Performance study on ST/JT hybrid cryocoolers working at liquid helium temperature

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Introduction

- The hybrid space cryocooler, which consists of a Stirling cryocooler and a J-T loop, has become the main cooling technology at liquid helium temperature (around 4 K) in the long-life space mission. It is usually used to directly cool the detectors or precool the other cryocoolers which work at lower temperature.
- There is little detail about the design and the performance analysis of the hybrid cryocoolers in the published literatures.
- For the required cooling power, better performance means less power consumption, which may reduce the weight and volume of the cryocoolers and the power equipment. It is meaningful to the space missions.

1. Common process and key unit

- The 1st process: 6.1-7.1-8.1-9-10-1.1, $T_{P}=20$ K;
- violate the 2nd law of thermodynamics
- $q_{e}=\Delta h_{u,v}=\Delta h_{0,1}$
- $T_{s,1}=T_{s,2}$
- The 2nd process: 6.2-7-2.8-2-9-10-2, $T_{P}=20$ K;
- $q_{e,2}$ with $P_{u,v}$ around 2.5 MPa
- $T_{s,2}=T_{s,1}$
- As $P_{u,v}$ decreases, $q_{e}$ decrease with $\Delta h_{0,2}$
- The 3rd process: 6.3-7-3.8-9-10-3,
- $T_{P}=10$ K;
- larger $q_{e,u,v}$ with lower $P_{u,v}$ around 1.1 MPa
- same $q_{e}$ as $\Delta h_{0,1}$ of the 2nd process with $P_{u,v}$ around 0.6 MPa

The key unit can reach liquid helium temperature as long as the precooler is powerful enough.
- Ineffectiveness of the last (3rd) stage recuperator has no compensation provider.
- $T_{P,2}$ has great impact on the cooling power.
- The function of the upper stages is reducing the precooling load of the last stage.

2. Pressure-Enthalpy map analysis

3. Thermodynamic calculation of the key unit

4. COP optimization of the ST/JT hybrid cryocooler

References