The Control Strategies of a 40L/h Helium Liquefier

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Abstract. A 40L/h helium liquefier has developed by Technical Institute of Physics and Chemistry, Chinese Academy of Sciences. It uses ATEKO’s electromagnetic bearing turbine expanders and KAISER’s helium screw compressor as its main components. Its control system uses the SIEMENS PLC S7-300 and its related programming software Step7 V5.5 and process monitoring software WinCC V7.2. The control strategies of the machine mainly include three parts. One is to ensure the compressor supply enough power and refrigeration mass flow; another is to ensure the turbines supply enough refrigeration capacity; and finally is to make the dewar cool down to the set temperature and the refrigeration material change to liquid helium stably. All of these are achieved by adjusting various control valves of the system. This paper will detailed describe the control strategies of these parts, and give the PID control parameters.

1. Introduction

40L/h helium liquefier is the smallest scale liquefier in the series of turbo expansive helium refrigerator. The key requirement is to improve the stability of gas bearing turbine expander with the speed grade of about 200,000 rpm, which is unique to cryogenic systems in the 4.5K temperature zone.

A 40L/h helium liquefier has developed by Technical Institute of Physics and Chemistry, Chinese Academy of Sciences. Its principle block diagram is shown as figure 1. It’s mainly composed of one compressor, six heat exchangers, two turbine expanders, one dewar and control panel. It uses ATEKO’s electromagnetic bearing turbine expanders and KAISER’s helium screw compressor as its main components. Its control system uses the SIEMENS PLC S7-300 and its related programming software Step7 V5.5 and process monitoring software WinCC V7.2. It works in the liquefaction mode with the target of 40L/h. The highest frequency of its compressor is 50HZ, and the set speed of turbine expanders (TM3 and TM4) is 212,100 rpm and 200,300 rpm.
2. Control strategies of the system

The helium liquefier has only two active refrigeration sub-systems, one is the compressor unit, which supplies enough power and refrigeration mass flow; and the other is turbine expander unit, which expands the refrigeration mass flow to supply enough cold capacity [1].

2.1. Compressor unit

In the compressor unit, the most important thing is to keep system’s high pressure and low pressure stable at the set point, to ensure the compressor speeds up smoothly. Control valves (CV0010, CV0110, CV0210) in the gas management panel can do this. Compensation gas valve (CV0110) and exhaust valve (CV0210) adjust high pressure, while bypass valve (CV0010) adjusts low pressure [2]. We ensure the compressor speed up linear with the control valves automatically adjusted by their PID control loops.

The structure principle of PID control loops in the gas management panel is shown as figure 2. The controlled object is the set point of system’s high pressure or low pressure, and the actuator is the three control valves. When the controlled object deviates from set point, the PID module will calculate a movement to cause actuator acting for adjusting the pressure return to its set point value.

The PID control algorithm is as follows:
\[
    u(n) = K_P \left\{ e(n) + \frac{T}{T_I} \sum_{i=0}^{n} e(i) + \frac{T_D}{T} [e(n) - e(n-1)] \right\} + M
\]

In equation (1), \( e(n) \) is the deviation; \( M \) is the integral initial value; \( K_P \) is the proportional coefficient; \( T_I \) is the integral time constant; \( T_D \) is the differential time constant; and \( T \) is the sampling time. The main PID control coefficients of gas management panel are shown as table 1, and its sampling time is 1s.

| Controlled Object   | Actuator           | \( K_P \) | \( T_I \) | \( T_D \) |
|---------------------|--------------------|----------|----------|----------|
| High pressure       | Compensation gas valve | 0.07     | 3        | 0        |
|                     | Exhaust valve      | -1       | 1        | 0        |
| Low pressure        | Bypass valve       | 0.9      | 0.5      | 0        |

2.2. *Turbine expanders unit*

In this system, turbine expanders have their own control system made by ATEKO, we only need to adjust the control valve (CV2120) upstream of the turbine expander, which would control the mass flow of helium, and then change the system’s refrigeration capacity. In this process, we keep the axial forces of the turbine expanders below 23N. We make the control valve changes step by step before 10% opening, and then linear changes. Its maximum opening can reach 44%, with system’s mass flow reaching 21.4g/s.

2.3. *Dewar unit*

In this system, we cool down the cold box with liquid helium stord in dewar together. When the outlet temperature of TM4 reaches about 60K, we open the control valve after dewar (CV2260) lineary to 100%, and then slowly open the JT valve (CV2160) before dewar manually, increasing the outlet pressure of dewar to 1.25bar. Meanwhile we close the bypass valve of coldbox (CV2150). Then the dewar begins to cool down. When the outlet temperature of dewar reaches about 4.5K, the system begins to produce liquid helium. The whole process from turbine reaching its set speed to producing liquid helium takes about one and half an hours.

3. *Result from experiment*

We have finished the experiment of this system in 11th June, 2018, the result is shown as figure 3 and figure 4. Its average value of liquification rate reaches 52L/h from in 50 minutes. And the efficiency of the first turbine is more than 71%, while the second turbine is more than 66%.
4. Acknowledgement
This work is supported by the research fund of State Key Laboratory of Technologies in Space Cryogenic Propellants (Fund No.SKLTSCP1603).

References
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