TEMPERATURE PRECISE CONTROL IN A LARGE SCALE HELIUM REFRIGERATOR

J. Wu, W. Pan, B. Wang, Qiang Li, Qing Li

Key Laboratory of Cryogenics, TIPC/CAS, Beijing, China, 100190

Abstract

Precise control of operating load temperature is a key requirement for application of a large scale helium refrigerator. Strict control logic and time sequence are necessary in the process related to main components including a control load, turbine expanders and compressors. However control process sequence may become disordered due to improper PID parameter settings and logic equations, and causes temperature fluctuation, load augmentation or protection of the compressors and cryogenic valve function failure etc. The experimental study, PID parameters for temperature adjustment, in a large scale helium refrigerator of 2kW@20K at TIPC is present. The methods and rules of general parameter settings are revealed and the suitable control logic equations are discussed for temperature stabilization.

INTRODUCTION

As the development of science, a lot of new results had been discovered under a series of extreme conditions, such as super high magnetic field, very low temperature and so on. The human being looks forward to the critical breakthrough in the fundamental theory as well as some very important technical progresses for the globe societies. Such important progress can not be reached without some super large scale science project, such as LHC in CERN, as well as NIF in Lawrence Livermore National Laboratory (LLNL). In such large science project, there are a lot of cryogenic systems, which supplied low temperature sources to cool down some sub-systems to setup the special function for the project. Such high technical sub-system requires a series of features, in which the temperature is one of the most important parameters. This paper discussed the study on precise temperature control in our developed a large scale helium refrigerator.

A LARGE SCALE HELIUM REFRIGERATOR

The basic refrigeration thermodynamic cycle for a large scale refrigerator is reverse Brayton Cycle [1], the principle cycle diagram shown in Fig. 1. But each large scale helium refrigerator will modify some parts according to the practical refrigeration system. Normally, a large scale helium refrigerator are composed mainly by helium screw compressor (light blue), regenerated heat exchanger (at low temperature, gray), control valve (gray), turbine expander (green). For testing the large scale helium refrigerator, a cold load as well as a control load (heater at low temperature, yellow) is needed. The function of the control load will be explained later.

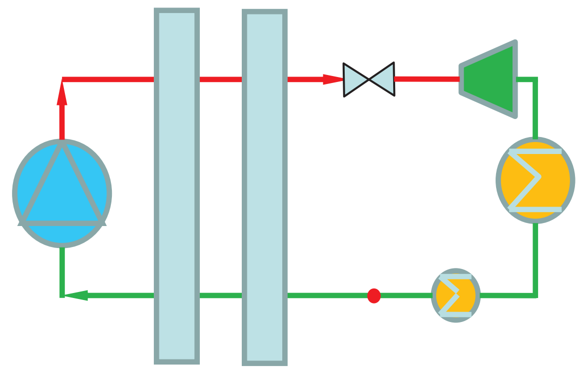

Figure 1: Diagram of a large scale helium refrigerator.

In China, one of national large science project, Chinese Spallation Neutron Source (CSNS) has been under constructed, in charged by the Institute of High Energy Physics, Chinese Academy of Sciences. In the project one of a large scale helium refrigerator will help to cool down the most important neutron source, according to the design, the refrigeration capacity is 2kW@20K. The key laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences developed such large scale refrigerator in the last three years, which can supply 2kW@20K cold capacity. Fig. 2 shows the onsite picture of the large scale helium refrigerator.

Figure 2: The large scale helium refrigerator on site.

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TEMPERATURE ADJUST STRATEGY

The cold load of the spallation cold neutron source is changed in rather large region. The large scale helium refrigerator, as a very complex mechanical system, was composed by a lot of sub-system. Each sub-system was a thermal system, which had different thermal features. By analysis the dynamics features of the whole refrigerator and its effects on the temperature adjustment, the temperature adjustments were divided into three levels, which come from the functions of the important sub-system of refrigerator. In the large scale helium refrigerator, there were only two active refrigeration sub-system, one was the helium screw compressor, which supply refrigeration power and refrigeration material, the other was the turbine expander, which expand the refrigeration material to supply the cold capacity. Both of the two sub-systems were complex mechanical system, so they would not suitable to change the operation condition frequency. From other hand, the adjustment of the helium screw compressor would decide the whole cooling capabilities of the refrigerator, which was arranged for large temperature fluctuation adjustment, and the turbine expander was arranged for a middle temperature fluctuation adjustment. Considering the precious temperature adjustment, a control load (a heater) was designed in the large scale helium refrigerator, which heating capacity was set at less than 10% of the refrigeration capacity by estimating with refrigeration modeling simulation. The control system used the Siemen PLC S7-300 system, programming with Step7 and WinCC program system.

The three temperature adjustment regions were divided as:

1. When temperatures fluctuation was around 20K±0.3K, the control load was operated. Its maximum heating capacity was less then 10% of the refrigeration capacity, and it was maintained at one fifth of heating capacity as a basic heating load. The control load PID system was as normal, the parameters of K_P , T_I , T_D individually as proportion coefficient, integration coefficient and differential coefficient.
2. When the temperature fluctuation was beyond to the temperature region, between ±0.3K and ±3K, the temperature adjustment system would start adjusting the speed of the turbine expender, which got the temperature signal, and by PID control loop to adjust the adjust valve before the turbine expander, that would control the mass flow of refrigeration material, and the speed of the turbine expander as well as the refrigeration capacity were changed. After the refrigeration material went through the virtual load, the temperature of the outlet would be changed either.
3. When the temperature fluctuation beyond ±3K, the control system would start logically to adjust the speed of helium screw compressor. By the modeling analysis, there are still some uncertainties. Large regions speed adjustment of the compressor could induce large pressure fluctuation at low pressure side of the cycle, which possibly causes two reactions. When the pressure was too low, it could induce the interlock protection to stop the whole refrigerator. Conversely, it could induce the frequency jump protection of the compressor. Despite as a rare condition, analysis and experimental studies need to be explored in depth.

STUDY AND EXPERIMENT ON INDIVIDUAL ELEMENT

Under the guidance of adjustment strategy mentioned in upper paragraph, a series of research works for control load, the control valve, virtual load as well the heat exchanger had been studied.

For example of the control load, the considered models were among the first-order inertial element, first-order delay element and two-order damping oscillation element, and so on.

At first, a heat transfer processes in the control load was simulated by CFD program [2], the results, shown in Fig. 3, indicated that some decade temperature difference between center heater and cooling material.

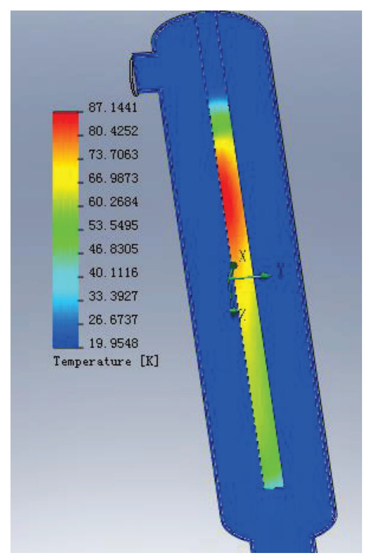

Figure 3: Simulation results of the control load.

According to the simulation condition, a similar experiment had been arranged with a heater at a center and surrounding space with flow gas. From the analysis of heat transfer, the more important features for temperature adjustment of the control load were its dynamic processes. The Fig. 4 shows several experimental results under different heating power with the method of upward curve. The temperature rose rather quick which presented the features of first-order inertial element [3]. By parameters identification, the parameter models were obtained [4], and the model curves were also drawn in Fig. 4.

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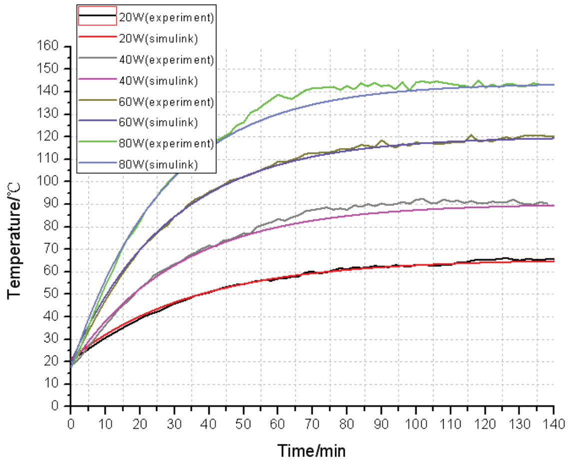

Figure 4: Experiment results with model simulation.

By such individual components study, it was roughly clear the functions of important temperature adjustment components.

OPERATION OF WHOLE LARGE SCALE HELIUM REFRITOR

By combination with the whole refrigerator operation, more detail identification of the parameters was carried out. The two main temperature adjustment parameters, the control load PID coefficients and the turbine expander speed control PID coefficients had been listed at Table 1.

Table 1: PID Coefficients at Present

Control loop	Kp	T_I	T_D
Control load	1.1	650	0
Turbine expander	2.6	200	10

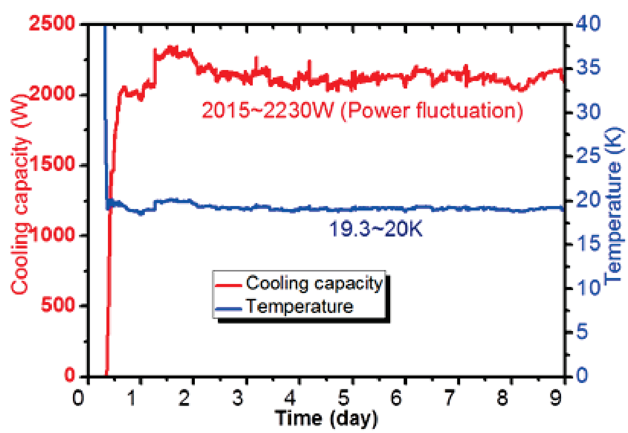

Figure 5: Long period temperature stability of operation situation for the large scale helium refrigerator.

After studying the main components of thermal dynamic features concerning with temperature adjustment, the temperature adjustment strategy was programed with other control strategies, such as safety, stability and so on, into the Siemens PLC S7-300 system. In the last year, the large scale helium refrigerator had been operated at stable cooling capacity of 2kW@20K for 9 days. The operation out-come was shown in Fig. 5.

CONCLUSION

Based on the functions analysis of a large scale helium refrigeration process, the three levels precise temperature adjustment strategy was decided, and a series of thermal features for individual main thermal components were studied further. After carefully experiments and adjustment, a large scale helium refrigerator of cold capacity 2kW@19.7±0.3K had been operated successfully in the Technical Institute of Physics and Chemistry, Chinese Academy of Science.

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