ELASTOCALORIC SYSTEMS
EFFICIENT COOLING SYSTEMS WITHOUT THE NEED FOR HARMFUL REFRIGERANTS

Cooling systems available on the market today are based almost exclusively on compressors. However, for efficient operation, the technology relies on refrigerants that are harmful to the environment or to health and sometimes even flammable or explosive. New EU regulations are increasingly restricting the use of such harmful refrigerants. Innovative cooling concepts are therefore in urgent demand for many areas of application.

Solid-state cooling systems based on caloric materials are widely regarded as a promising alternative to compressor technology. In the steadily growing global refrigeration market, they could prove to be an environmentally friendly alternative. Fraunhofer IPM develops elastocaloric cooling systems. In these systems, an innovative heat transfer concept makes a decisive contribution to efficiency.

Principle of the elastocaloric cooling cycle

Elastocaloric cooling systems use the shape memory effect of certain metals to induce a reversible temperature change through the application of force. In elastocaloric (EC) materials, mechanical pressure causes a crystalline phase transformation, which heats up the material from the initial temperature $T_0$ to $T_0 + \Delta T$. The heat generated is transferred to a heat sink and the temperature of the material drops back to the initial temperature $T_0$. When the mechanical stress is removed, the material cools to a temperature below the initial level ($T_0 - \Delta T$). On placing the material in contact with an object that needs to be cooled, it absorbs heat until the initial temperature is reached. By repeatedly exerting stress...
on the material and then releasing it, and combining this with an appropriate means of heat transfer, a cooling cycle can be established. Shape-memory alloys such as the commercially available nickel-titanium alloy Nitinol are among the materials with a distinct elastocaloric effect that enables a large temperature rise. In an experimental setup, scientists at Fraunhofer IPM achieved a temperature difference of 15 K when applying a pressure of 750 MPa to Nitinol rods.

**Passive heat transfer for higher efficiency**

The heat transfer between the EC material and the heat exchanger unit determines the overall efficiency of the elastocaloric cooling system. In conventional systems, heat transfer is achieved by actively pumping a fluid, which limits the cycle frequency of the system to just a few Hertz. Fraunhofer IPM relies on a passive approach of latent heat transfer, a concept also used in heat pipes and thermosiphons. Here, heat is transferred by evaporating and condensing a fluid, e.g. water or ethanol. The fluid is contained in a hermetically sealed tube that is free from all non-condensing gases, and is present in both liquid and gaseous form. The heat transfer coefficient reaches values of up to 100 kW/(m²*K), and is therefore many orders of magnitude higher than that achieved using classical system concepts.

In an elastocaloric cooling system, individual elastocaloric segments, designed as thermal diodes, are connected in series. This way, heat is transported segment by segment in a single direction, and one side of each segment is cooled while the other is heated. Heat transfer from one segment to the next is carried out within milliseconds, so that the system can be operated with a frequency of over 10 Hz. Combining latent heat transfer and thermal diodes in a patented system concept enables enhanced pump performance and high efficiency of the overall system.

**Functioning principle of an elastocaloric segment**

(a) The material is compressed and heats up, the liquid present evaporates.
(b) The vapor pressure in the segment rises, the valve to the right opens, the gaseous fluid escapes and transfers latent heat to the next segment.
(c) The external force is removed, the EC material cools.
(d) The vapor pressure falls and a vacuum develops in relation to the previous segment. Gaseous fluid flows in and heat from the previous segment is absorbed.