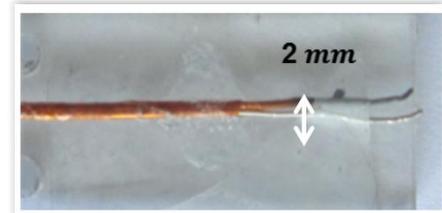


Figure 4 Thermocouple used.

Even though this method is sensitive to oxidation and the quality of mechanical contact, it has fulfilled the bandwidth needed. Because the Seebeck measured voltage comes from the temperature at successive junctions, here especially the copper/MCM and MCM/constantan junctions, the thermal exchange through the glue is no longer needed, as illustrated on Figure 3 and Figure 4. An example of measurement is shown in Figure 5. At low speed, we measure the voltage of the thermocouple and using the thermocouple relation of  $40 \mu\text{V} \cdot \text{K}^{-1}$ , we obtained as expected 1.25 K in the Gadolinium (Figure 5).

The high speed temperature change involves an adiabatic transformation, because at 400 rpm a complete magnetization needs of time length of respectively 0.15 seconds (Figure 1), while the diffusivity of Gd and Plexiglas, material of the sample holder are respectively around 4.5 and  $0.1 \text{ mm}^2 \cdot \text{s}^{-1}$ . Accordingly in the Figure 5, we have a small temperature change during the magnetization and the demagnetization states because of a heat exchange.

However, this method has low sensitivity because of the small detected signal of  $40 \mu\text{V} \cdot \text{K}^{-1}$ , the background noise of  $10 \mu\text{V}$  and the induced voltage due to a strong time variation of the magnetic field. Despite geometry efforts to minimize the loop generated by the wires, the induced voltage is around  $150 \mu\text{V}$  for a rotational speed of 2000 rpm, as illustrated in Figure 7.

To overcome the undesired effect of the induced voltage in the thermocouple, clockwise (CLW) and anticlockwise (ACLW) measurements are investigated, rotating the system at the exact speed but in the two opposite ways, e.g. +400 rpm vs -400 rpm. In fact, in that cases, as measurements are perfectly synchronized

with the rotational angle, the detected signals have symmetries. Figure 6 illustrates this clearly for 400 and 2000 rpm rotation speeds. So by averaging the CLW and ACLW signals, we can extract the time evolution of the EMC. Figure 8 shows that results are independent of the magnetic field direction which is characterizing the EMC property.

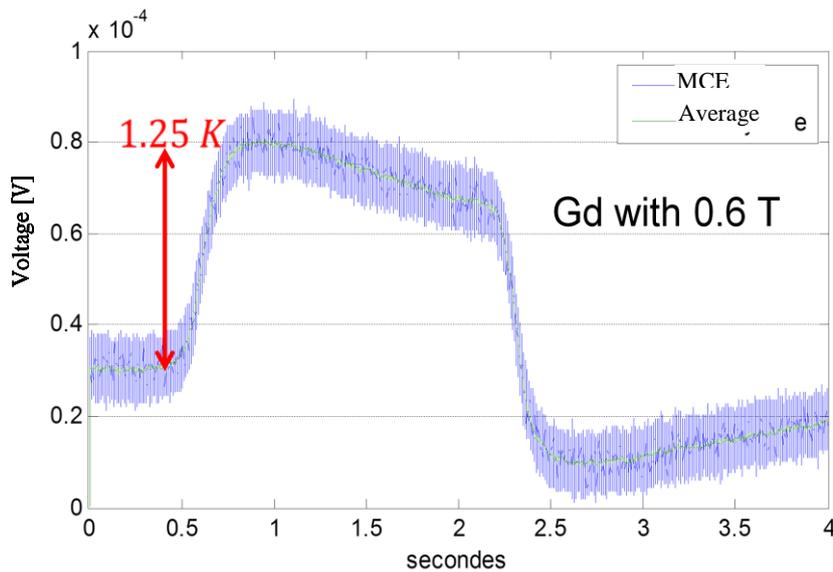


Figure 5 Example of measurement at low speed.

It is surprising that the values of the first measurement (Figure 5) at low speed are different from the ones at higher speed (Figure 7). But those experiments have been made at different times, therefore it could come from the sample. But other explanations could be appropriate as: the heterogeneity of the field inside the sample for different frequencies, different placement of the thermal thermocouple junction or different average temperature of the sample.

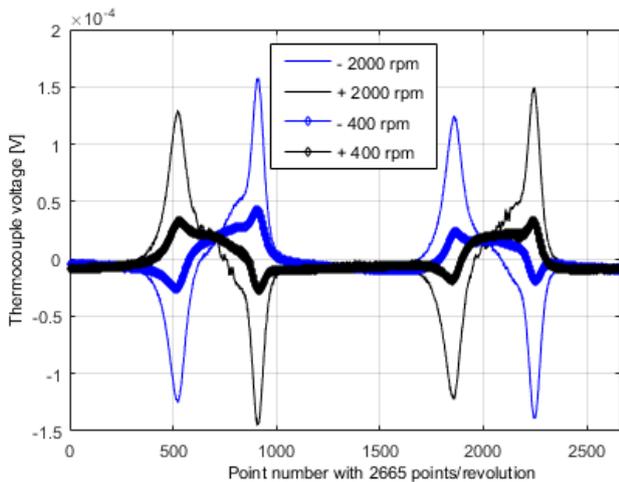


Figure 6 Thermocouple voltage for different rotational speeds.

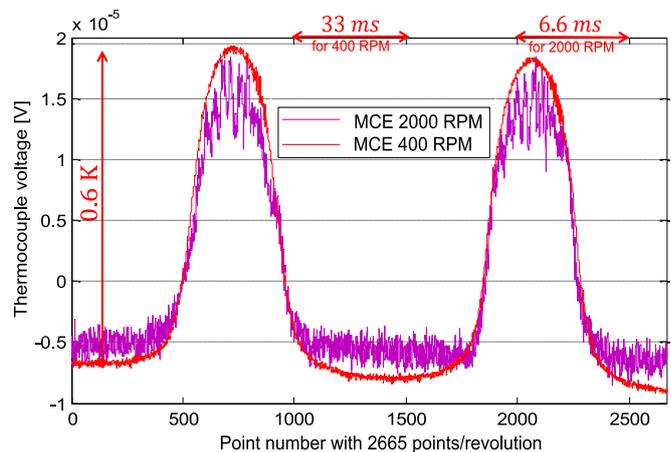


Figure 7 Thermocouple voltage function of the position of the rotor for different speeds with Gd.

The control of the average temperature, currently done with air flow, will be improved by Peltier cell, as shown in the Figure 8.

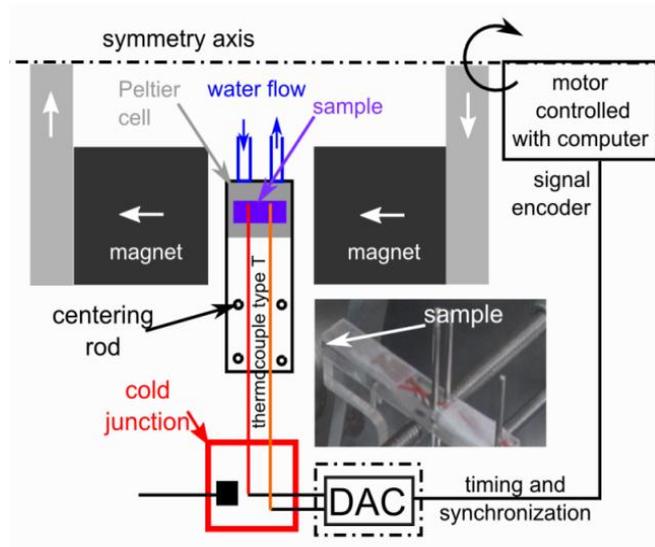


Figure 8 Synoptic of the system with the control of temperature.

#### 4. CONCLUSIONS

A prototype to measure high dynamic response of the magnetocaloric temperature change is proposed. The magnetic source uses rotating magnets while the temperature measurement uses open junction thermocouple. Using superposition of clockwise and anticlockwise measurement, the effect of the induced voltage in the thermocouple is removed. However, experimental investigations have shown dependence respect to the speed of rotation, contrary to the results expected on Gadolinium at our frequencies. Although possible explanations have been raised as the heterogeneity of the field at high frequency, further measurement using different MCM and different shapes are needed to conclude.

#### ACKNOWLEDGMENTS

The authors are grateful to the French ANR-MagCool.

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