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Operating characteristics of a single-stage Stirling-type pulse tube cryocooler with high cooling power at liquid nitrogen temperatures

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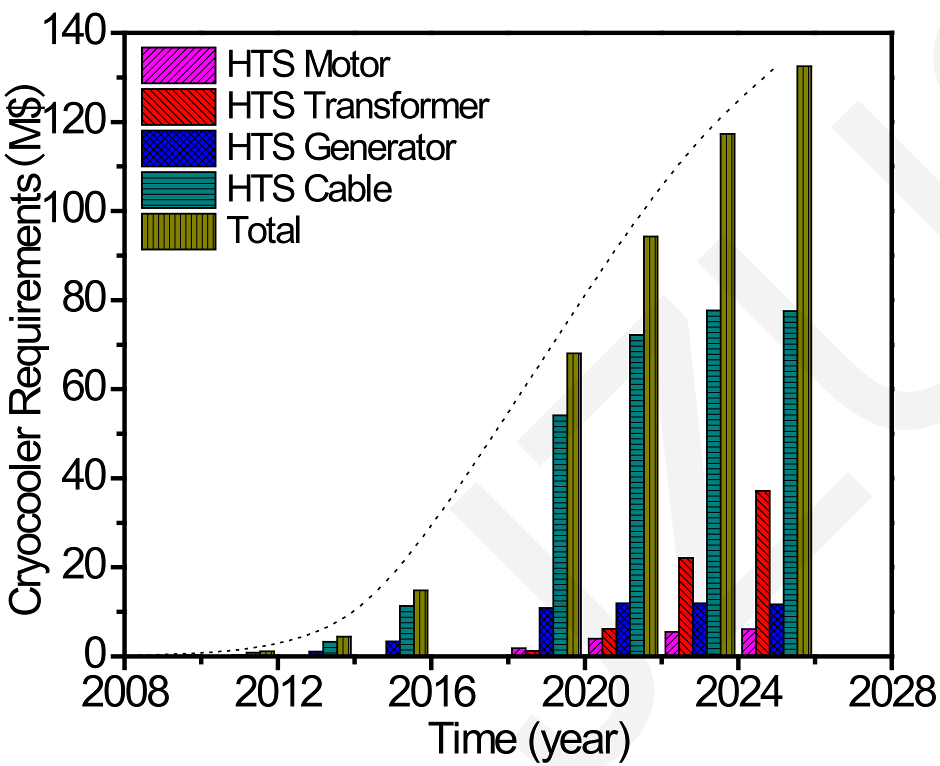
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

University of Giessen, Germany & Zhejiang University, China

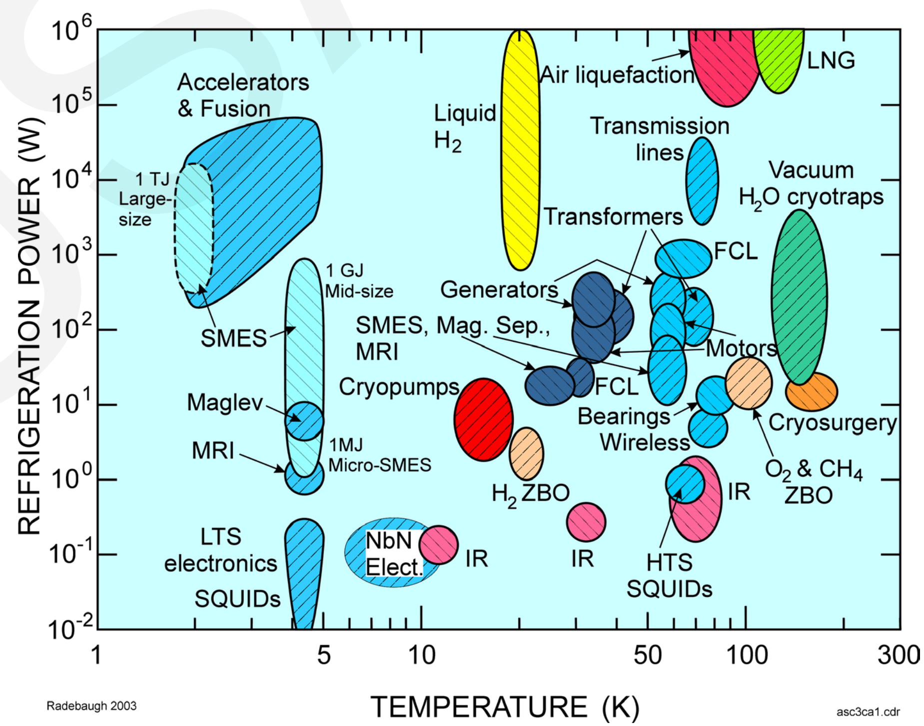
Energy
HTS Motor&Cable

Cryocooler Requirements

High-power cryocoolers show promise in satisfying the increasing requirements of high temperature superconductor applications. The Stirling-type pulse tube cryocooler (SPTC) is one of the best candidates among the regenerative cryocoolers, because of its advantages of compactness, low vibration, high reliability, and high efficiency.



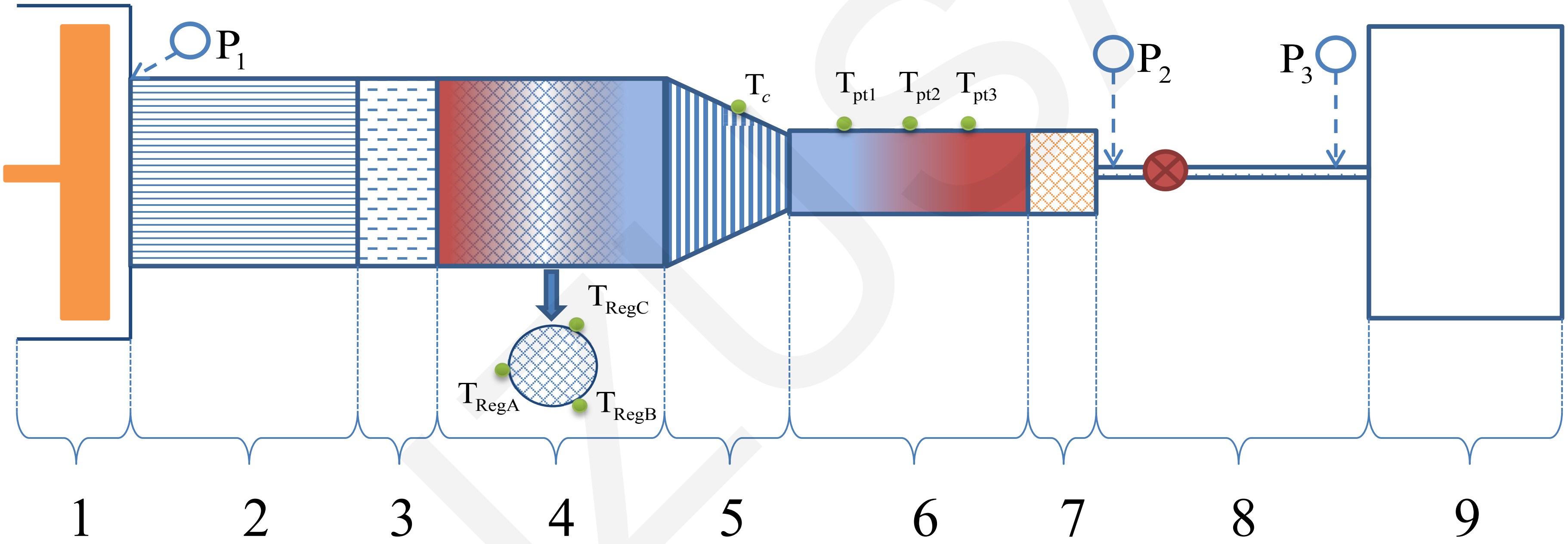
HTS cryocooler requirements



Cooling requirements for HTS applications

Illustration of the High power SPTC setup

In this study, a single-stage high power SPTC numerical model and experimental step up were employed to investigate the dependence of cooling performance on the charge pressure and operating. The influence of operating characteristics on the temperature no-uniformity in the regenerator was also investigated.

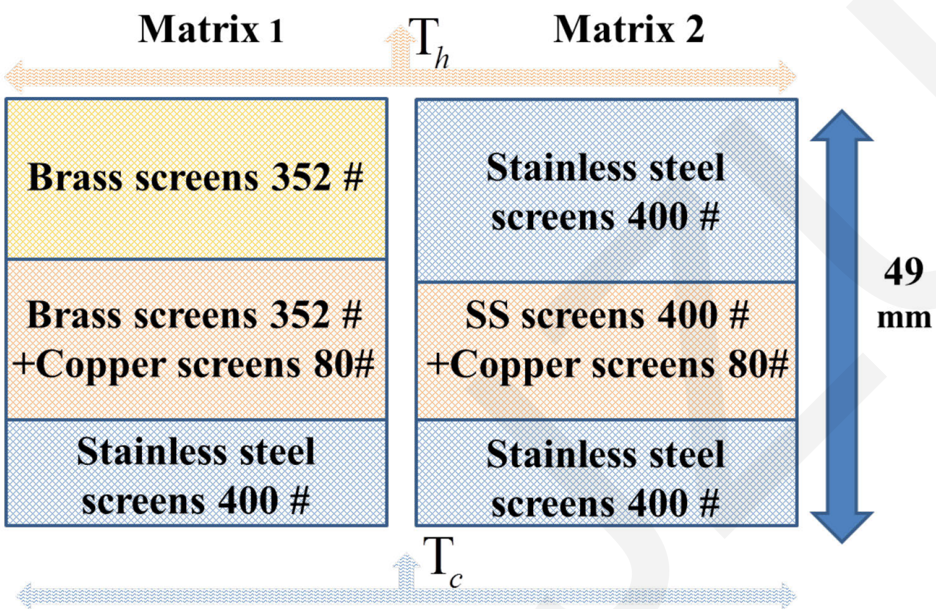


1: Compressor
2: Aftercooler
3: Flow straightener
4: Regenerator
5: Cold heat exchanger
6: Pulse tube
7: Warm heat exchanger
8: Inertance tube
9: Reservoir

Details of the High power SPTC setup

Hybrid regenerator fillings are used to increase the transverse thermal conductance of the regenerator matrix, in order to reduce the temperature inhomogeneity

Sandwich type fillings



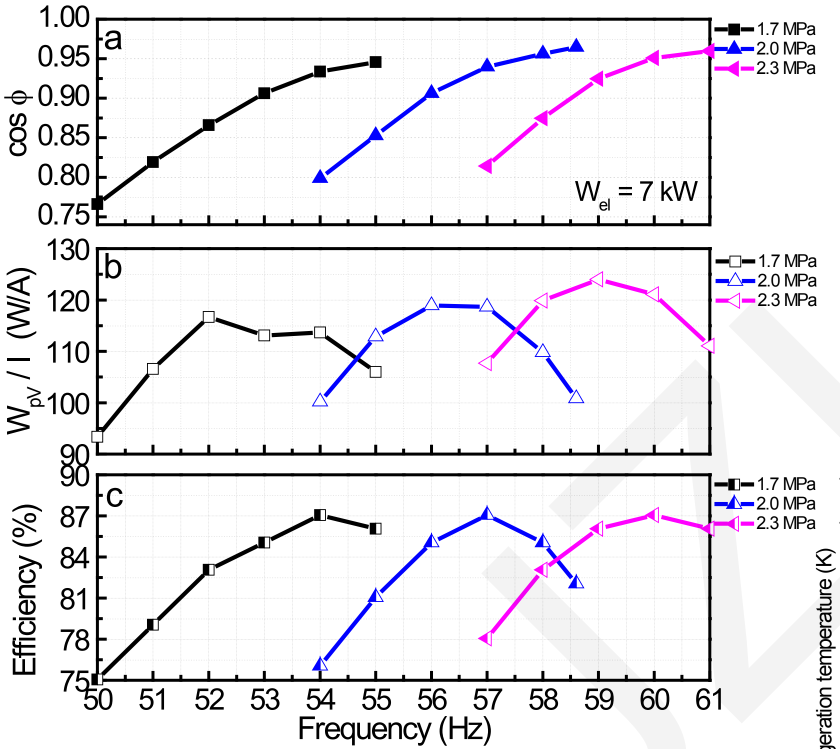
Schematic of the hybrid regenerator fillings

Component	Quantity	Value
Regenerator	Diameter	117 mm
	Length	49 mm
Regenerator matrix	Wire diameter	30 μm
	Porosity	0.65
Pulse tube	Diameter	45 mm
	Length	170 mm
Inertance 1	Diameter	13 mm
	Length	0.62 m
Inertance 2	Diameter	15 mm
	Length	1.0 m
Inertance 3	Diameter	20 mm
	Length	1.0 m

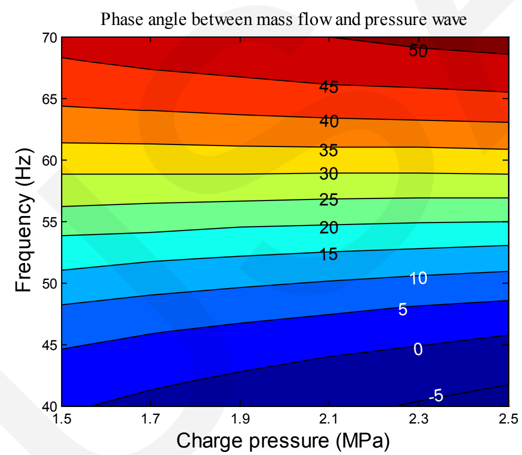
Dimensions of the main components of SPTC

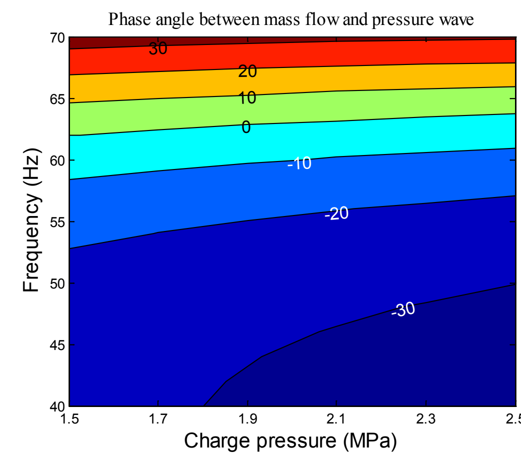
Effect of operating frequency

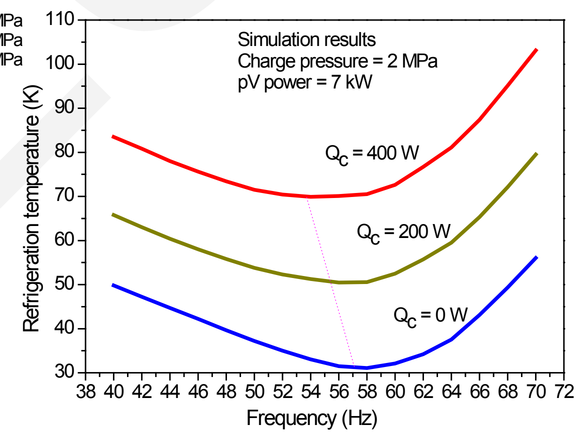
The operating frequency does not only influence the electrical impedance of the compressor, but also affects the mechanical impedance that is strongly related to the efficiency of the compressor. Hence, the frequency should be optimized in order to achieve the maximum compressor and regenerator efficiency.

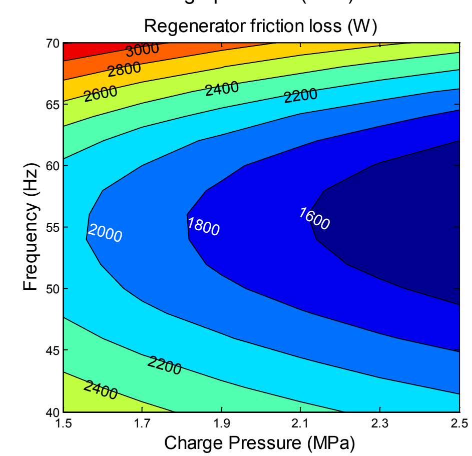


Measured pV power conversion efficiency, and electrical (*cosϕ_{el}*) and mechanical (*W_{pV}/I*) response as function of frequency.



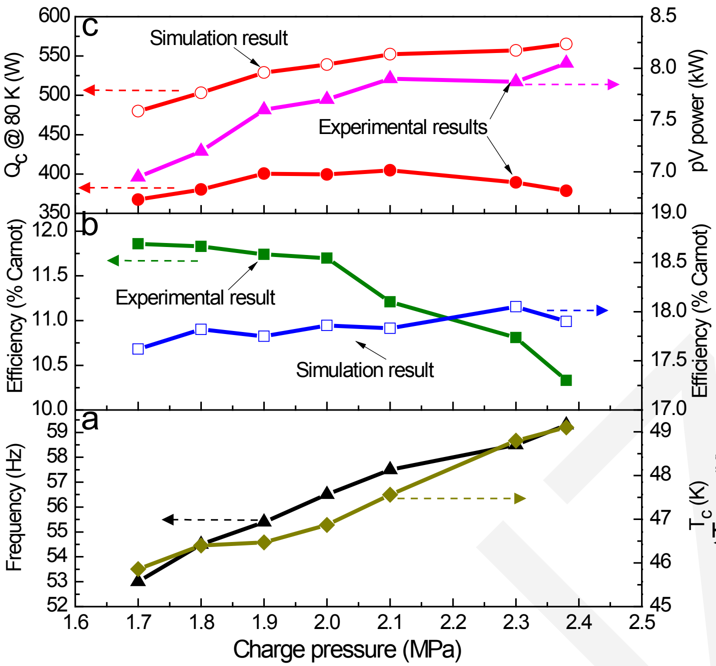




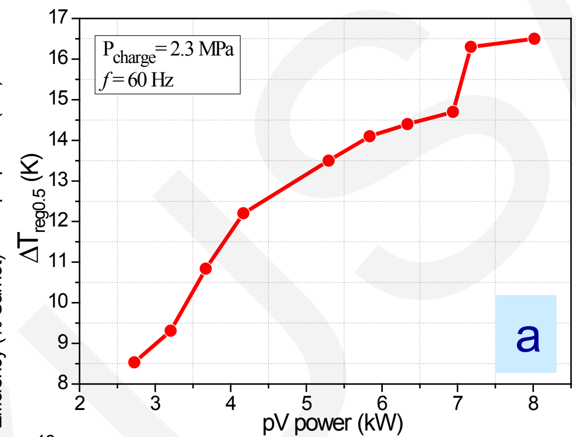


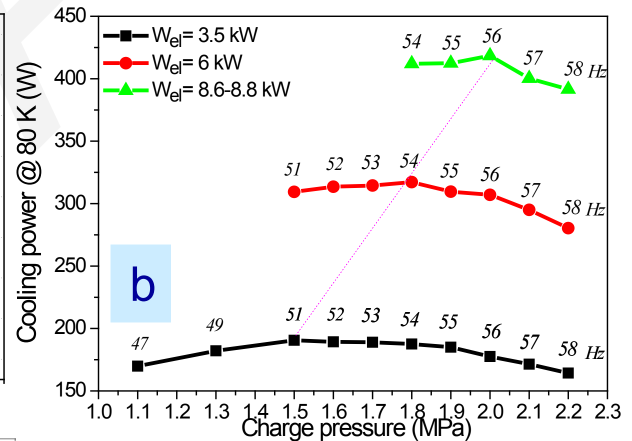
Effect of Charge pressure

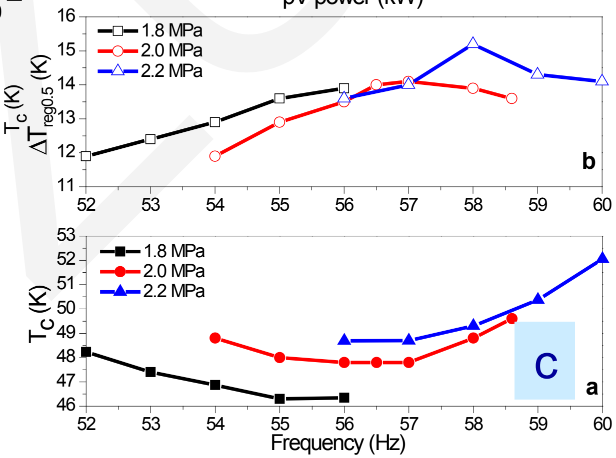
For each charge pressure, there is a certain frequency for which a maximum temperature inhomogeneity in the regenerator is reached. The temperature non-uniformity increases with the increase of input power. The optimum charge pressure also rises with increasing input power.



Cooling power (Qc) at 80 K, relative Carnot efficiency, available pV power, corresponding frequency and refrigeration temperature versus charge pressure from experiment and simulation with matrix 1.







a: Measured azimuthal temperature variation as function of pV power;

b: Measured cooling power at 80 K versus charge pressure;

c: Measured azimuthal temperature variation in the middle of the regenerator (matrix 1) and refrigeration temperature as function of frequency

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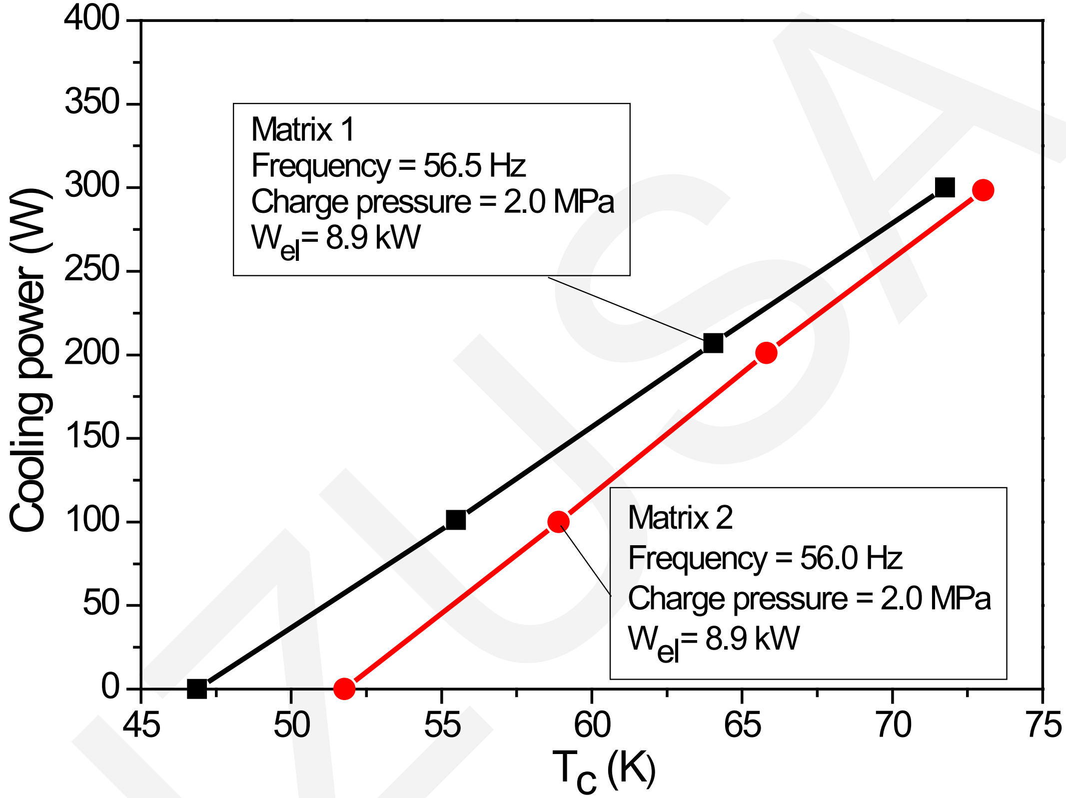
Optimized cooling performance



At 56.5 Hz and 2.0 MPa, the minimum no-load refrigeration temperature with matrix 1 is 46.9 K, and a cooling power of 300 W at 71.8 K is obtained with an input power of 8.9 kW. The no-load refrigeration temperature with matrix 2 is roughly 5 K higher than that with matrix 1. The SPTC can still provide a cooling power of 299 W at 73 K with matrix 2.