Investigation on a High-Power Stirling Cryocooler working at 77 K

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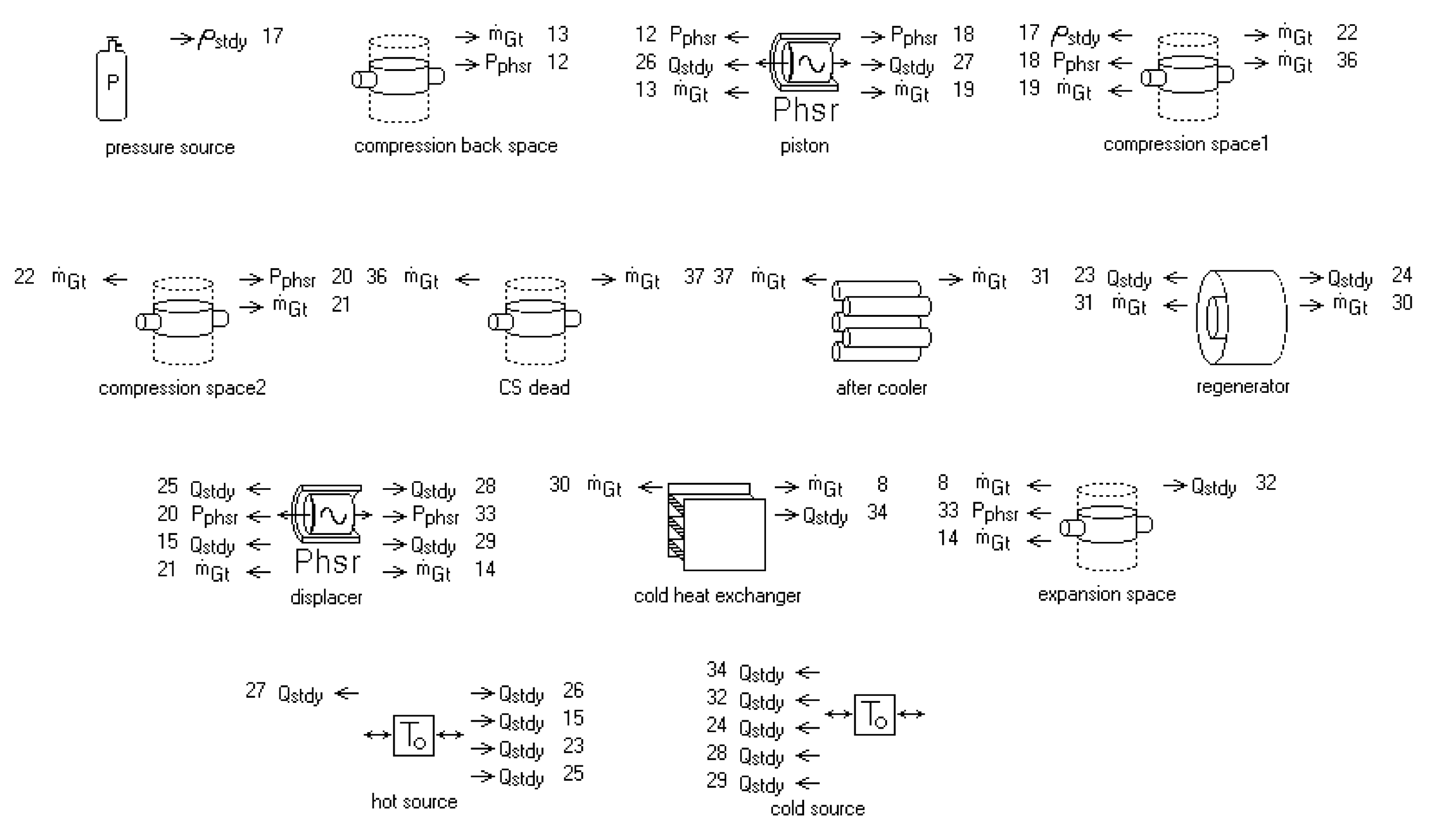
Abstract

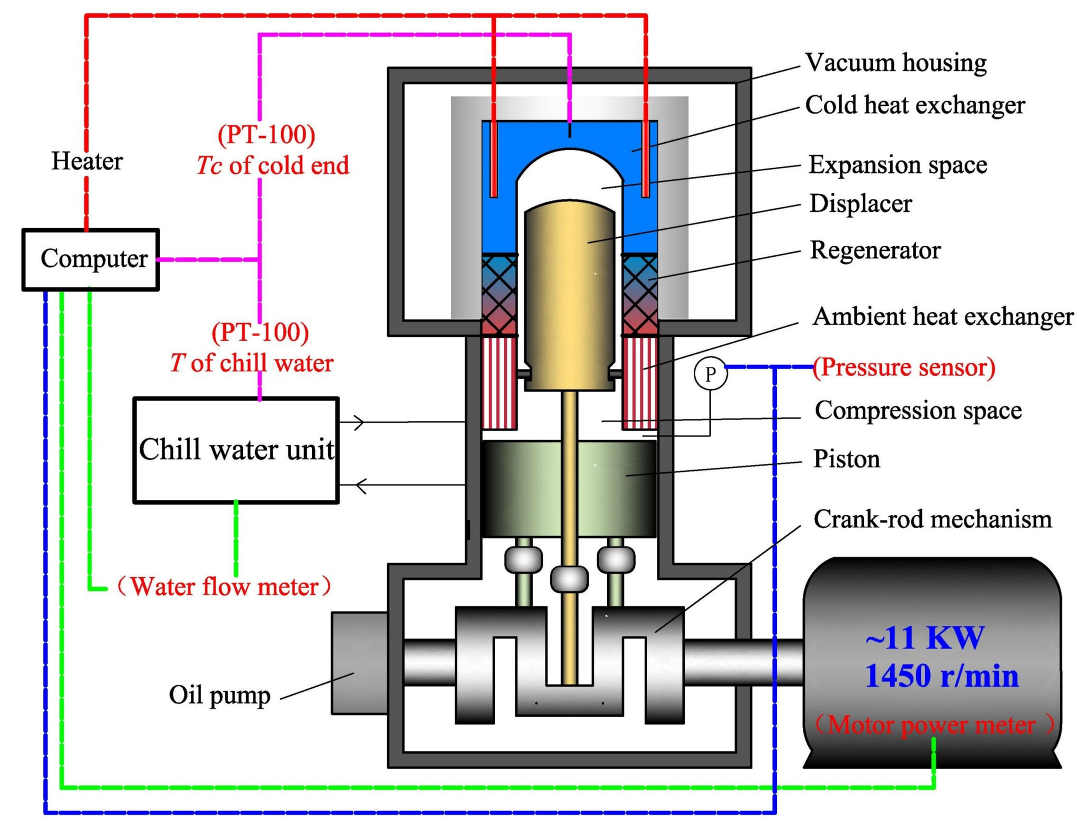
Stirling cryocoolers are promising in high temperature superconductivity application and small scale gas liquefaction, due to their high efficiency, wide operating temperature range and fast cool-down process. A high-power Stirling cryocooler driven by a crank-rod mechanism was studied systematically. A numerical model built upon SAGE-software was used to show the detailed characteristics of mass flow, pressure oscillation, temperature profile, acoustic power distribution and enthalpy flow in the cryocooler. The cooling performance of the cryocooler was tested and analyzed under various operating conditions. A cooling power of 636 W at 77 K with an electrical input power of 11 kW and the charging pressure of 1.65 MPa has been achieved up to now. The comparison analysis between the simulation results and experimental results shows the direction for further design optimization of the high-power Stirling cryocooler.

Conclusion

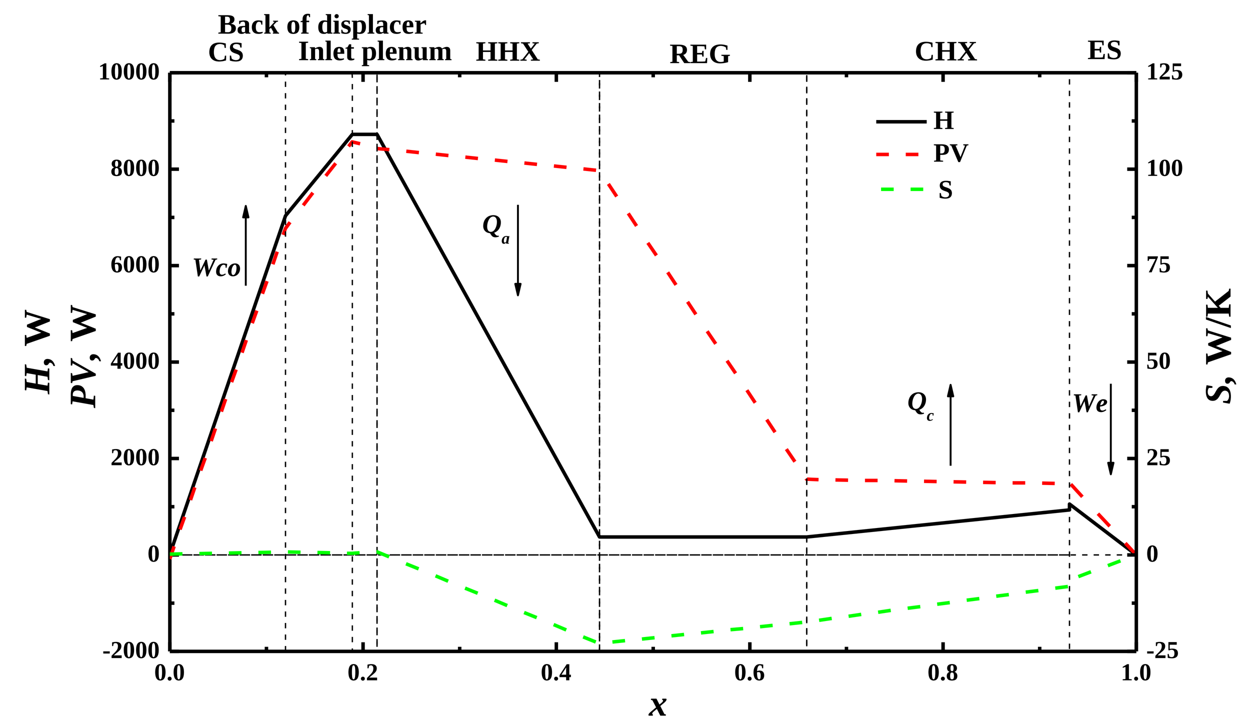
- The cooling power of 636 W at 77 K has been achieved with the electrical input power of 11 kW and the charging pressure of 1.65 MPa.
- Based on experimental performance and SAGE results, the optimal mean pressure is 2.65 MPa, and the optimal frequency can increase to 27 Hz.
- Based on SAGE results, the optimal regenerator length is 37 mm with the mean pressure of 2.65 MPa. With the mean pressure increasing, the optimal regenerator length increases linearly but the corresponding COP will decrease.

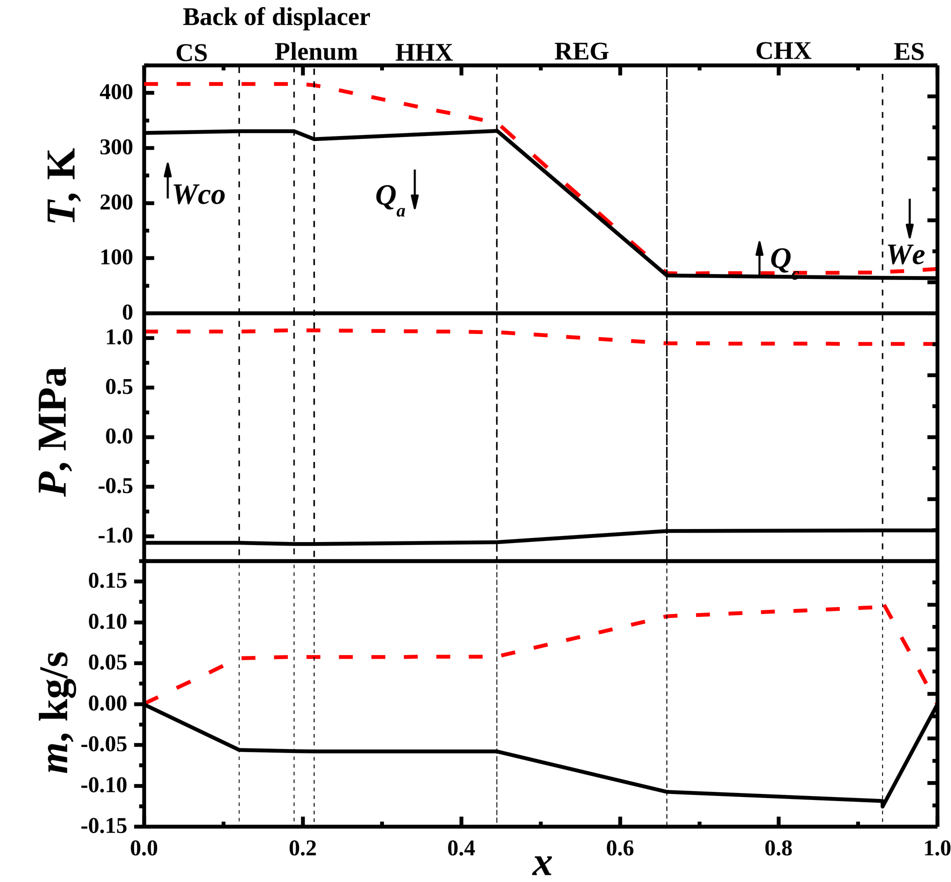
Model & Setup





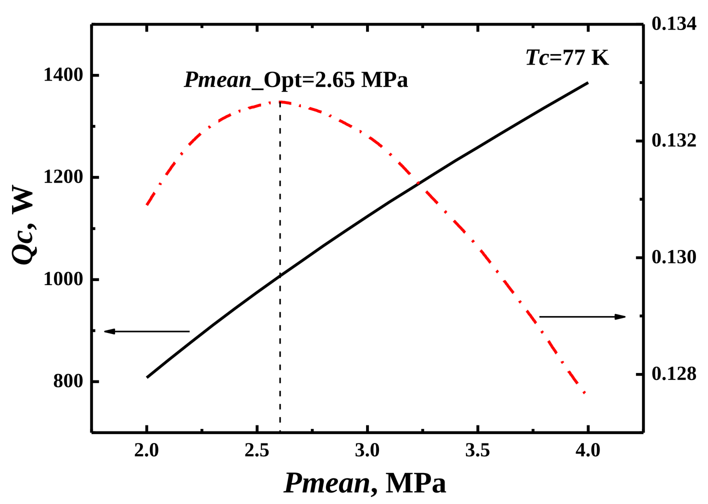
Thermodynamic parameters distribution



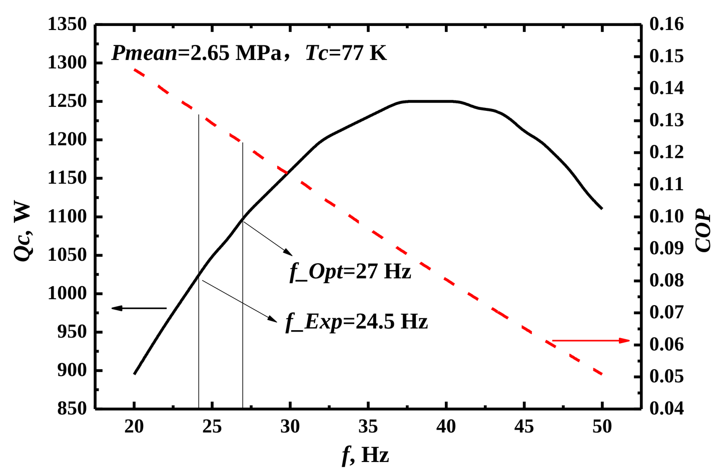


Results

Working condition optimization

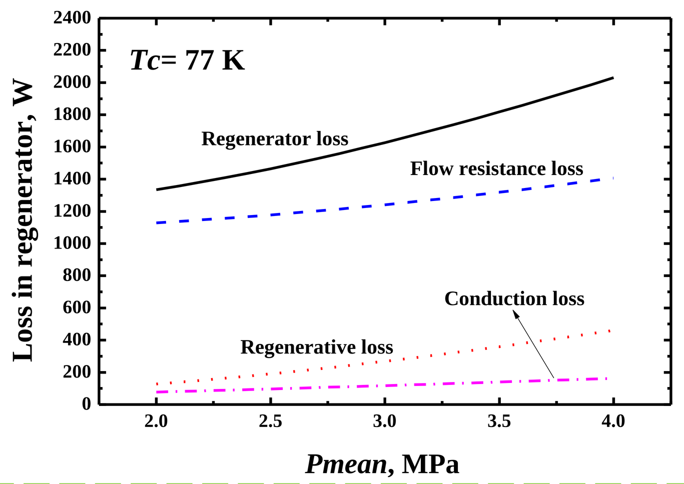


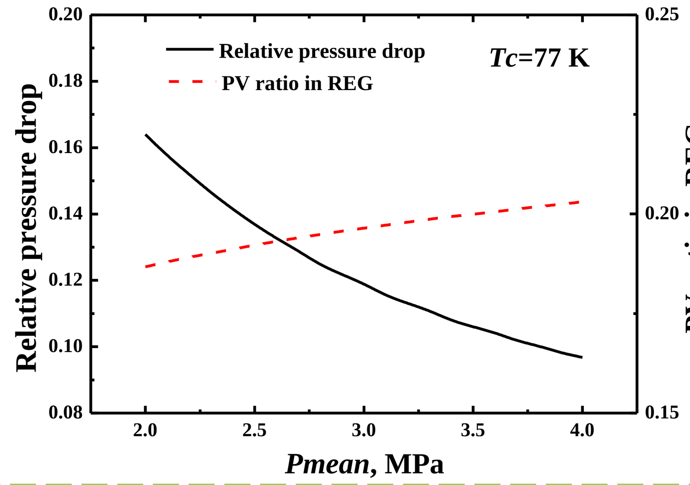
According to the SAGE model result, the optimal mean pressure is 2.65 MPa with the maximum COP as optimization goal, corresponding to the charging pressure is about 1.65 MPa before the cryocooler running.



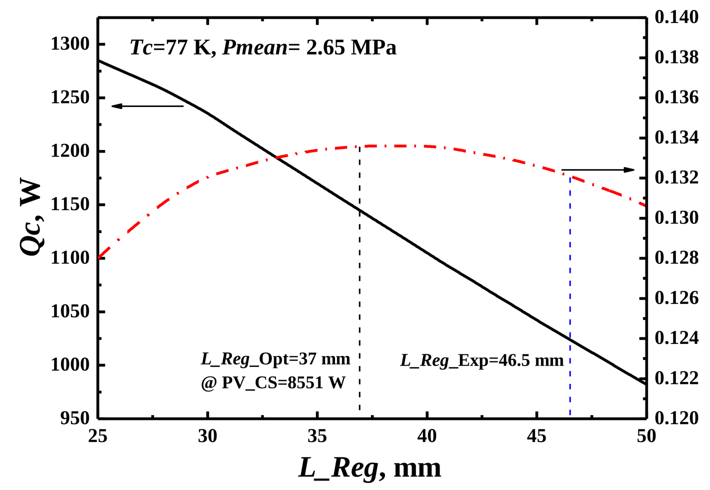
With the frequency increases, the cooling power will reach a peak value. But the COP decreases linearly. So considering the motor performance and the mechanical wear, the optimal frequency can increase to 27 Hz.

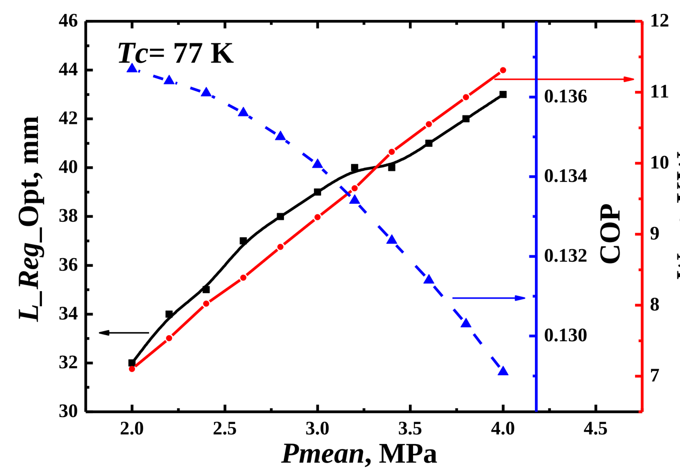
Regenerator optimization





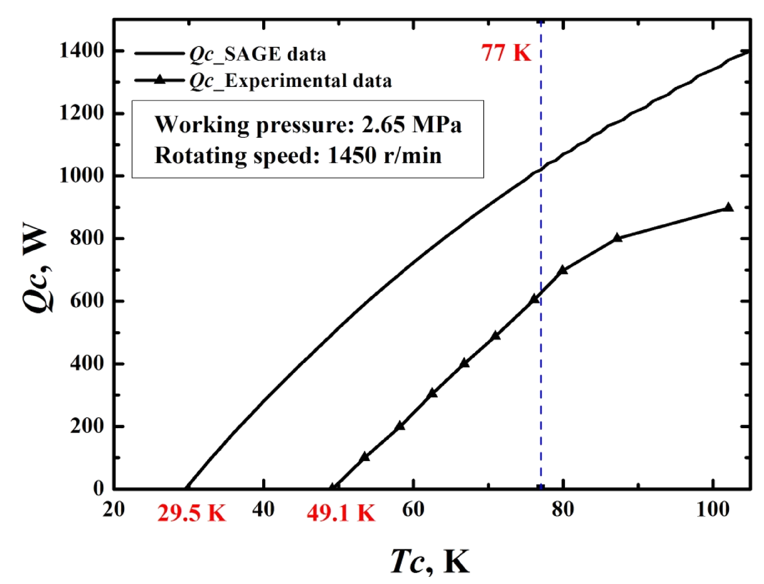
With the mean pressure increasing, although the PV ratio in the regenerator increases, the loss in the regenerator also increase obviously, such as the flow resistance loss and the regenerative loss. So the optimal mean pressure is 2.65 MPa corresponding to the maximum COP.





With the mean pressure of 2.65 MPa, the optimal regenerator length is 37 mm. Compared with the experimental regenerator length, the cooling power will increase by 130 W. Meanwhile, with the mean pressure increasing, the optimal length of regenerator increases linearly and COP decreases.

Performance comparison and analysis



- Experimental result:
  636 W @ 77 K; no-load temperature: 49.1 K.
  Working pressure: 2.65 MPa; Rotating speed: 1450 r/min; Chill water temperature: 293 K.
- SAGE result:
  1020 W @ 77 K; no-load temperature: 29.5 K.
  Working pressure: 2.65 MPa; Frequency: 24.17 Hz; Rejected temperature: 293 K.

Main reasons for difference：

1. The working medium (helium) is susceptible to oil pollution because this type of driving mechanism needs oil lubrication. In the SAGE model, the performance deterioration caused by medium pollution is not considered.
2. Power consumption increases because of some frictional dissipations which usually occur in the clearance between the compression piston and cylinder, the junction between the crank shaft and connecting rods, and crankshaft gears, etc.

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