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Design and development of a demonstration unit for the magnetic refrigeration system

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Abstract. Due to global warming and ozone depleting concerns of current refrigerants in the vapour compression refrigeration system, it is importation to find alternative refrigeration system or not-in-kind technology. One of the promising systems is the active magnetic regenerative (AMR) refrigeration system or simply called magnetic refrigeration system. In order to understand better the magnetic refrigeration system, the demonstration unit is required. This paper presents the design and development of a demonstration unit for the magnetic refrigeration system. The two dimensional magnetic flux is simulated by Maxwell SV computer program. The demonstration unit consists of a set of permanent magnets driven by a motor, a set of regenerator containing Gadolinium and a set of water/ethylene glycol system.

1. Introduction

Typical refrigerants used in common vapour-compression refrigeration systems are well known for environmental impact (i.e. ozone depleting or global warming impact) and are gradually phased out by Montreal Protocol or Kyoto Protocol. Many alternative refrigerants have been proposed, however, they may rise another concern of their flammability. Apart from searching for new refrigerants, alternative systems or not-in-kind technologies are studied.

Magnetic refrigeration is an emerging technology to replace the vapour-compression system [1]. Its principle is based on the magnetocaloric effect (MCE), e.g. the adiabatic temperature change due to a varying magnetic field [2] that is ocurring in magnetocaloric materials (MCM). If a solid refrigerant (MCM) is used, an impact on the atmosphere can be completely avoided [3].

For near-room temperature application, permanent magnets are more applicable, due to its compactness. Though the adiabatic temperature differences in magnetic materials found are not strong enough for the required near-room temperature applications, the temperature span can be increased by applying a regenerative thermodynamic process. A system applying this method is generally named active magnetic regenerator (AMR) refrigeration system [4]. There are four main processes in AMR: magnetization, hot blow, demagnetization and cold blow [5]. The performance of the AMR system depends on various parameters such as materials, fluids, design and the operation characteristics [6]. To educate engineering students regarding to new technology, therefore, the demonstration unit is required.

The objective of this paper is to present the design and development of a demonstration unit for the magnetic refrigeration system.

2. Design a set of permanent magnet

The magnets selected here are permanent magnets because it is feasible for refrigeration application. Two dimensional magnetic flux is simulated by Maxwell SV computer program, developed by ANSOFT Corporation. The formulations are based on the Maxwell's Equations and the simulation technique applied is the Finite Element Method by computing as magnetostatic vector potentials. Type of the magnet used is NdFeB, N35 grade with 500 mT surface flux. Each magnet has a cubic shape of 30 mm ×30 mm×30 mm. Three sets of assembly are simulated by Maxwell SV program. Set A: one magnet on the top and another one at the bottom of the regenerator. Set B: two magnets on the top and other two at the bottom of the regenerator. Set C: three magnets on the top and other three at the bottom of the regenerator.

Figures 1-3 show the magnetic flux density simulated by Maxwell SV with the solver residual of 1×10^{-5} and percent error of 1×10^{-3}. In the figures, the white squares are permanent magnets, while the white rectangles are the soft magnetic material; in this case, it is iron. The arrows represent the north pole of the permanent magnets.

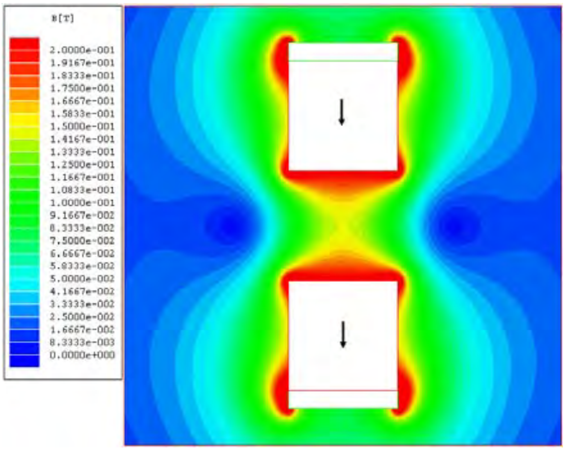

Figure 1 The magnetic flux density of Set A

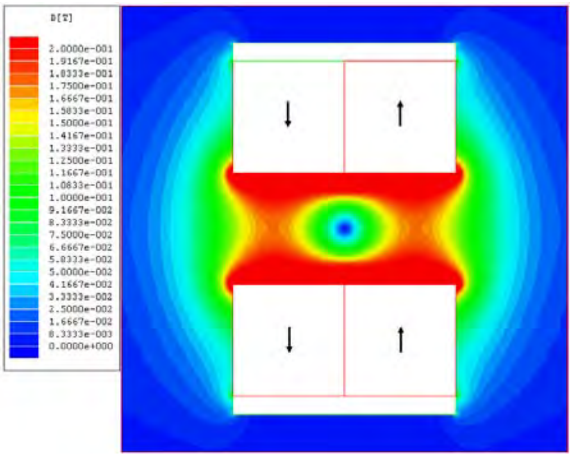

Figure 2 The magnetic flux density of Set B

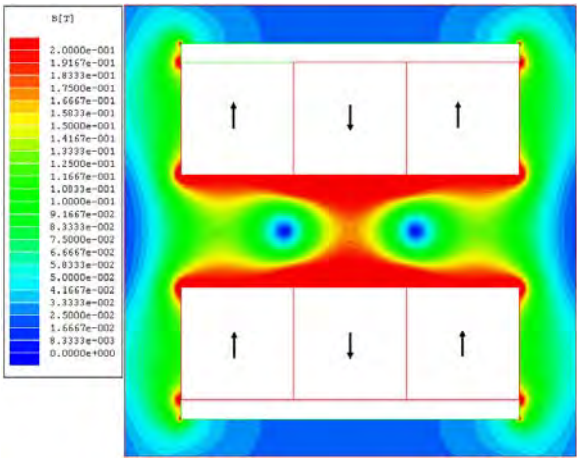

Figure 3 The magnetic flux density of Set C

It is seen from Figure 2 that there is a neutral point at the center of operating area, in which the regenerator is installed. Thus, this design is not considered to use in this experiment. For Set C, there are two neutral points occurring between the center of operating area. The magnetic flux density at the center is about 0.167T. Comparison between Set A and Set C, it shows that set A provide magnetic flux density of 0.16T at the center and it increases when approaching the magnet. However, considering the area around the center (the location of the regenerator) in Set A and Set C, it is founded that the magnetic flux density in Set C is averagely higher than that in Set A. Therefore the demonstration unit will use Set C.

A further discussion about the magnet assembly should be done here. In Figure 4, it displays the magnetic flux density of magnets arranged following Halbach array principle. It is clearly observed that the magnetic flux density in regenerator varies between 0.250-0.288 T (see the legend scale), which is higher than those of other previous cases. Moreover, the neutral points shift away from the center, when compared with Set C. However, in our practice without a rigid holder, when trying to arrange magnets in Halbach array, the side magnets were not stable then caused serious impact of magnets, as a result were cracked. Therefore, in this article, the authors selected Set C arrangement (Figure 2) to use in this demonstration unit.

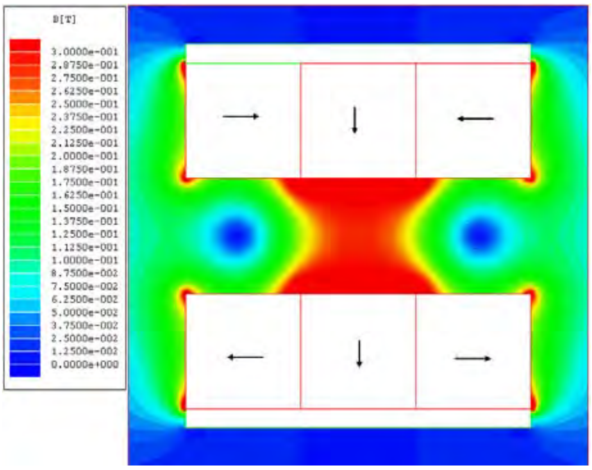

Figure 4 The magnetic flux density of Halbach array

3. Development of a demonstration unit

The main components for the present demonstration unit are an assembly of permanent magnets (Figure 5), a set of regenerator containing magnetocaloric material (Figure 6) and a motor controlling the linear movement of the magnet assembly (as seen in the demonstration unit shown in Figure 7).

The permanent magnets in Figure 5 are assembled according to Set C (or Figure 3 in the previous section). As earlier described, each magnet has surface flux of 0.5 T. Nevertheless, the magnetic flux obtained in the regenerator is expected to be smaller than 0.5 T, based on the simulation results it is about 0.16 T in the regenerator area. This flux is enough for demonstration purpose.

The magnetocaloric material used is Gadolinium ingot (purity of 99.99%) with various sizes roughly from 12×7×3 mm to 11×13×9 mm and total mass of 90 g. In fact, the size of Gd should be small as possible. However, due to its flammability and complicated fabrication, at the present stage, we select those available from the supplier without further fabrication. Therefore the total weight of 90 g is simply from those available sizes for the current regenerator. Undoubtedly, the present regenerator should be redesign in shape or dimension for certain amount of magnetocaloric material and in fluid flow path to improve the utilization of magnetocaloric effect and heat transfer process.

A 1 horsepower servo motor is used for the present unit. This unit can be used with or without heat transfer fluid, when applying the fluid, we suggest usage of distilled water/ethylene glycol with at least 20 percent weight of ethylene glycol in order to avoid serious corrosions of Gd which can be easily corroded in water. From our experiment (not shown here) even with the distilled water with ethylene glycol of 67/33 percent weight, the slight corrosion of Gd is still observed. One of the probable reasons is that in the present demonstration unit, the heat transfer fluid system is an open system. The corrosion should be minimized if the fluid part is operated as the close system.

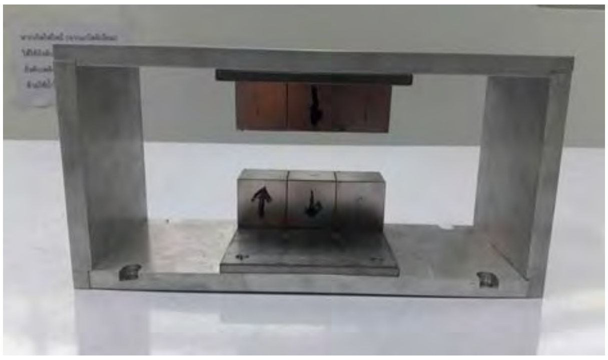

Fig.5 The magnet assembly (according to set C simulation as in Fig.3 in previous section)

Fig.6 The regenerator with Gadolinium

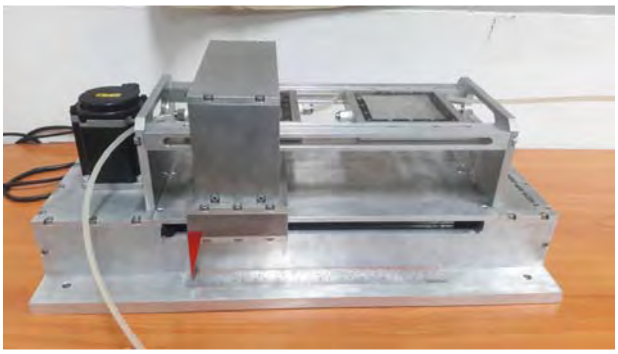

Fig.7 The motor (left) with the moving magnet assembly (middle) and the stable regenerator (right).

4. Conclusion and outlook

The demonstration unit for preliminary study of magnetic refrigeration is presented. The design of magnetic flux by Maxwell SV assures the desirable magnetic flux area for this magnetic refrigeration application. Further improvements are required in the design of the regenerator, the fluid system, and the length of magnet movement.

Acknowledgement

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References

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