The Research of PID Control in a Large Scale Helium Refrigerator

*Wei PAN, Ji hao WU, Lai feng LI, Hui ming LIU, Qing LI**

State Key Laboratory of Technologies in Space Cryogenic Propellants, TIPC/CAS, Beijing, 100190, China

*Email:liqing@mail.ipc.ac.cn

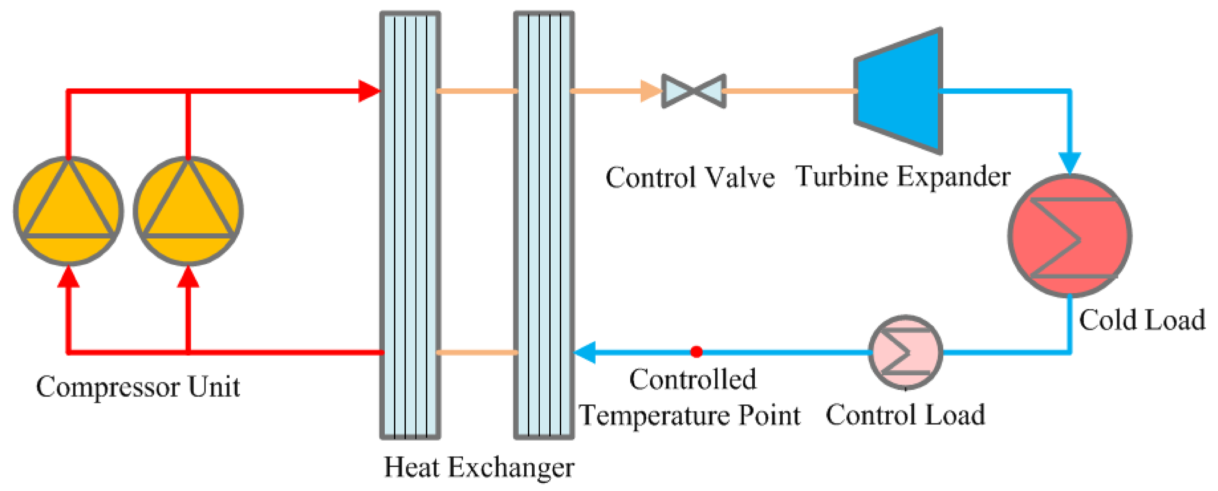
Technical Institute of Physics & Chemistry/CAS

Presentation ID : C3PoA-06

Review

A 10kW@20K large scale helium refrigerator is developed by Technical Institute of Physics and Chemistry, Chinese Academy of Sciences. It is mainly composed by compressor unit, heat exchanger, control valve, turbine expander, cold load, control load and so on.

There are many different kinds of signals in the system, such as temperature, pressure, valve opening, flow, rotate speed, power, switching value and so on, whose quantity can usually reach to hundreds. And refrigeration equipments also have characteristics of large time-delay, strong non-linear, coupling of many factors and variable parameters.



At present, the Programmable Logic Controller (PLC), which is based on a microprocessor, is widely used in areas of industrial production. It uses a programmable memory to store and perform instructions, such as logical operation, sequential control, timing, counting, arithmetic operation and so on. And through digital and analog inputs and outputs, it can control various types of machinery and production processes.

The 10kW@20K large scale helium refrigerator uses Siemens' S7-300 PLC to achieve automatic controls.

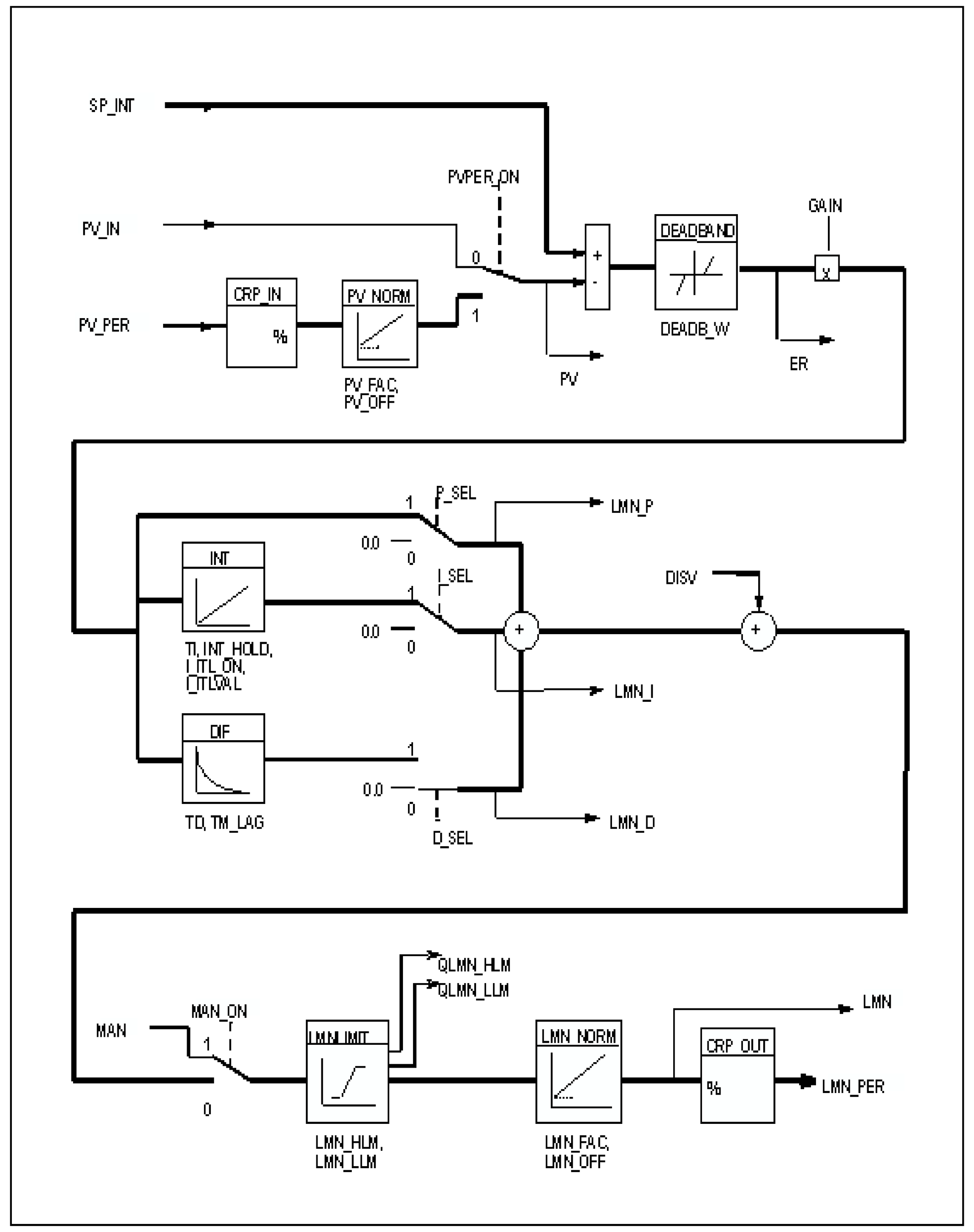
Position-type PID Control Algorithm

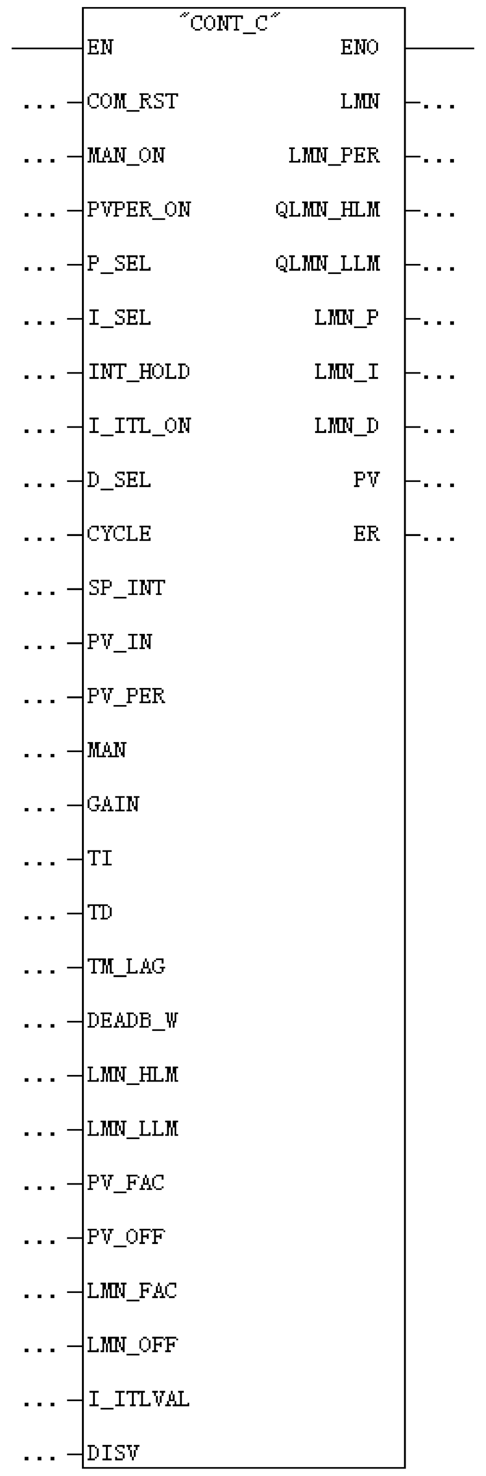
The FB41 controller uses a position-type PID control algorithm.

$$u(n)=K_P\left\{e(n)+\frac{T}{T_I}\sum_{i=0}^{n}e(i)+\frac{T_D}{T}[e(n)-e(n-1)]\right\}+M$$

- $e(n)$ - deviation;
- M - integral initial value;
- K_P - proportional coefficient, set by GAIN pin;
- T_I - integral time constant, set by TI pin ;
- T_D - differential time constant, set by TD pin;
- T - sampling time, set by CYCLE pin.

FB41 Digital Controller in PLC S7-300





The digital PID controllers of S7-300 PLC system are all integrated in its host-computer software called STEP 7. The controllers are provided to users in forms of encapsulated control blocks. Users can customize control parameters through block pins.

All the control loops of the 10kW@20K system have used the FB41 (CONT_C) control block. Their inputs and outputs are all continuous variables.

FB41 executes an algorithm principle as:

◆ Put the deviation of the dynamic process value (PV_IN: input process variables of floating point form; PV_PER: input process variables of peripherals direct) and the set point value (SP_IN) into P, I, D controllers respectively.

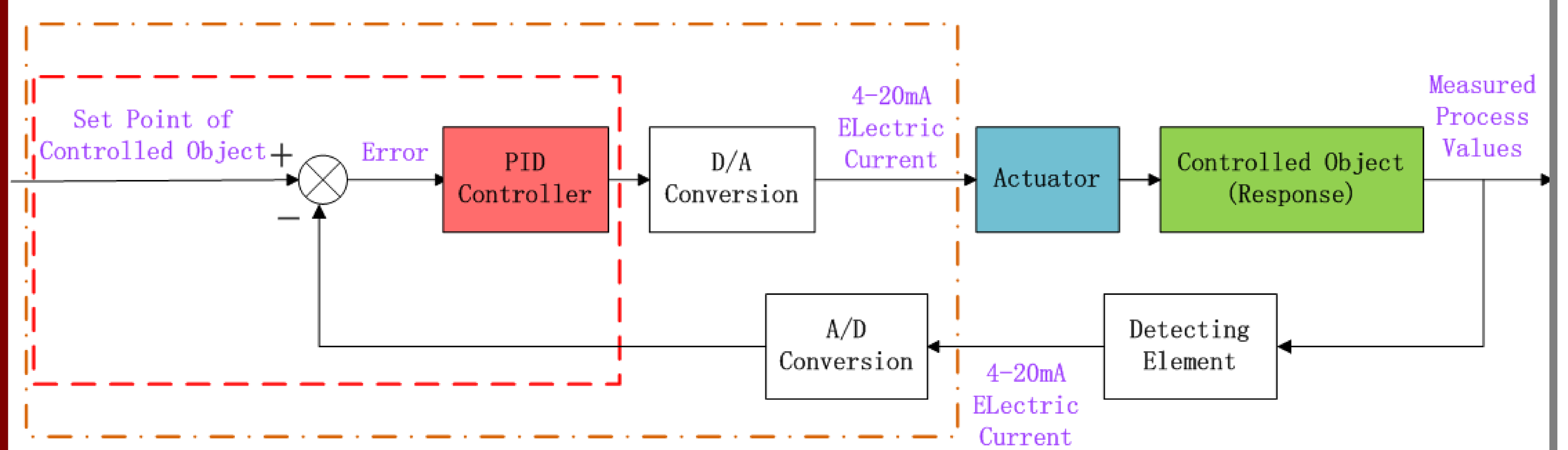
◆Then each controller uses its own control coefficient (GAIN: ratio coefficient; TI: integral coefficient; TD: differential coefficient) to calculate, getting three items of control value (LMN_P, LMN_I and LMN_D).

◆Each controller can also be enabled or cancelled separately through their switching values (P_SEL, I_SEL and D_SEL).

◆When the PID mode switch value MAN_ON = 1, the control comes to manual mode, and the final output of PID control (LMN) is equal to the manual value (MAN), which is limited by the upper (LMN_HLM) and lower limit (LMN_LLM).

◆When MAN_ON = 0, the control comes to automatic mode, and the final output of PID control (LMN) is equal to the amount of the three control value (LMN_P+LMN_I+LMN_D), which is also limited by the upper (LMN_HLM) and lower limit (LMN_LLM).

PID Control Loop

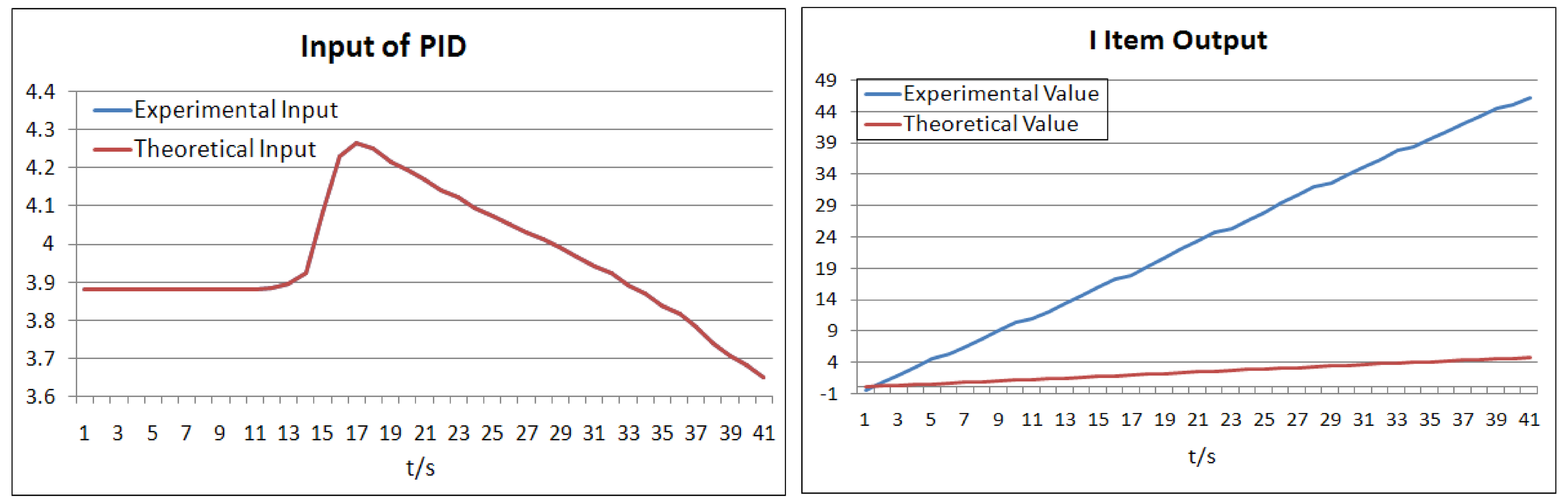


Research of PID's Calling Time and Sampling Time

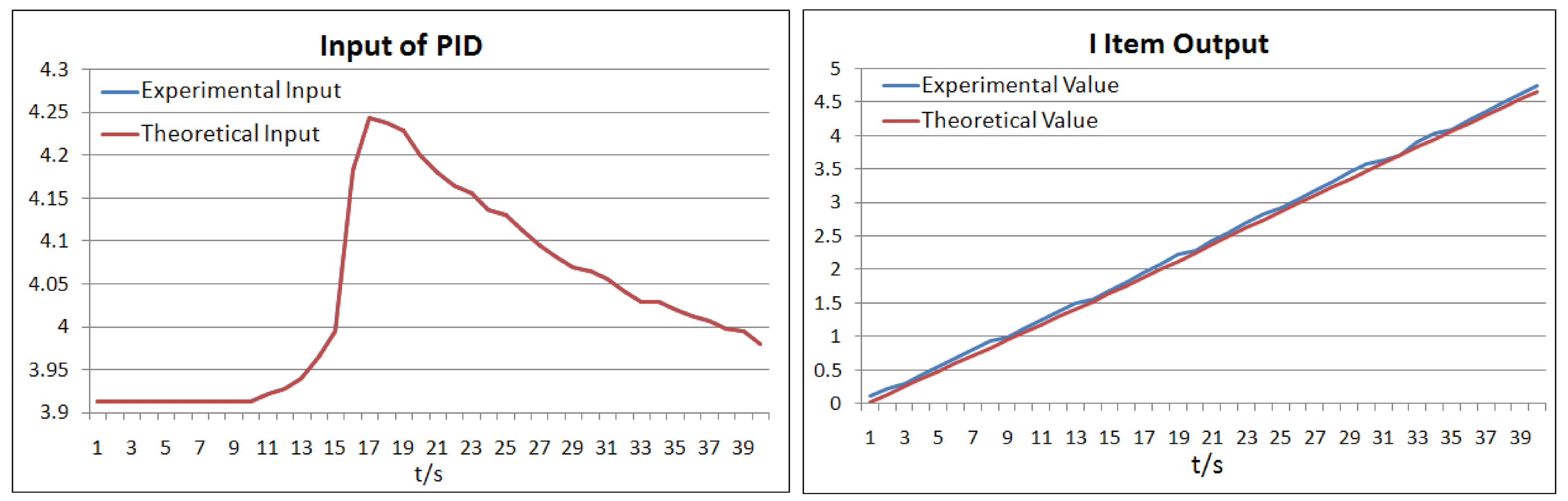
We put FB41 into a cyclic interrupt block OB35 to execute. The cyclic interrupt time of OB35 (calling time of FB41) is controlled by the CPU operating system. Every this time, OB35 performs the cyclic interrupt program once, and at the same time calls FB41 to adjust the process variable using PID arithmetic. But the sampling time CYCLE of PID is used to control the input of FB41. Every this time, the input data of FB41 refresh once. It's the time between FB41 calls.

The sampling time should be consistent with the calling time, otherwise, it will cause FB41's integral output and differential output different from their theoretical calculation values. Then the PID parameters we obtained from theoretical analysis or historical experience will lose its reference value. When we enter the PID parameters into the control system, the system will be in a serious imbalance, and any fine-tuning is unable to make the system stable

An Example



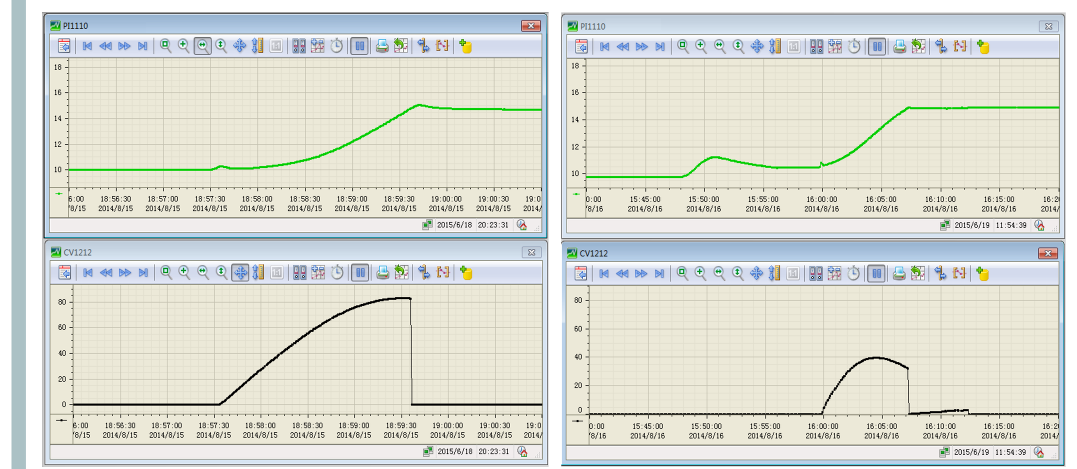
when the calling time=0.1s and sampling time=1s



when the calling time=0.1s and sampling time=0.1s

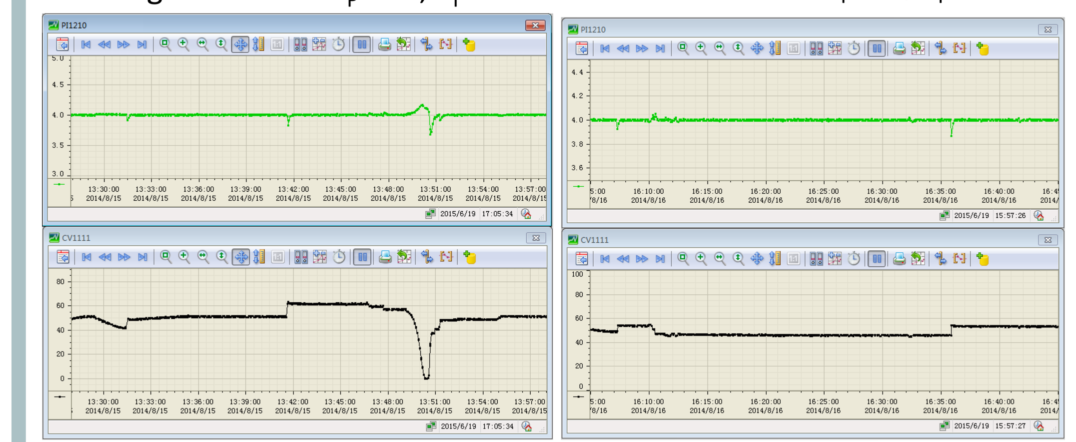
Research on PID Parameters' Setting

Two Setting Examples



Wrong result with K_P=5.3, T_I=180. Ideal result with K_P=10, T_I=3000.

Adjusting effect of high pressure supply. The upper curve is high pressure, and the lower curve is the opening of compensation gas valve. High pressure should not overshoot, and the valve should be closed in a small opening.



Wrong result with K_P=55, T_I=180. Ideal result with K_P=50, T_I=100.

Adjusting effect of low pressure. The upper curve is low pressure, and the lower curve is the opening of bypass valve. The valve should response quickly to keep low pressure a small fluctuation.

Stable Running Result of the Refrigerator

The 10kW@20K large scale helium refrigerator has successfully run for 72 hours, with the controlled temperature holding steady at 19.7K±0.3K, while the load heating at 10.7kW±0.3kW.