Active magnetic regenerator refrigeration with rotary multi-bed technology

Magnetic refrigeration is an emerging cooling technology with potential advantages over conventional vapor compression, the most important being higher efficiency. This thesis presents experimental and theoretical research into the possibilities of realizing this potential with actual active magnetic regenerator (AMR) prototypes. The starting point is the design and experiments with a rotary multi-bed prototype at the Technical University of Denmark. Promising results were obtained with this machine in terms of temperature span and cooling power. However, issues limiting the energy efficiency, mainly relating to heat leaks and flow system friction losses, have given rise to new ideas for taking the technology a step further. On this background, a second generation multi-bed prototype was designed, built and used in experimental investigations.

A central feature of the new prototype is a novel system for handling the heat transfer fluid, providing a reciprocating flow inside the AMR beds while ensuring a continuous unidirectional flow in the surrounding flow circuit, communicating with the hot and cold reservoirs. With this system it is possible, via an arrangement of poppet valves and check valves, to control the flow rate versus rotational angle of the magnet system providing a time varying magnetic field in the beds with very minor losses compared to more traditional rotary valve based systems. Numerical AMR modeling capturing the variations in the azimuthal direction inside the beds has been used to investigate the effect of the shape of this flow profile, which confirms the importance of carefully optimizing it for the desired operating conditions.

Numerical modeling and heat transfer calculations addressing heat leaks through the walls of the regenerator housing has revealed a necessary trade-off between the amount of magnetocaloric material and an insulating air gap in the magnetized volume provided by the Halbach-like cylindrical permanent magnet system, when designing for high efficiency rather than maximum cooling power. The central part of the magnet system is a flux conducting iron core which was laminated for electrical and thermal insulation to minimize heat leaks and eddy current losses. Experimental investigations with different configurations of iron and insulation in the core focusing on the impact on temperature span and COP were conducted.

AMR experiments with the new prototype revealed strong impacts on COP and cooling power by minor adjustments of the individual valves controlling the flow in each bed. This effect, inherent to rotary multibed AMRs, is addressed with a numerical modeling approach and confirmed experimentally with the new prototype by carefully evening out the variations by the means of needle valves. An experimental performance analysis of the new prototype was carried out. A breakdown of the losses indicate pressure drop in external components and regenerator losses as the main contributors to entropy generation. While the former may be reduced by simple design improvements, the latter is non-trivial and requires detailed geometrical optimization assisted by numerical modeling and improved manufacturing techniques. Finally, possible applications are discussed and a concept of operating the AMR machine in combination with a thermal storage is introduced and demonstrated experimentally. Furthermore, a novel shunt valve technology, which was developed as a spin-off from the magnetic refrigeration research, is presented.

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