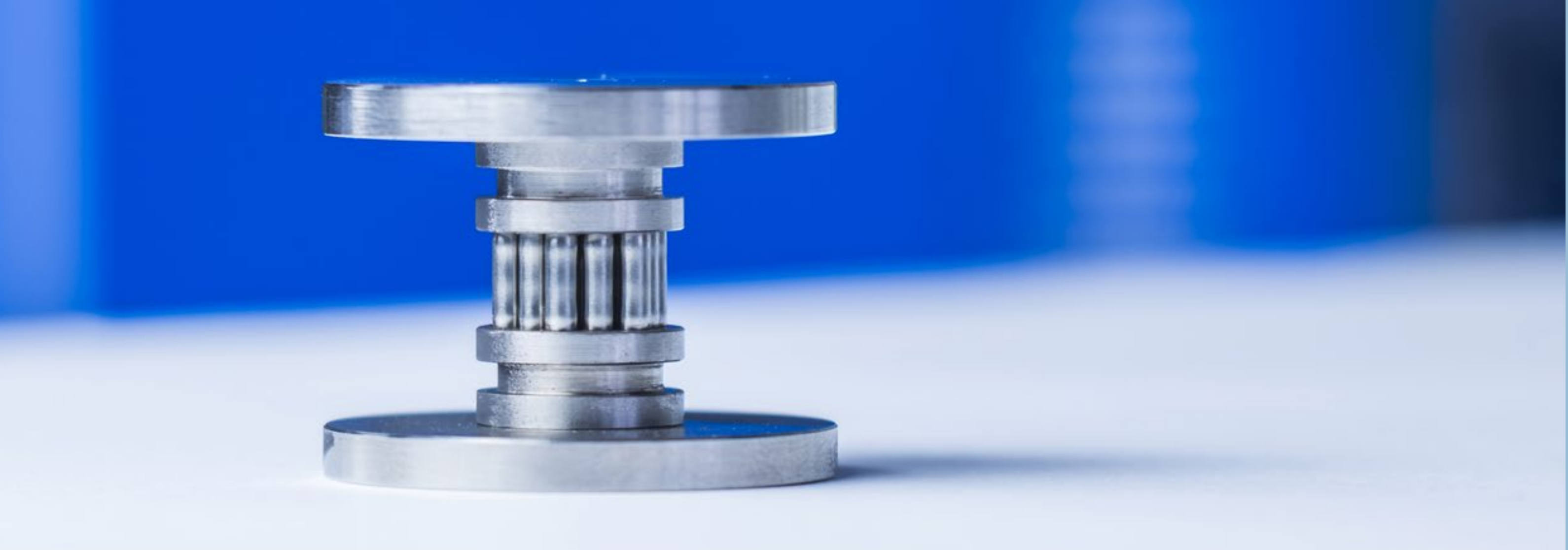

< For cooling, Fraunhofer IPM relies on pressure-based elastocaloric systems, which prove to be particularly stable in the long term.

GROUP **CALORIC SYSTEMS**

Small fridge, big potential: Cooling with elastocaloric materials

For some years now, scientists at Fraunhofer IPM have been researching solid-state cooling technologies. And their research has yielded success. At the cooling technology trade fair Chillventa 2018, the team presented the world's first mini refrigerator operated with the assistance of an elastocaloric cooling system.

Solid-state heat pumps using caloric materials may one day be able to replace the compressors commonly used in cooling technology today. This is because caloric cooling systems have two big advantages: They may be more efficient than compressors and they operate without harmful refrigerants.

The elastocaloric cooling principle

When tensile force or pressure is exerted on elastocaloric materials, a crystalline phase change takes place in which they are heated 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 returns to the temperature T_0. If 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 is formed. Such an elastocaloric cooling system was constructed at Fraunhofer IPM and has now surpassed the three million cycle mark for the first time – an important step toward long-term stability and thus toward marketability. The benchmark for potential commercialization lies at around three billion cycles. When we consider the operating principle of elastocaloric systems, it is obvious why this presents something of a challenge, since the principle is almost inherently designed to suffer from material fatigue. Rapid stretching and releasing of the material causes microcracks to form, which sooner or later lead to tearing. As a consequence, elastocaloric systems that employ material stretching to induce temperature change currently only achieve some ten thousand cycles.

A new approach using compression

In view of this, Fraunhofer IPM has adopted a different approach: Instead of stretching the elastocaloric (EC) material, it is compressed using a special compression system. The system constructed at Fraunhofer IPM utilizes Nitinol rods measuring 11 mm in length and 2.5 mm in diameter. Compressing the materials is equivalent to subjecting them to tensile stress at comparable temperature differences, but without inducing cracking. Nevertheless, this approach does present significant challenges compared to the application of tensile force. When stretching elastocaloric materials, ultrafine wires – if necessary several meters in length – can be employed so that relatively low system force is needed. Such fine wires would simply buckle if compressed. As a result, the length of the rods – and thus the surface area available for heat transfer – is lower in pressure-based systems than in stretching systems.

ELASTOCALORIC (EC) MATERIALS are shape-memory alloys which revert to their original shape after being deformed, for instance as the result of stretching or compression. The commercially available nickel-titanium alloy Nitinol is one of the best-known EC materials. However, it suffers from material fatigue after just a few thousand cycles when stretched. New materials promise to push this threshold far higher in future. In 2015, a German-American research team developed an alloy ($Ti_{54}Ni_{34}Cu_{12}$) which, through the addition of copper to the conventional nickel-titatnium compound, has achieved a stability of more than 10^7 cycles.

Patented heat transfer concept

The system developed by Fraunhofer IPM offsets the low levels of heat transfer resulting from this unfavorable aspect ratio using a particularly efficient patented concept for transferring heat between the EC material and the heat exchanger unit. This heat transfer is usually achieved by actively pumping a fluid or by means of pressure contacts between the elastocaloric material and the heat exchanger. Fraunhofer IPM, however, relies on a passive approach of latent heat transfer, a concept also used in heat pipes and thermosiphons. Here, heat is transferred (latently) by evaporating and condensing a fluid – in this case water. The fluid is contained in a hermetically sealed tube that is free from all non-condensing gas, and is present in both liquid and gaseous form. Individual elastocaloric segments are connected in series and designed as thermal diodes so that heat is then transported segment by segment in a single direction, and one side of each segment is cooled while the other is heated. 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 other heat transfer concepts. This approach enables cycle frequencies of over 10 Hz, which are an essential prerequisite of cost-effective, marketable systems.

The prototype for the elastocaloric mini refrigerator demonstrates that solid-state cooling concepts can achieve the long-term stability required. However, there is still much to do to make them market-ready. At present, the team is working on improvements to the system design using simulations of optimized components as well as on strategies for fully recovering the pressure energy used for compression. This will allow them to increase cooling performance and energy efficiency. In addition to elastocaloric cooling concepts, Fraunhofer IPM is also conducting successful research on magnetocaloric cooling technology. Read more about this in the interview with Dr Jochen Kopitzke from cooling technology manufacturer Philipp Kirsch GmbH (p. 22-23).

Prototype of an elastocalorically operated mini refrigerator developed at Fraunhofer IPM.

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