CENTER for ENVIRONMENTAL ENERGY ENGINEERING

Design and Operation of a 100 W Elastocaloric Compression-Based Active Regenerator

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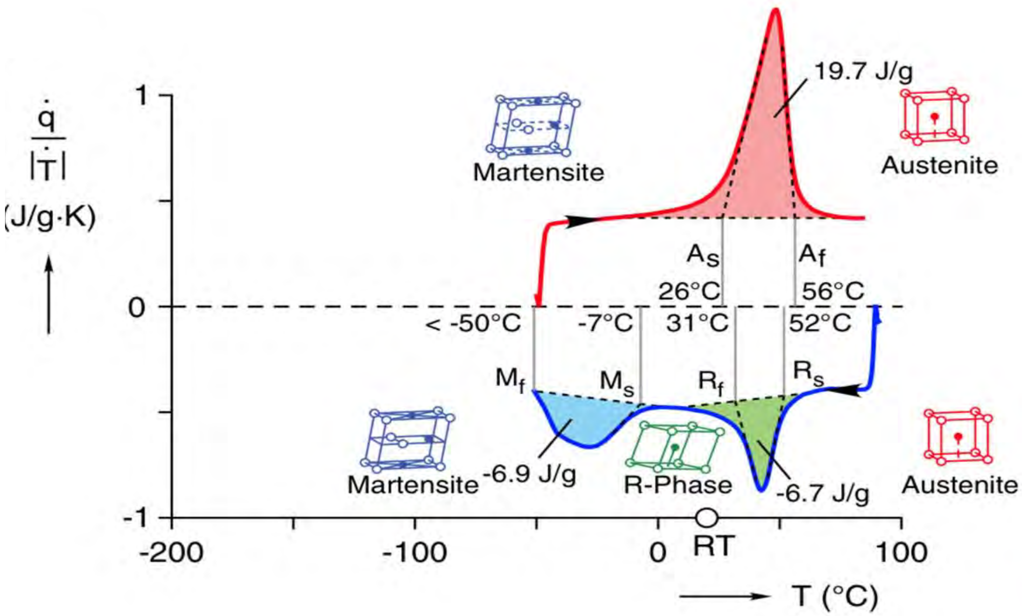
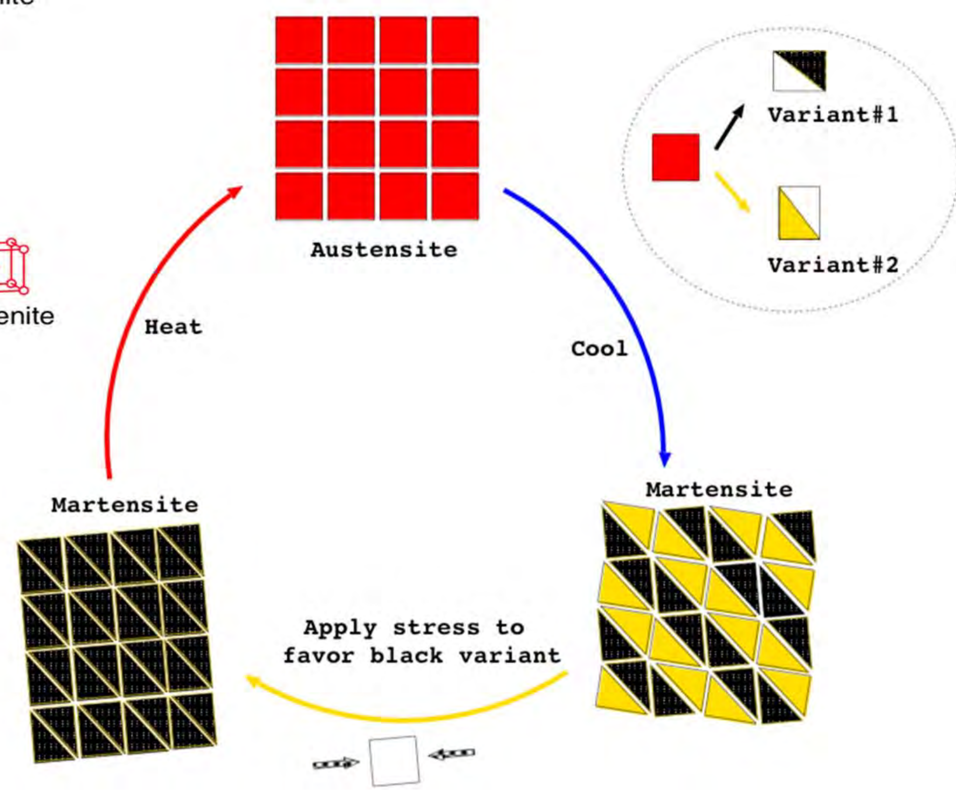
Shape memory effect and elastocaloric cooling





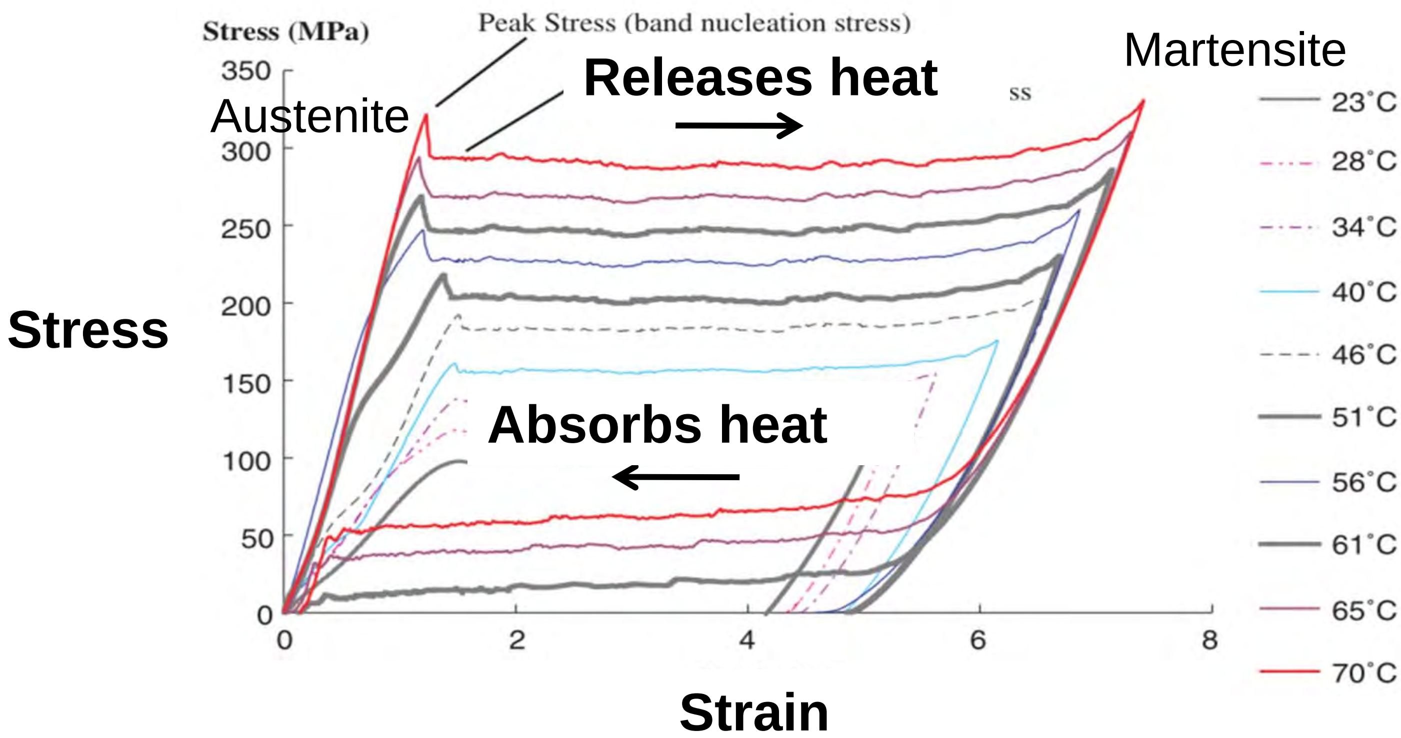
Differential scanning calorimetry

Latent heat associated with Martensitic transformation

Material: NiTi

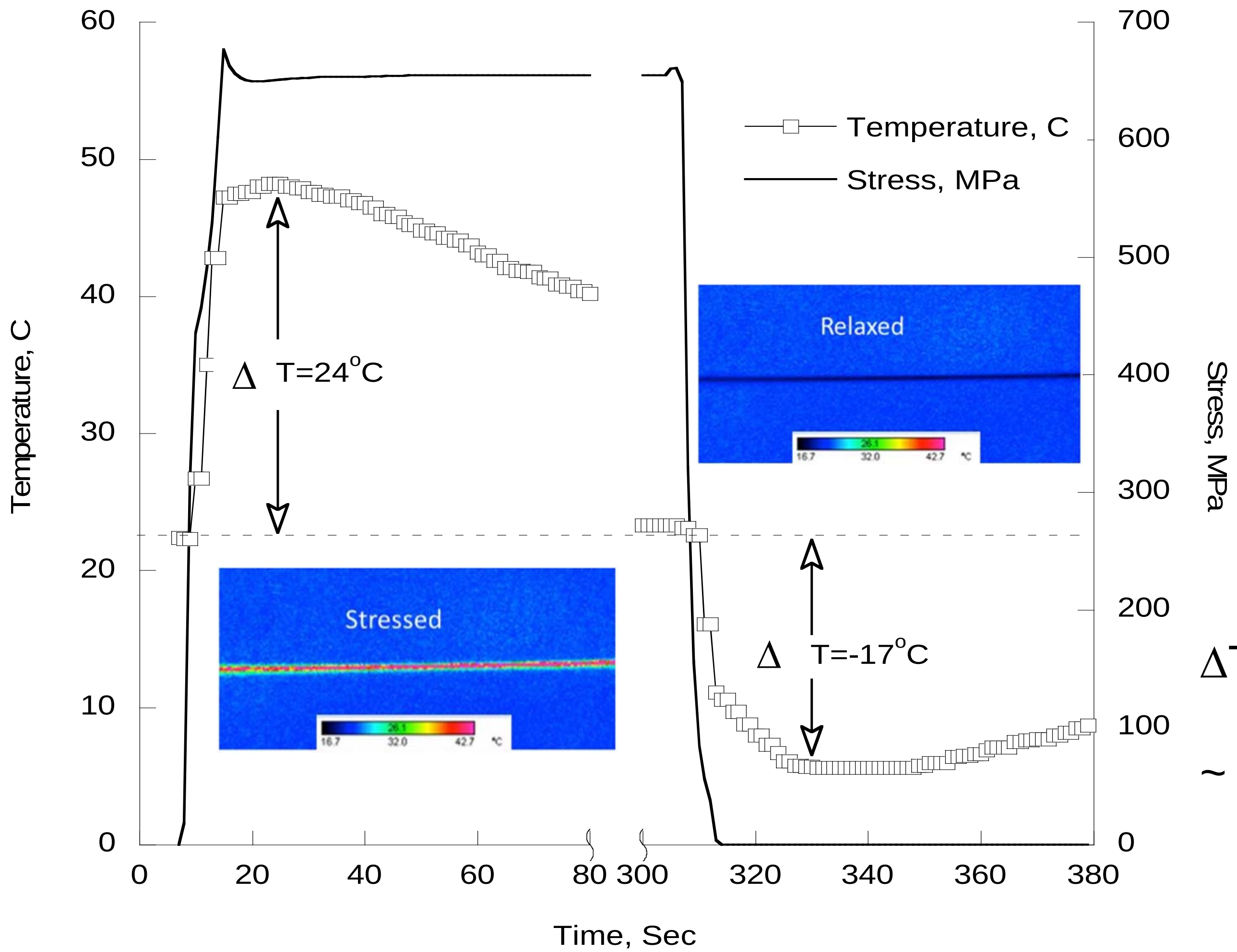
Superelasticity of shape memory alloys

Stress induced martensitic transformation can be used to run a heat pump cycle



Stress- strain curves at various temperatures

Measured temperature change (tensile test)

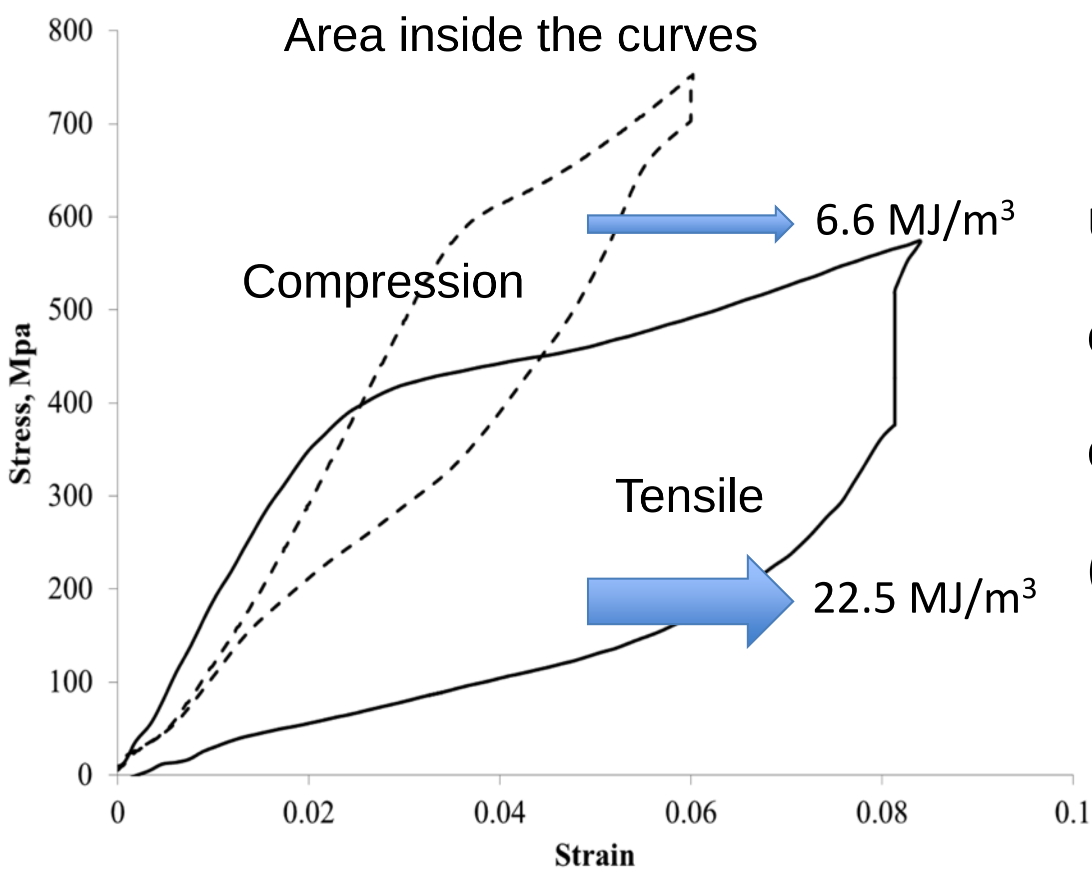


3 mm
NDC
NiTi wire

ΔT can be large

~ 17K

Comparison of Compression vs Tension Operation



3 mm wires (NDC)

Using latent heat of 12 kJ/kg:

COP (tension) = 3.05

COP (compression) = 11.8

(T_c = 278 K; T_h = 298 K)

assuming full work recovery

Comparison of different solid state cooling materials

COP_{mat}/COP_{Carnot}

$\Delta T_{ad}/\Delta T_{lift}$

$\Delta T_{ad} = L/c_p$

ΔT_{lift} set to be 10K

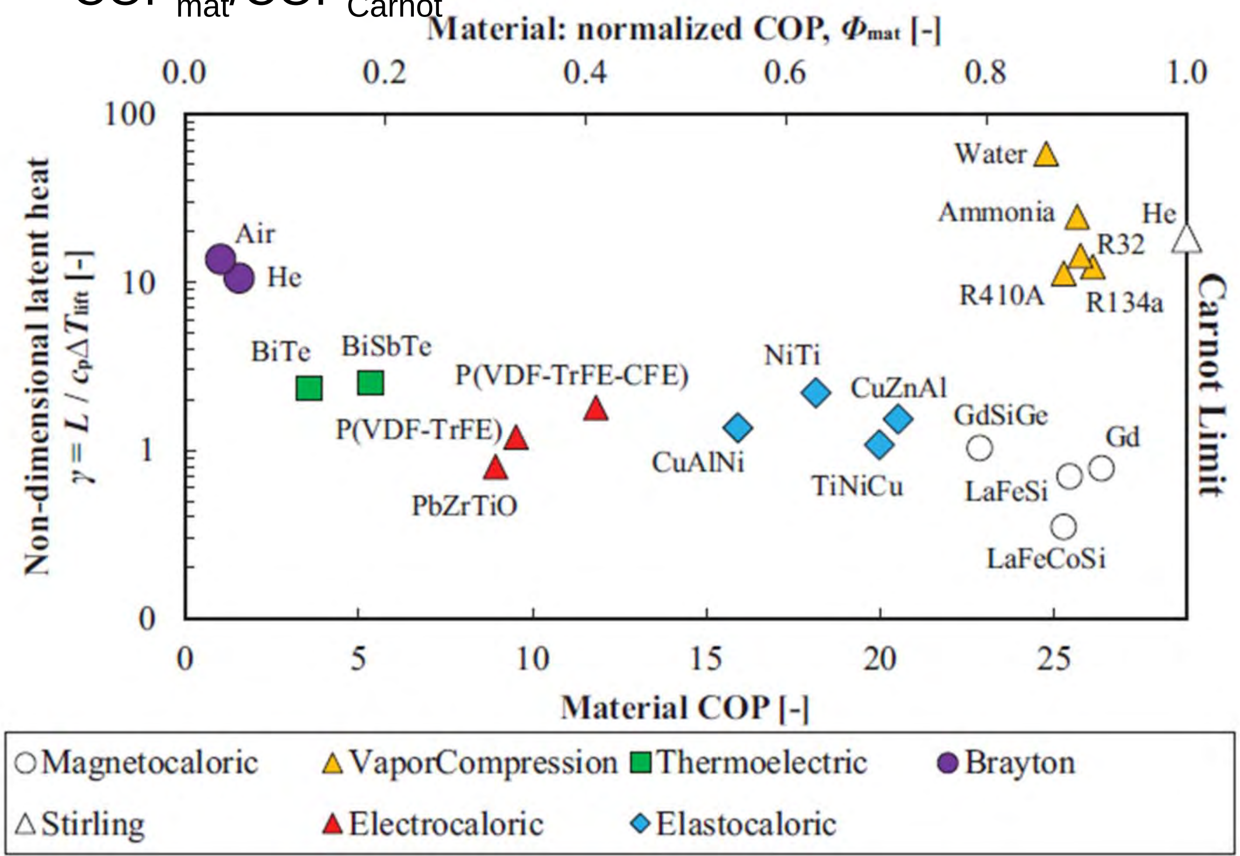
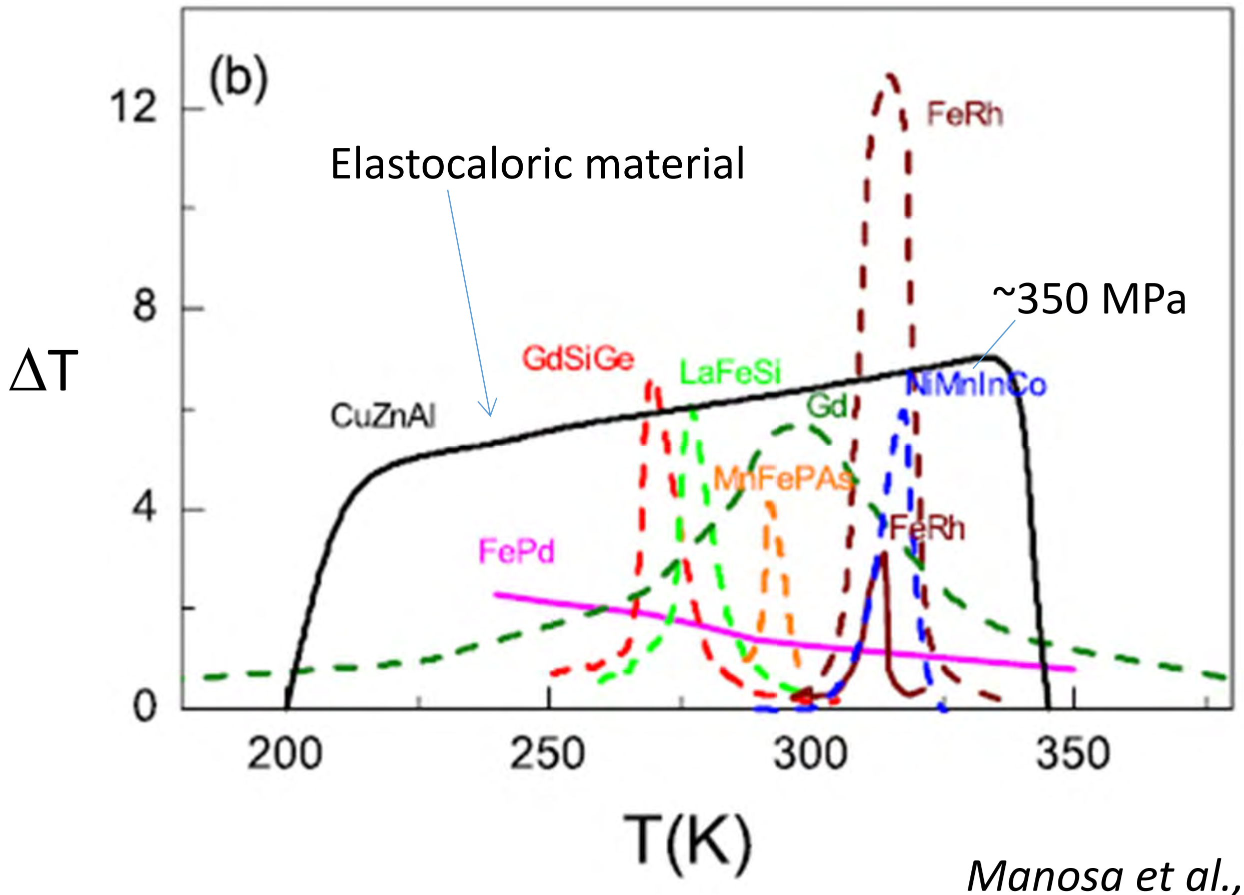


Fig. 5 – Comparison of the materials/refrigerants of various cooling technologies on the COP_{mat} and non-dimensional late heat diagram ($T_c = 288$ K, $T_h = 298$ K, Carnot COP = 28.8).

Qian et al. IJR **62**, 177-192 (2016)

Operation temperature range:
comparison of elastocaloric materials and other caloric materials



Manosa et al., 2013

Elastocaloric materials can operate over 100 K span

But what about fatigue?

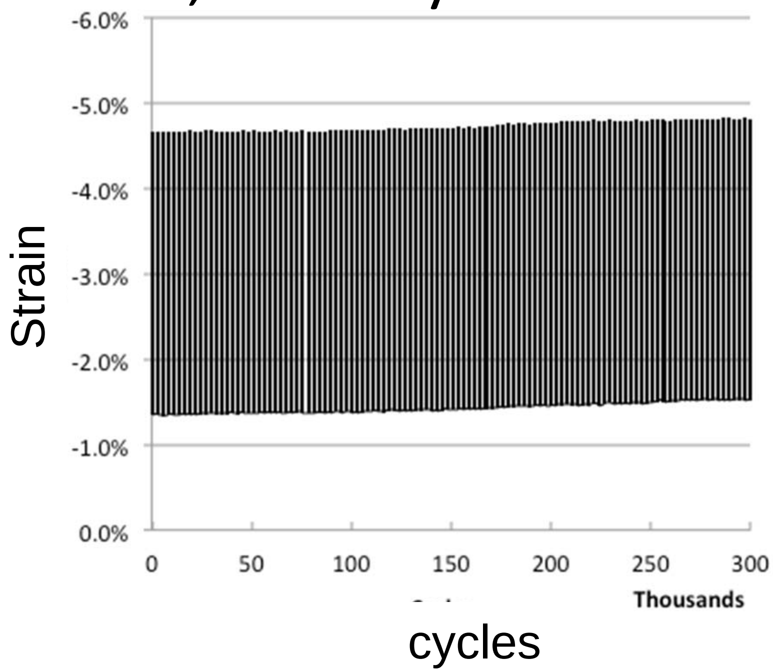
- Air-conditioners: typical lifetime ~10 yrs
- Elastocaloric air conditioners: 1 Hz operation, 6 months per year - > 78 million cycles

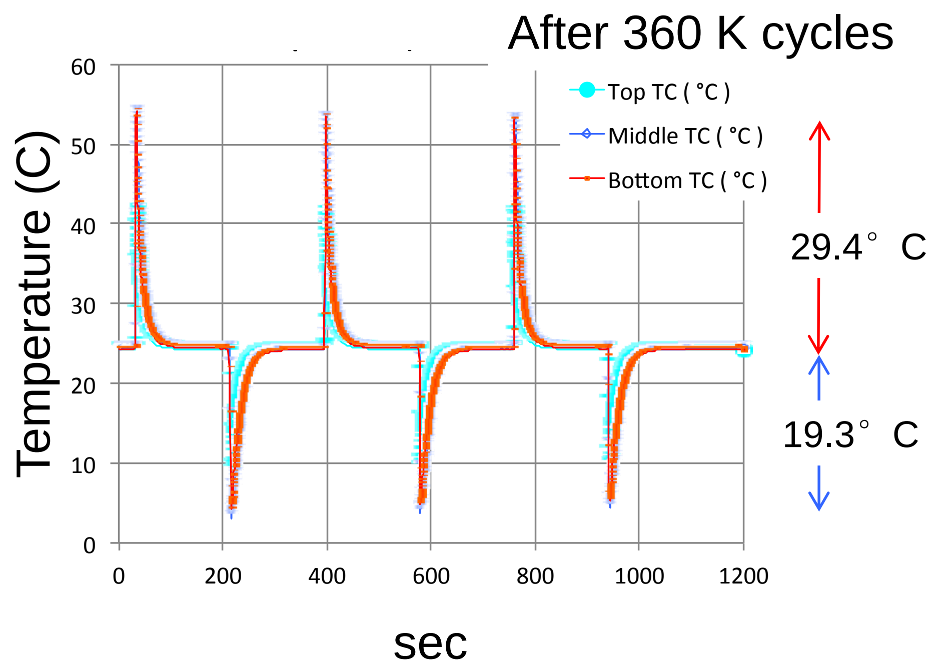
  (for low frequency operation, # of cycles decreases:

  20 sec/cycle: 50 mHz, -> a few million cycles)
- For tension, crack propagations can lead to fatigue in SMAs
- Lattice engineering through non-linear theory: combinatorial study
- Reduced strain operation
- Compression mode

possible solutions

Compression test of NiTi tubes: 360,000 cycles





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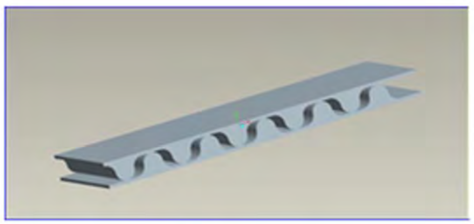
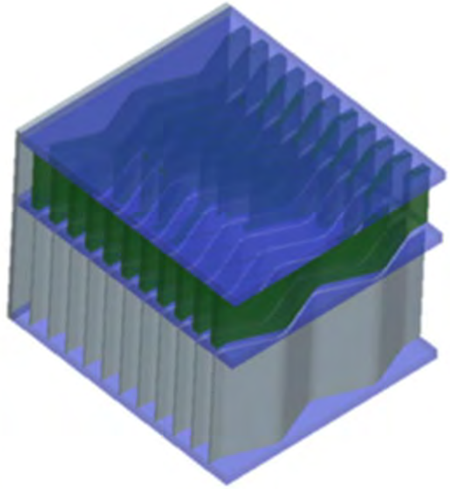
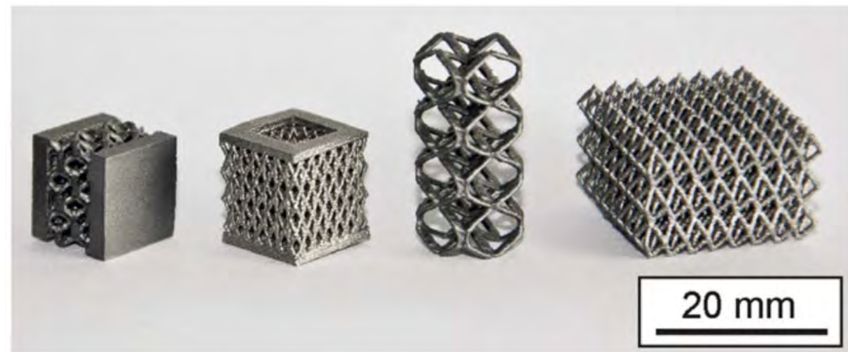
J. Cui, PNNL

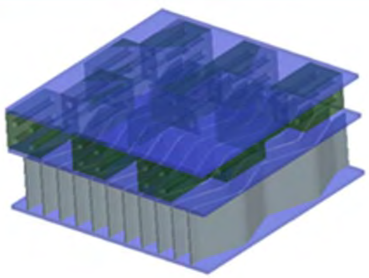
Different “wishful” shapes/structures of heat exchangers made of SMAs

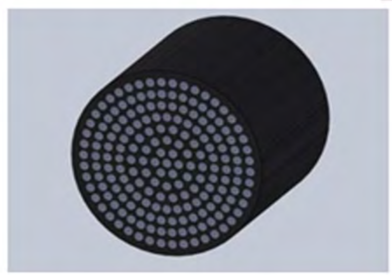






Christoph, H., et al. (2014). Smart Materials and Structures 23(10): 104002.



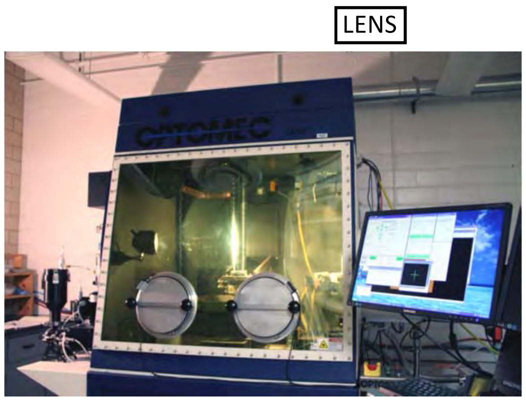


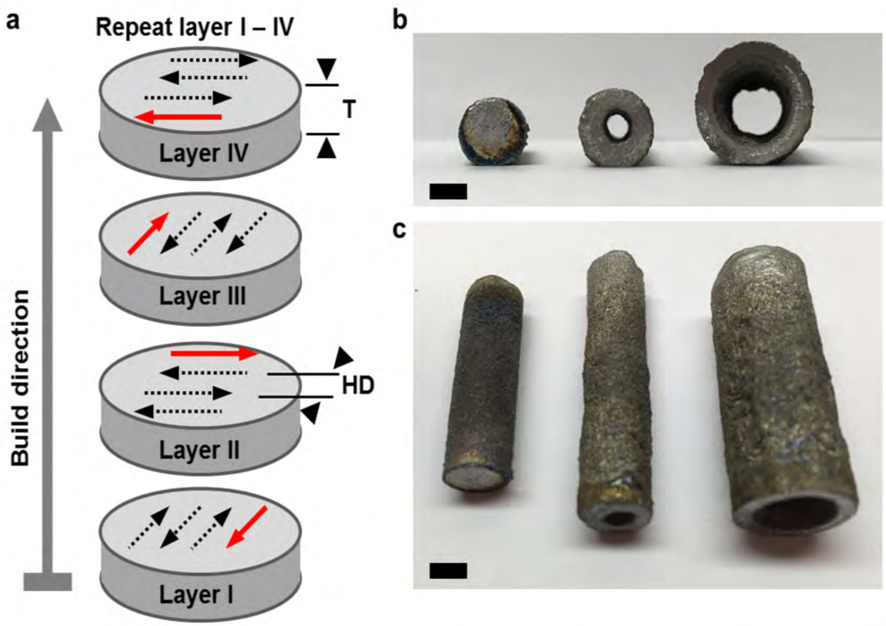
From HVAC (heating, ventilation, and air-conditioning) engineering point of view, we would like to see SMAs in these shapes. Why not?

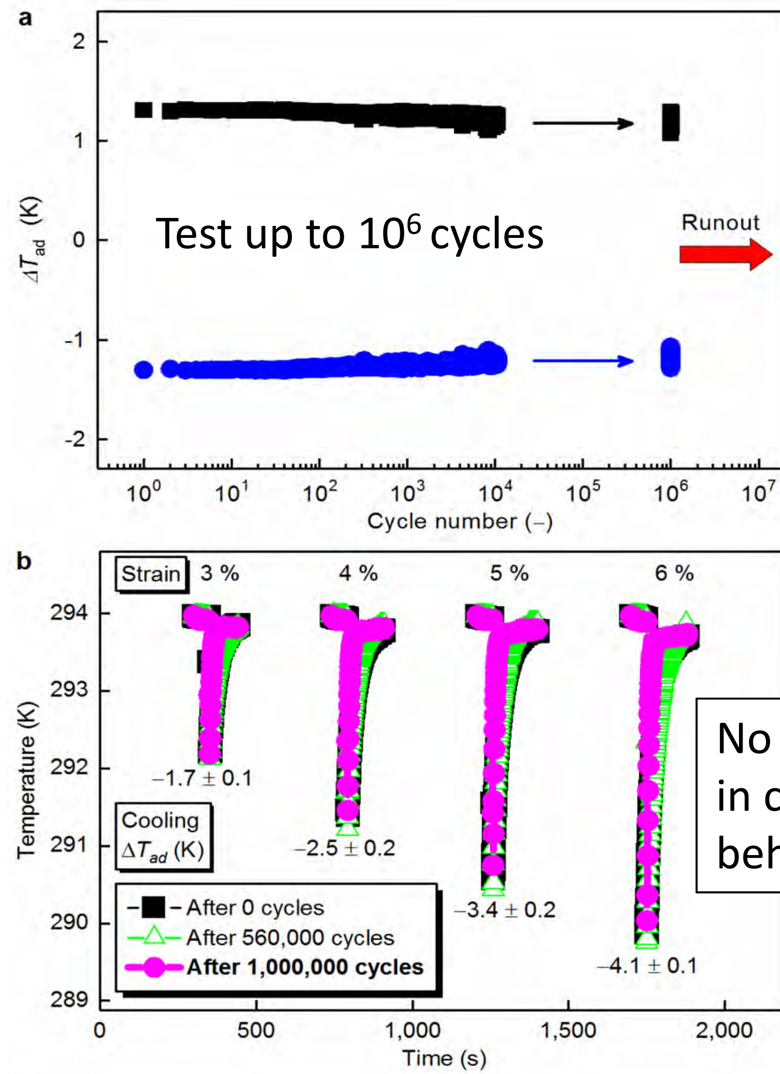
But only wires, tubes, and sheets of fixed dimensions are commercially available

Additive Manufactured NiTi

LENS system at Ames Lab



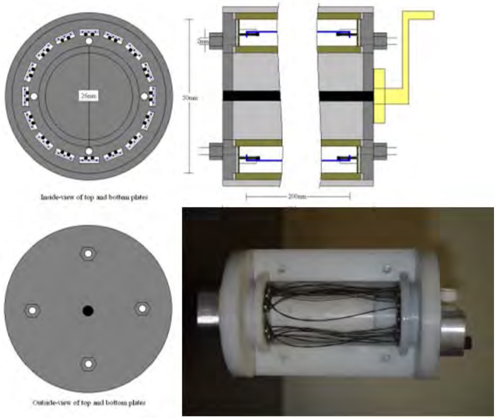




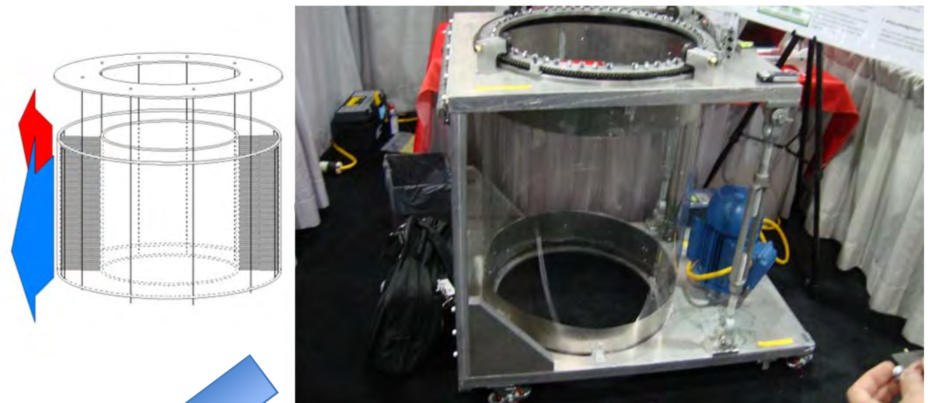
No change in cooling behavior

As printed NiTi, stable over 1 million cycles, ΔT = 4 K

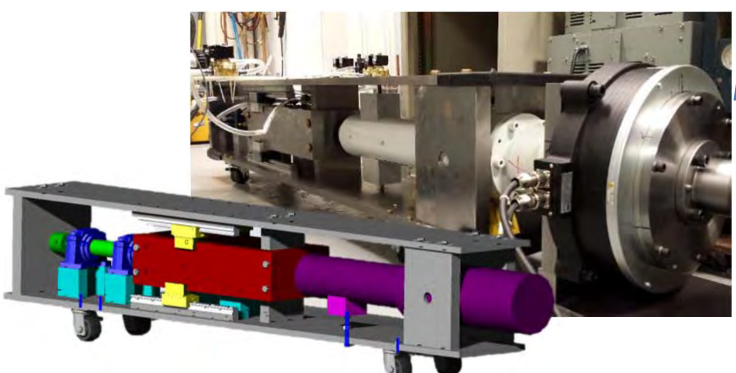
Elastocaloric cooler prototypes
(and their designed cooling powers)



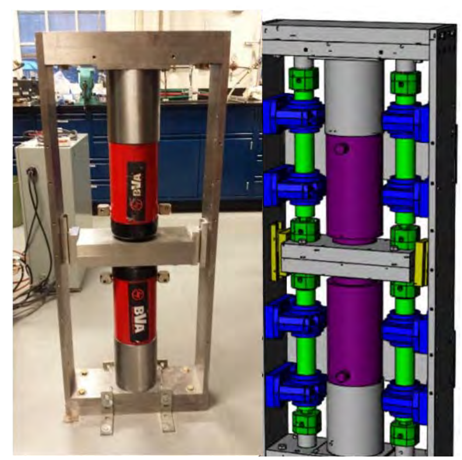
GEN-0: hand crank/tension
35 W (2010)



GEN-1: tension based 1 kW
Direct air cool (2012)

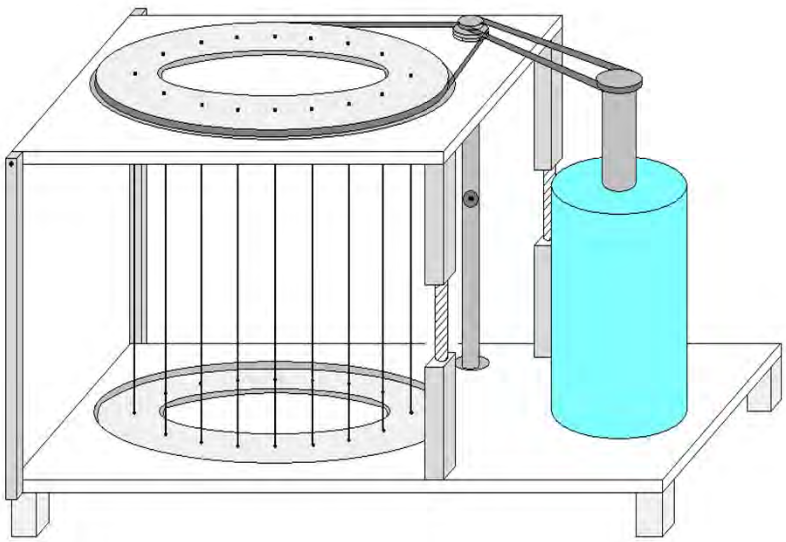


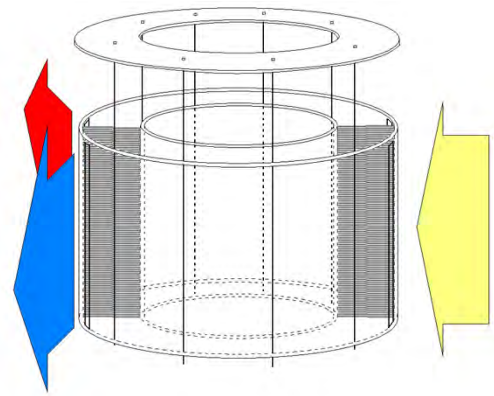
GEN-2: compression based
140 W water cooling (2014)

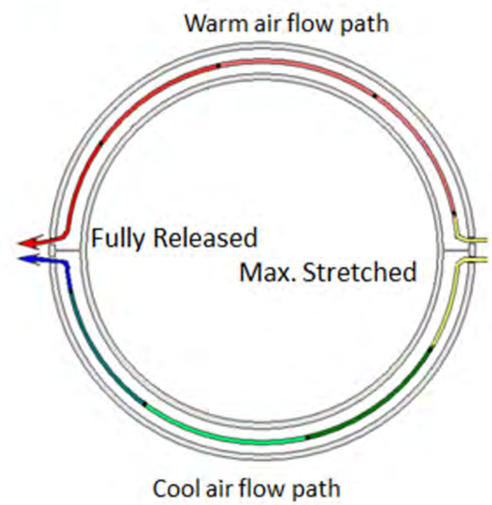


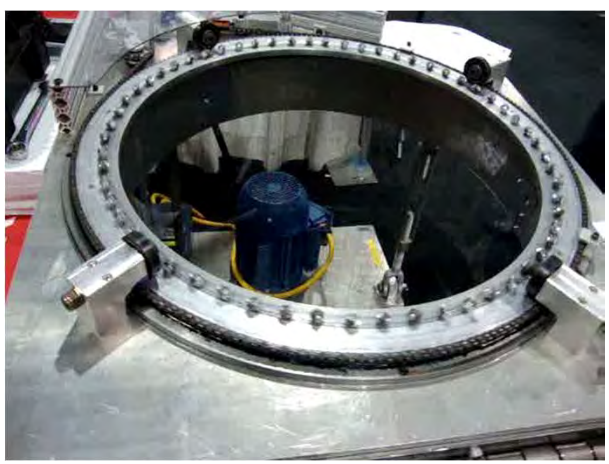
GEN-3: compression based
400 W water cooling (2016)

Elastocaloric air-conditioner: “rotating bird cage”
Tension based 1 kW direct air cooling (2012)



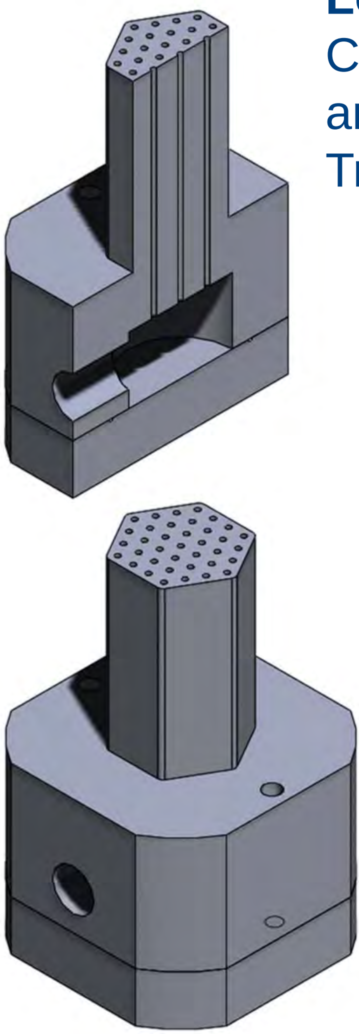






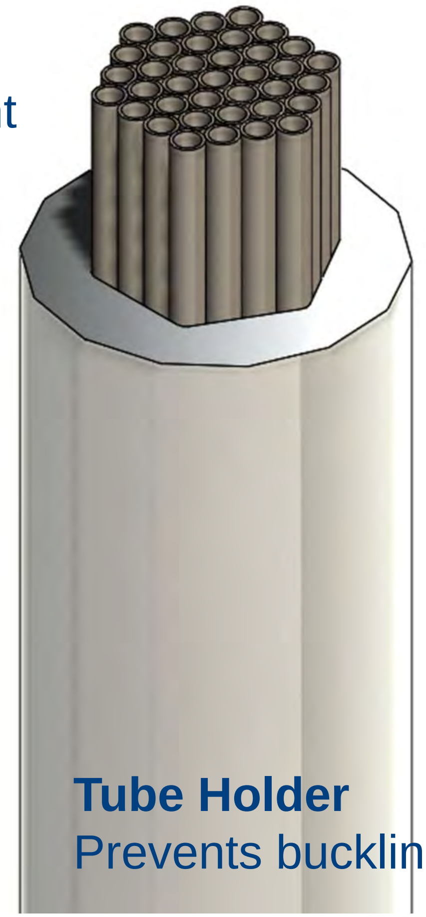
Problems encountered: friction; air/metal heat exchange; tension

Heat Exchanger Architecture



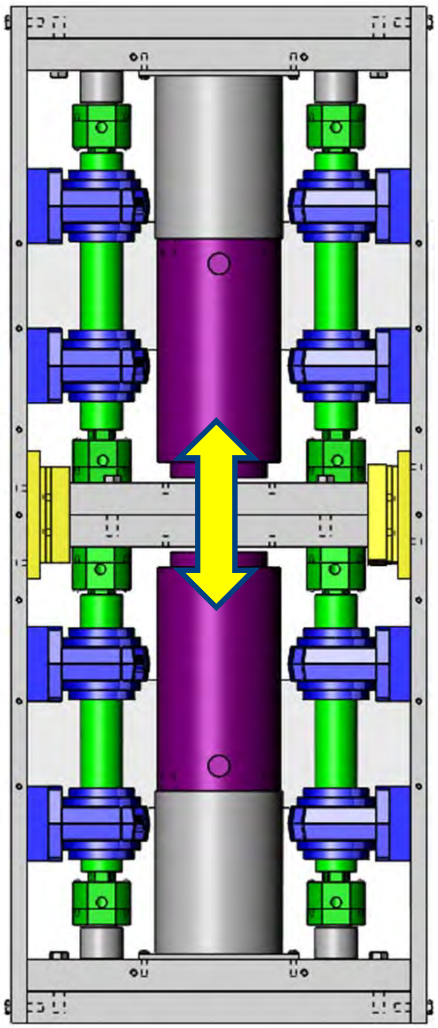
Loading Head
Compression and Heat Transfer

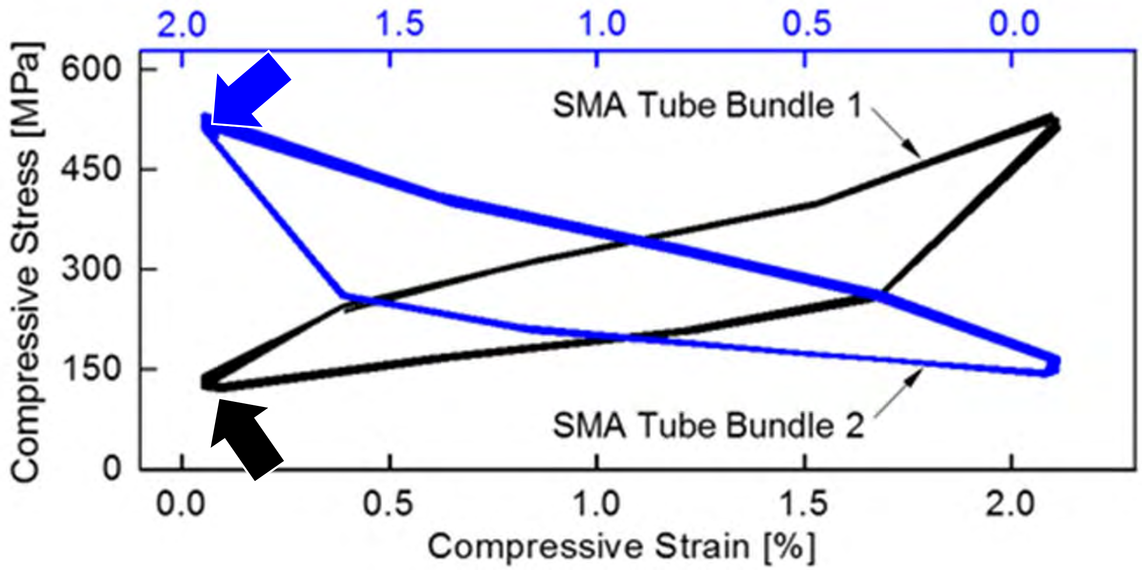
Nitinol® Tubes
Packed in hexagonal arrangement

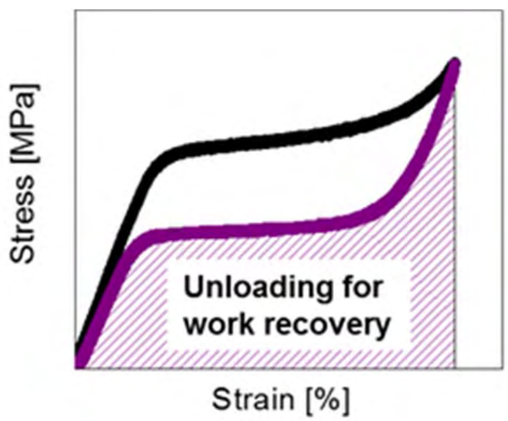


Tube Holder
Prevents buckling

Actuation and Work Recovery







The unloading process of one tube bundle assists the hydraulic cylinder in the loading of the opposite tube bundle.

Hou, H., Cui, J., Qian, S., Catalini, D., Hwang, Y., Radermacher, R., & Takeuchi, I. (2018). Overcoming fatigue through compression for advanced elastocaloric cooling. *MRS Bulletin*, *43*(4), 285-290.

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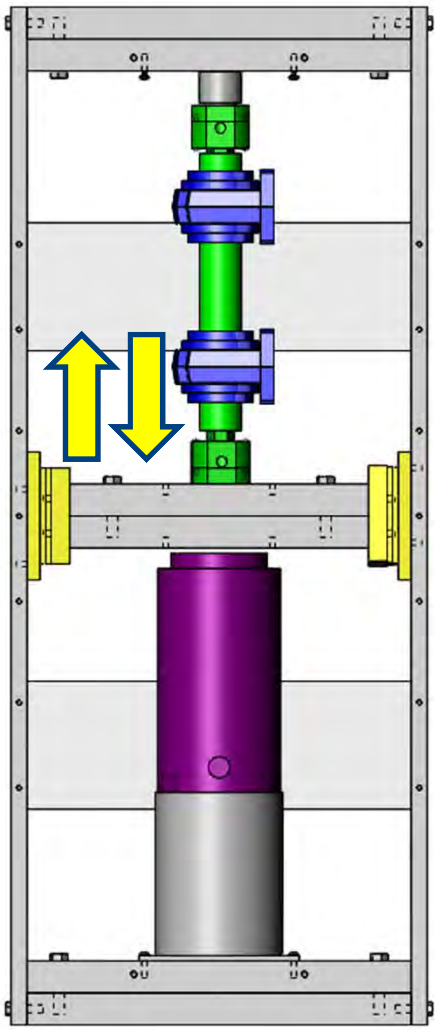
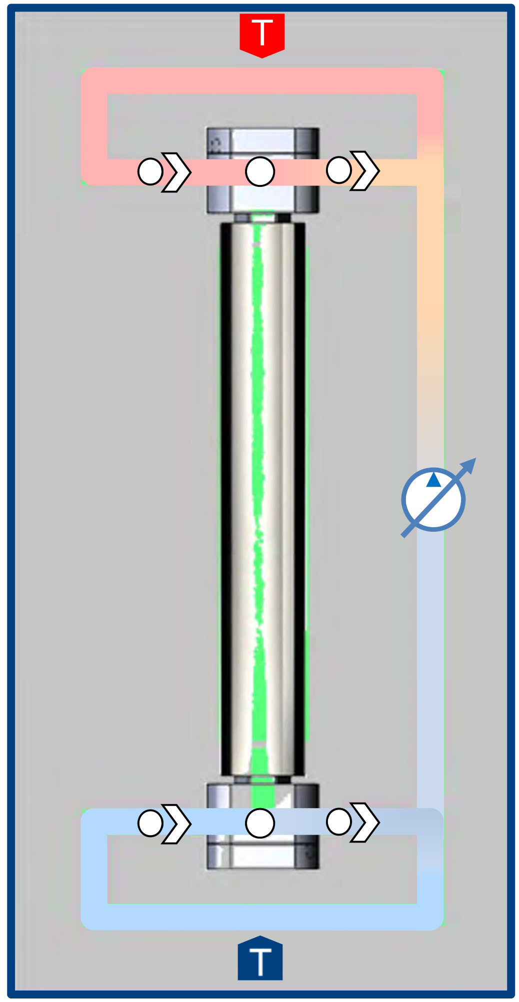
Active Regenerator



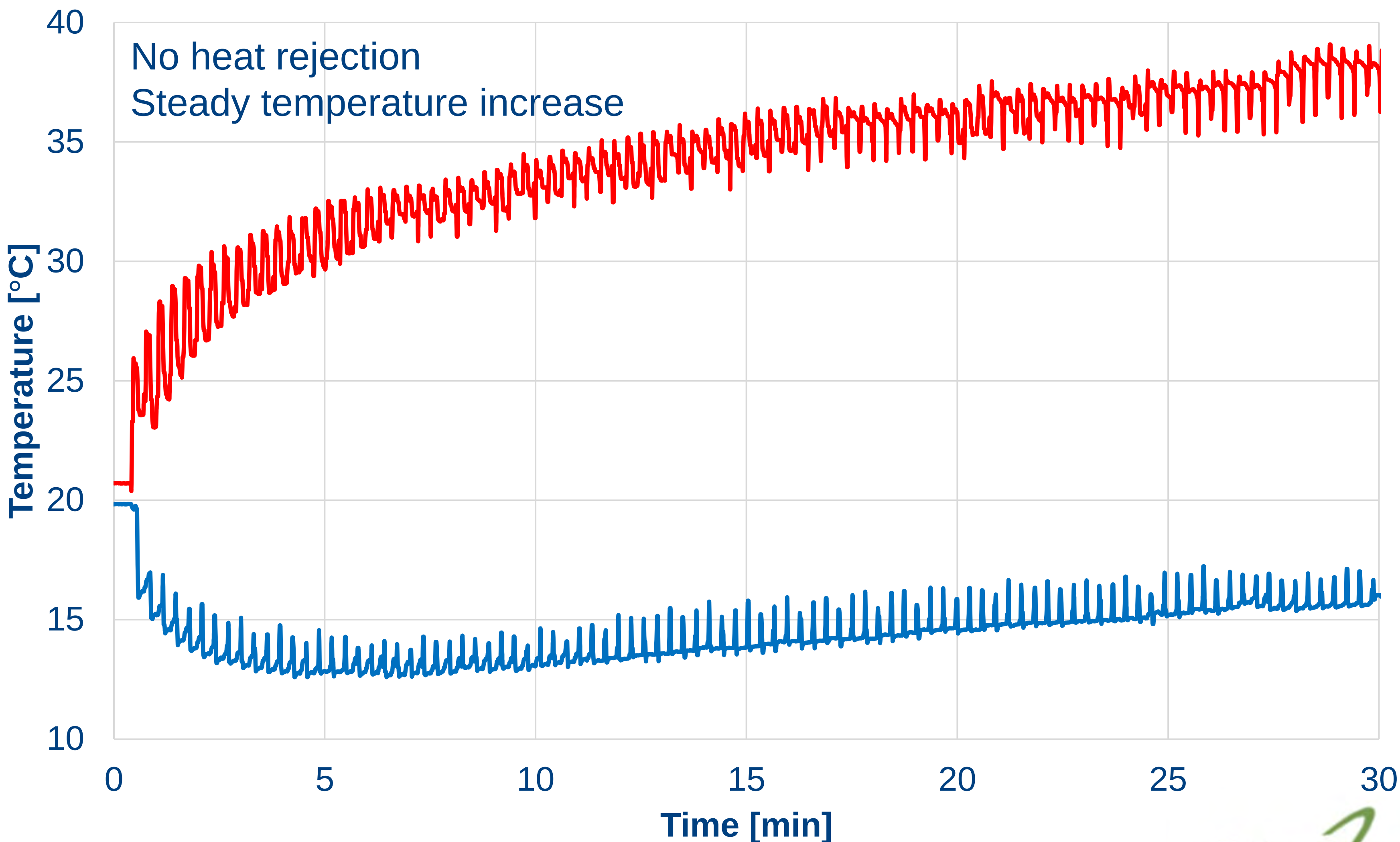


1. **Loading:** Nitinol increases T. No fluid flow.
2. **Heating:** Strain is maintained while fluid flows towards hot side.
3. **Unloading:** Strain is removed. No fluid flow.
4. **Cooling:** Fluid flows towards the cold side.

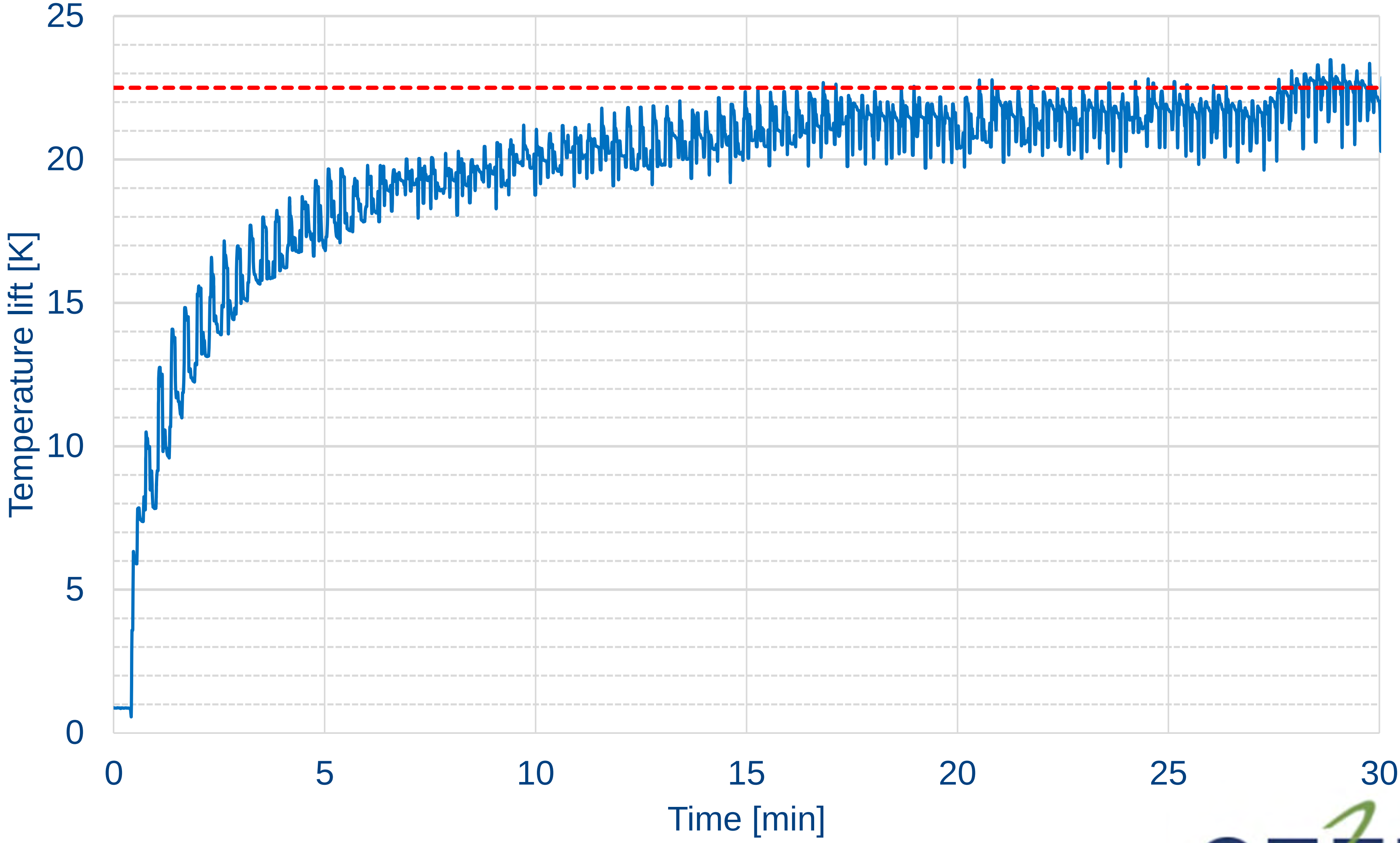
A temperature gradient develops along the tubes

Key Parameters
Strain: 4.5%
V* (Utilization Factor) = 0.7
Mass flow rate = 4 g/s
Loading time = ~6 s
HT time = ~6 s
Unloading time = ~1 s

Performance: Hot and Cold Temperature



Performance: Temperature Lift



Conclusions

- We have implemented an **Active Regeneration Cycle** in an Elastocaloric Heat Pump

- We have obtained a maximum temperature lift of **22.5 K** in the heat transfer fluid at zero cooling capacity.

- Cooling capacity measurement is on-going