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# DESIGN AND INITIAL TESTING OF A COMPACT AND EFFICIENT ROTARY AMR PROTOTYPE

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ABSTRACT — MAGGIE, a new AMR prototype, is presented. It has been designed to produce a temperature span and cooling power relevant to commercial refrigeration applications combined with an attractive COP and a compact design. Concepts and design considerations are described. Initial non optimized tests show a COP of 3.6 at a temperature span of 7.2K with 103 W of cooling power.

## 1. INTRODUCTION

An increasing number of magnetocaloric devices and prototypes showing promising results have been developed during the recent years. However, significant challenges still need to be overcome before the technology can be a competitive alternative to conventional vapor compression, one of the most important being the ability to exploit the potential for high efficiency. The presented prototype is intended to take a step in this direction and it has been designed primarily with the experience from our previous prototypes [1,2] as a starting point. A thorough investigation of the most recent machine has identified heat leaks to surroundings and friction losses in the fluid handling system as main issues limiting the COP of the system [2]. Bringing these losses down has therefore been a main focus point in the design of the presented prototype.

## 2. DESIGN

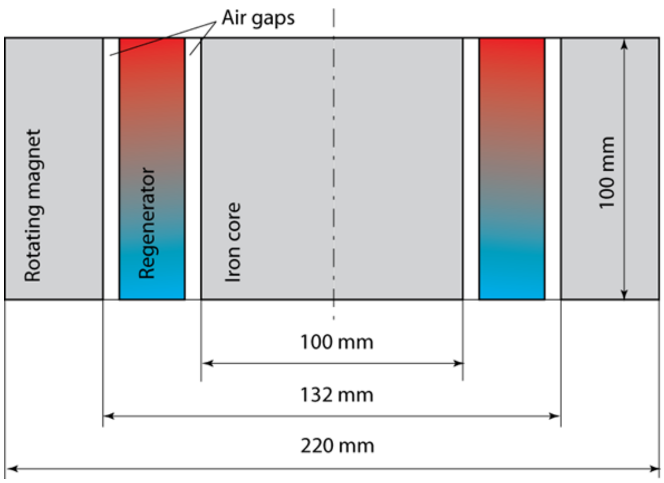
*Overall concepts and design*

The presented machine consists of a stationary cylindrical regenerator compartmentalized with eleven beds filled with spheres between 0.3 and 0.6 mm of different amounts of commercial grade Gd and GdY alloys with a total mass of 1.7 kg. This graded regenerator is designed to operate within a temperature range between 273 K and 308 K and the materials have Curie temperatures of 272 K, 283 K, 287 K and 291 K respectively. The housing of the regenerator consists of two concentric non-magnetic stainless steel cylinders with a thickness of 0.5 mm. The compartments are separated by 0.5 mm walls made of glass fiber reinforced epoxy to eliminate eddy currents. The thin shell structure leaves a maximized fraction of the magnetized volume available for the actual magnetocaloric material (MCM) while providing adequate mechanical strength for the expected operating pressures. It also ensures low magnetic torque fluctuations when the regenerator is placed in a time varying magnetic field. The regenerator is surrounded by a rotating Halbach-like magnet assembly containing 1.5 liters of NdFeB permanent magnet with a stationary iron core in the middle giving a field which is alternating between 0 T and 1.13 T in two low/high field regions. The iron core is laminated in the axial direction to minimize eddy currents. In the future a new iron core will be installed allowing the magnet system to reach 1.4 T. The magnet is rotated by a brushless DC motor with a gearbox and a spur gear transmission giving a maximum operating frequency of around 4 Hz in the current configuration. A flow handling system is built around the regenerator ensuring a unidirectional flow in the external flow system. The flow profiles have been carefully designed together with the magnet system based on 3D numerical simulations of the magnetic field and 2D AMR simulations taking the time varying non-homogenous field in the beds into account [3].

Fig. 1. MAGGIE. Rotating cylinder containing magnet, regenerator and flow handling system.

*Regenerator heat leak and COP*

Special attention has been given to reduce heat leakage into the regenerator from its surroundings. Through modeling and analytical calculations this heat transfer is seen to be dominated by radial conduction. Consequently, when designing for high COP, it can be desirable to have a certain thickness of the air gaps between the regenerator housing and the magnet/iron core that act as insulation, even though they reduce the magnetized volume available for MCM. Fig. 2 shows a sketch of the regenerator situated between the magnet and iron core with air gaps. A calculated COP is plotted as a function of the thickness of these gaps. This is done using a 1D numerical AMR model [4] and heat leaks estimated by analytical calculations are simply subtracted from the predicted cooling power when post calculating the COP. The results clearly indicate that a significant increase in COP can be achieved by increasing the air gap up to a certain limit, especially when the machine is absorbing a lower cooling power. Based on these considerations, an air gap of 2 mm has been chosen. Avoiding a narrow gap between parts rotating relative to one another is furthermore an advantage from a manufacturing cost standpoint as it reduces the necessary tolerance demands for part machining and assembly.



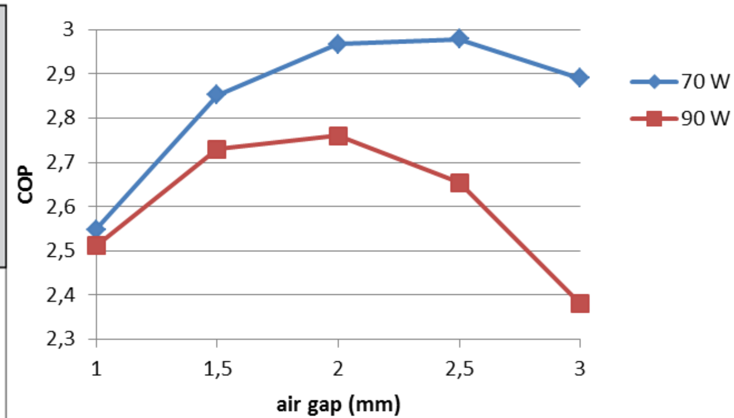




Fig. 2. Regeneator between iron core and rotating magnet. Calculated COP as a function of air gap taking radial heat losses into account for 70 W and 90 W cooling power.

## 3. SYSTEM CONSTRUCTION AND INTITIAL TESTS

At the time of writing the construction of MAGGIE is just being finalized and the first preliminary experiments are being carried out. The actual machine shown in Fig. 1 containing regenerator, magnet and valves is surrounded by an external flow circuit with a continuous unidirectional flow. The hoses coming out of the top deliver fluid in and out of each bed at the hot side of the regenerator. It is pumped through a heat exchanger connected to a chiller to reject heat and control the hot side temperature. On the cold side of the regenerator the flow is collected in a compact manifold and sent through an electrical resistance heater simulating a thermal load. This cold side installation will be fully encapsulated in an insulated box for final testing.

Power input to the motor and rotational frequency is controlled and monitored using a PC. Pressure drop over the regenerator and valve system, volumetric flow rate and temperatures in and out of the regenerator are measured and logged as a function of time.

A preliminary experimental result shows a COP of 3.6 (9.1% of Carnot) at a cooling load of 103 W with a temperature span of 7.2 K. The COP is calculated as the power supplied to the heater divided by the sum of the power supplied to the motor and the flow rate times the pressure drop over regenerator and valve system. This result is obtained before the insulation of the cold side of the machine is completed, without an improved magnet and without final adjustment of the flow handling system. This is expected to increase the performance significantly as initial tests show a strong response to such adjustments.

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