Modeling and Dynamic Simulation of a Large Scale Helium Refrigerator

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Introduction

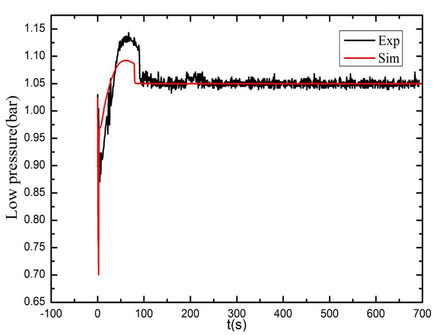
Dynamic simulation is one powerful tool to study transient behaviors of large scale helium refrigerators. CERN and National Institute for Fusion Science(NIFS) had developed their own simulators. In addition, availability of the commercial software Aspen Hysys® in cryogenic system also had been proved. Although the commercial process simulators use easily, it is difficult to debug the process without source codes. Therefore, it is necessary to develop dedicated numerical model to study the transient behaviors of a newly developed 2kW@20K helium refrigerator in TIPC.

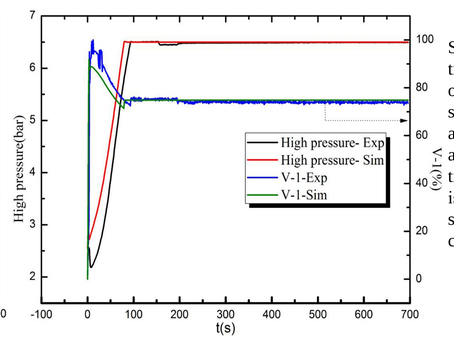
Objectives

- Developing the numerical model of the 2kW helium refrigerator;
- Simulating the start-up process of compressor and cool-down process of cold box;
- Finding the optimal increasing rate of heat load.

Results

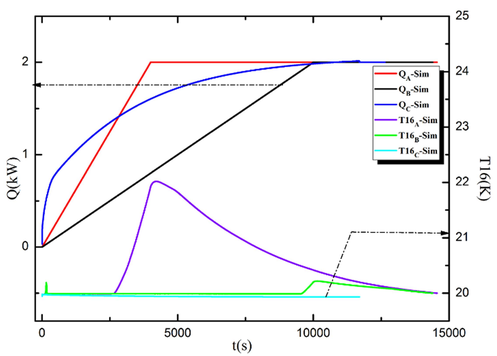
Simulation of start-up process of compressor





Simulation produced acceptable trends during the compressor operation. However, the simulation time was faster than actual operation. The reasons about it are as followings:1) the time lag of signal transmission isn't take into account in the simulation, 2) the inertia of compressor is unknown.

Simulation of different increasing rates of heat load



Cases A and B represented the increasing rates of heat load were 0.5W/s, 0.2W/s, respectively.

Case C was set to maintain the temperature at the location 16 (T16) about 20K by adjusting the heat load (Q).

Elapsed time from zero to 2 kW of cases A, B, C, was 4.17h, 4.12h, 3.58h, respectively. The results represented that T16 in condition B was in the range of 20 ± 0.5K . Case B was easy to implement and had acceptable thermal disturbance. Therefore, it is recommended to use case B in control of the increasing rate of heat load.

Conclusion

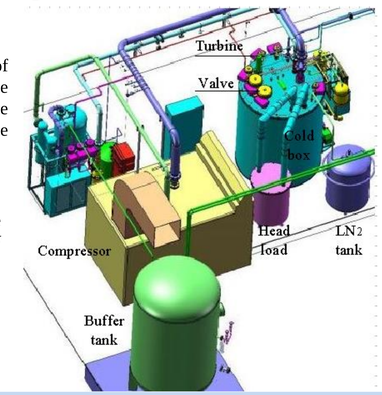
- ✓ The good agreement between the simulation and experiment data allows us to validate the component models.
- ✓ Simulation applied to the different increasing rates of heat load presents that there is a most suitable rate (case B) in actual operation Further experiments will be performed to verify this simulation result.
- ✓ The model will be further modified and performed in a helium liquefier to prove its ability in the near future.

Experiment setup

3D layout diagram of 2kW@20K

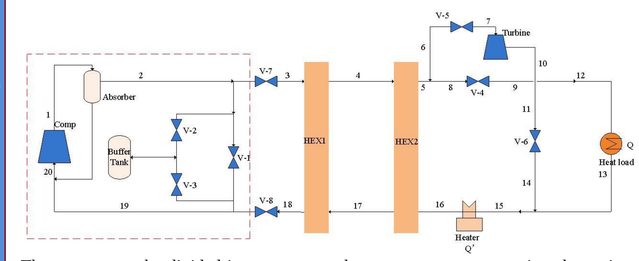
The system is composed of the compressor station, the purifier, the cold box, the turbine, valves, pipes and the heat load.

The reverse brayton cycle had been used in 2kW helium refrigerator.



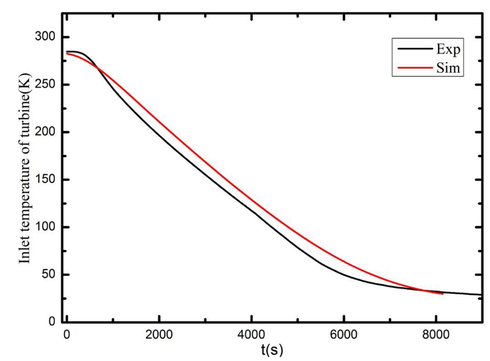
Process flow diagram

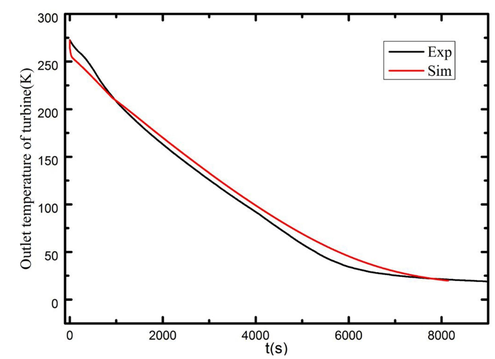
Process flow diagram of 2kW@20K



The process can be divided into two parts: the warm compressor station shown in the dotted lines and the cold box. In order to reduce the complexities in simulation, the process was simplified without affecting the accuracy of simulation results. The pipes and purifier were ignored and the pressure drops of them were added to their nearby equipment.

Simulation of cool-down process of cold box





From the results, it may be observed that the process takes about 2.5h to go down to 20K.The error of cool-down time between simulation and real data is about 10%. However, the temperature deviation still existed in Figures .The reasons may be as following: 1) the initial cool-down sequence of cold box is unknown, 2) fitted equations may be more suitable for full load conditions, and the model should be further modified to improve the accuracy of simulation results.

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