Theoretical and experimental investigations on the match between pulse tube cold fingers and linear compressors

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Introduction

The optimal match between the PTCF and the linear compressor of the SPTC plays a vital role in optimizing the compressor efficiency and in improving the cold finger cooling performance. although previous studies gave some explanations or suggestions on the match between the linear compressor and the PTCF, many questions are still to be solved. In order to develop high performance SPTCs for practical applications, it is necessary to study these problems thoroughly and give a clear explanation of the match mechanism.

Objectives

- To reveal the interactions between the PTCF and linear compressor for their optimal match.
- A design method of the PTCF and a reversal design method of the linear compressor to achieve the optimal matching have been put forward.
- Specific experimental investigations have been carried out to verify the validity of the match theory and design methods

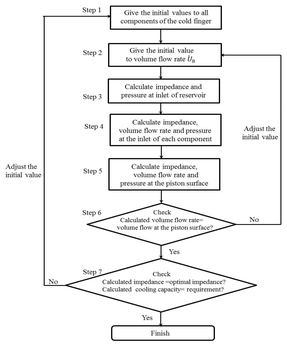
Conclusions

- For a given compressor, a new in-line PTCF has been designed and then matched with the given linear compressor. The compressor achieves the electric input capacities ranging from 0 W to 200 W with the mean motor efficiency of 82%, and the matched cooler achieves the cooling capacity of 10 W at 80 K with higher than 17% of Carnot efficiency.
- For a given coaxial PTCF, a new moving-coil dual-opposed linear compressor has been designed and then matched with the given PTCF. The compressor achieves the electric input capacity ranging from 0 W to 250 W with the mean motor efficiency of 83%, and the matched cooler achieves the cooling capacity of 2 W to 5.5 W at 60 K with higher than 9.6% of Carnot efficiency.
- The simulated results show fairly good agreements with the experimental ones. In both cases, the matched coolers show high efficiency cooling performance, which verify the validity of the theoretical investigations on the match and the proposed design methods for the PTCF and the linear compressor, respectively.

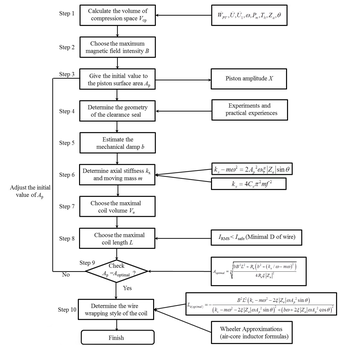
Design Methods

Design of PTCF for given compressor

- An ECA model of the SPTC has been proposed.
- Each part of the PTCF can be analogous to the combination of the basic fluid elements like resistance, inertance and compliance
- The PTCF can be analogous to an AC electrical circuit.



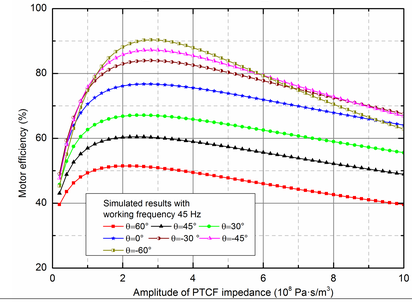
Design of compressor for given PTCF



- Choose the magnetic material with the maximum magnetic field intensity.
- Determine the geometry of the clearance gap by experiments and practical experiences.
- Determine the optimal moving mass and the axial stiffness of the flexure springs according to the condition of the resonance state.
- Volume of the motor coil in the magnetic field should be designed as big as possible.
- Design the optimal piston surface area and optimal coil inductance.

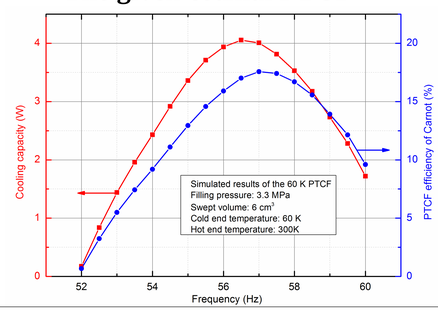
Simulations

The given compressor



With negative phase angles, highest motor efficiency can be achieved with impedance in the range of 2×10^8 Pa·s/m^3 to 3×10^8 Pa·s/m^3

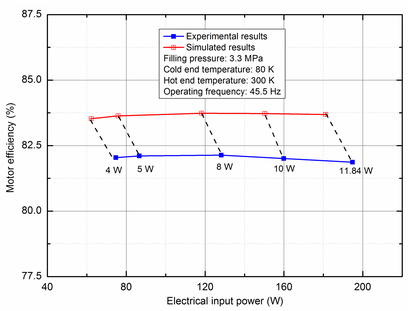
The given coaxial PTCF



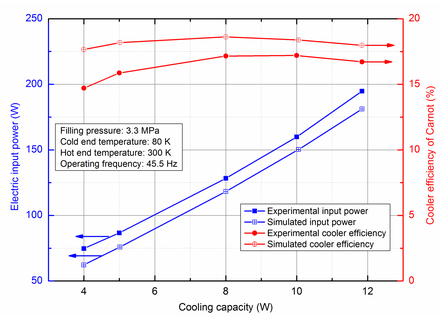
The highest cooling efficiency occurs at the frequency of 57 Hz and the highest cooling capacity occurs at 56.5 Hz.

Experimental results and comparisons

Performances of the 80 K matched cooler



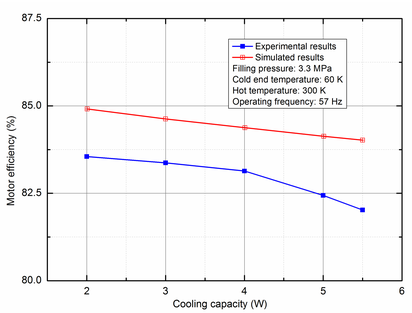
Comparisons between simulated results and experimental ones of the motor efficiency. The average motor efficiency reaches above 82%.



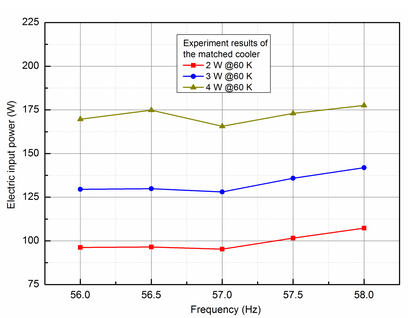
Comparisons between the simulated results and the experimental ones of the cooling performance.

The matched cooler can provide 4 to 11.84 watts at cooling temperature of 80 K with the electrical input power ranging from 75 W to 190 W. And the cooler's average efficiency of Carnot reaches above to 17%.

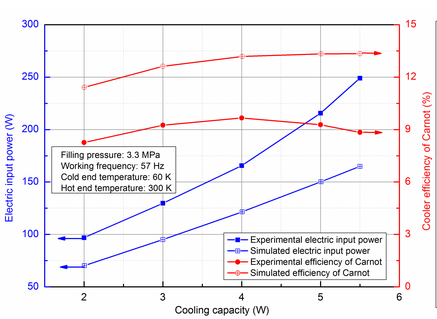
Performances of the 60 K matched cooler



Comparisons between simulated results and experimental ones of the motor efficiency. The average motor efficiency reaches above 82.5%.



Cooling performance of the matched cooler with different working frequency.



Comparisons of cooling performance between the simulated ones and the experimental ones.

- The experimental electric input powers are higher than the simulated ones with the difference increasing from 26 W to 44 W, and a difference of about 3.5% also exists between the experimental cooling efficiency and the simulated one.
- Some correction coefficients need to be added in the ECA model for the coaxial arrangement PTCF

The matched cooler achieves 2 W to 5.5 W at 60 K with the electric input power increasing from 97 W to 249 W, and 9.6% of Carnot efficiency has been realized.

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