AUTO-FILLING CRYOGENIC SYSTEM FOR SUPERCONDUCTING WIGGLER

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Abstract

In a cryogenic plant, in which a superconducting rf cavity is present, an independent automatic filling system provides liquid helium and liquid nitrogen to the superconducting wiggler. A PID controller, the kernel of the auto-filling system, controls the valves of the liquid helium and the liquid nitrogen to facilitate a stable and precise auto-filling process. This work presents the control algorithm for the pre-cooling mode and normal auto-filling mode and presents cryogenic testing results.

INTRODUCTION

In January of 2004 [1], a 3.2 Tesla superconducting wiggler with a periodic length of 6.0 cm (SW6) was constructed and installed downstream of the superconducting RF cavity (SRF) in the fourth straight-section to increase the photon flux in the hard X-ray range on a 1.5 GeV storage ring at the National Synchrotron Radiation Research Center (NSRRC). The SW6 is designed to operate in liquid helium. A helium cryogenic system at the NSRRC with the maximum liquefaction rate of 153 L/h provides liquid helium to the SW6 at an operating pressure of 1.1 bars [2]. An auto-filling system for SW6 was implemented and tested successfully in April of 2004. The control and safety protection system includes the cold valve box control associated with the PID system; the safety of the pressure of the helium and nitrogen vessels, and the operation of the magnet are ensured by recording the temperatures of the protection diodes and the vapor-cooled current leads. The control algorithm for the auto-filling system, and the results of commissioning are discussed

CONFIGURATION OF CRYOSTAT

Figure 1 illustrates the configuration of the cryostat. The cryostat is divided into three layers - the 4.2K, the 80K and the 300K layers. The 4.2K layer is a 200 liter liquid helium (LHe) stainless steel vessel. The magnet array is soaked in the liquid helium vessel. A 6 psig relief valve and a 25 psig burst disk is placed at the output port of the LHE vessel to protect the vessel against over-pressure. The 80K layer is a 60 liter liquid nitrogen (LN2) aluminum vessel. A relief valve of 6 psig is positioned at the output port of LN2 vessel and protects the LN2 vessel. The 80 K layer is used for thermal shielding and cools the beam tube. A total of 30 super-insulation layers are used to cover the 4.2 K and 80 K layers, respectively, and are used to shield against thermal radiation. Two temperature sensors were used to monitor the temperature of the vapor -cooled current leads; two temperature sensors measure the temperatures of the protection diodes. Furthermore, temperature sensors are present in the middle of the beam duct and at the beam duct taper.

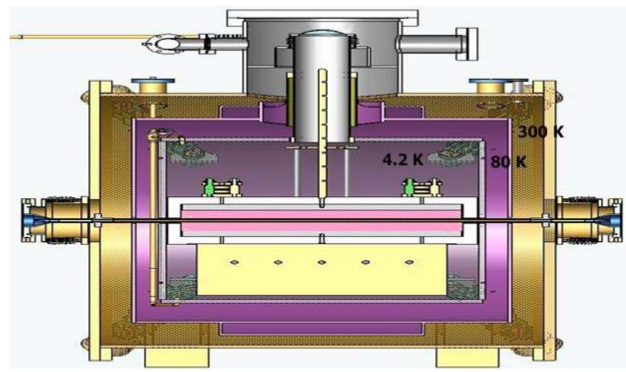

Figure 1. Configuration of the cryostat

CRYOGENIC FILING SYSTEM

Figure 2 shows the structure of the cryogenic filling system for SW6. The cryogenic filling system includes one 315 kW compressor, one 45 kW recovery compressor, one 10 kW refrigerator, one 2000 litter dewar and two 100 m^3 gas helium storage tanks. The system provides a liquefaction rate of 60.5 L/h or 153 L/h, depending on the refrigeration mode. The LHe is supplied from the main dewar and distributed to the valve box, and then via a flexible transfer line to the LHe vessel of SW6. The boil-off helium gas is recycled to the recovery compressor via a flexible suction line to a warmer that warms up the low-temperature helium gas.

COMPONENTS OF AUTO-FILLING SYSTEM

The basic components of the auto-filling system are the cryogenic level meters, the pressure sensors, the PID controller and the programmable logic controller (PLC). Figure 3 illustrates the structure of the SW6 auto-filling system. The cryogenic level meter monitors the levels of LHe and LN2 liquids. The meter converts the liquid level into an analog signal, in the range 0-10 V. The output signal is treated as the input of the PID controller. The PID controller compares the input value to the set value, and regulates the supply valves for LHe or LN2. The pressure sensors monitor the LHe vessel, the LN2 vessel and the warm gas return pressure. The range of the sensors is 0-30 psig and the pressure is converted into an analog signal, in the range 4-20 mA. The output signal is connected to the input of PID controller. Then, the output signal is connected to the PLC controller as an interlock signal. The PID controller is a kernel of the auto-filling system. It provides the manual and automatic modes of operation. The output signal includes an analog signal and a relay signal for system control. The PLC collects the signal associated with the LHe and LN2 levels as well as the all-pressure value; the quench signal of SW6 and the emergency close button are treated as hardware interlock signal. The two valves are the LHe supply valve and the warm return valve. The LHe supply valve is located at the distribution valve box, and is electro-pneumatic. The warm return valve is located at the front of He gas warmer, and is electro-magnetic.

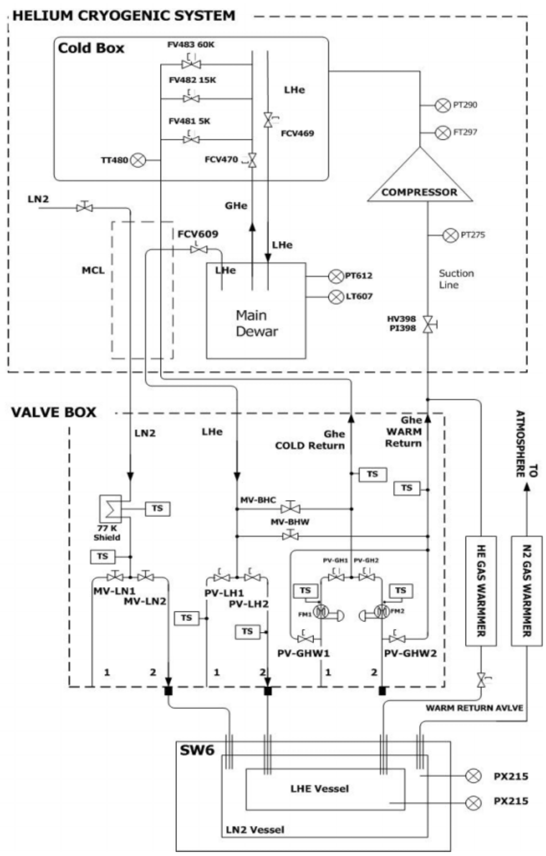

Figure 2. The structure of cryogenic filling system

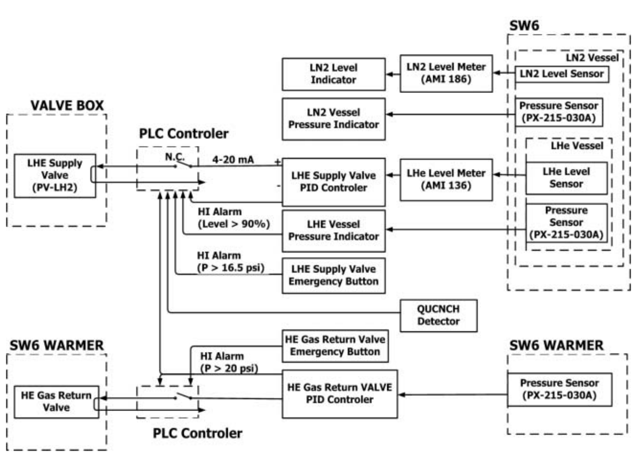

Figure 3. Configuration of Auto-filling system

CONTROL ALGORITHM OF AUTO-FILLING SYSTEM

The system supports manual and automatic LHe filling. The manual mode is used in the pre-cooling stage, in which the fluctuation of the LHe vessel pressure is large, as is required for manual operation. The user can set the open value to control directly the LHe supply valve. The automatic mode is used in the normal filling state, with PID and ON/OFF control modes. The PID control mode of the controller uses PID control logic to regulate the LHe supply valve, and keep the LHe level at the set value. The range of fluctuation is ±0.2%. In the ON/OFF control mode, the output value of controller is either 100% or 0%, depending on the difference between the reading and the set value. This is used to maintain the LHe level in the range ±1%.

During LHe filling, if the pressure of the LHe vessel exceeds 16.5 psig or the SW6 is quenched, then the hardware interlock will close the LHe supply valve and the LHe filling is stopped. When the pressure exceeds 20 psig, the warm return valve is closed to avoid affecting the operation of the recovery compressor and the SRF.

COMMISSIONING RESULT

Figures 4 (a) and (b) present the relationship between the LHe level and the vessel pressure in the PID control mode. The controller is governed by the difference between the LHe level reading and the set value, which difference is used to regulate the LHe supply valve and maintain the LHe level at 76 ± 0.2%. During this period, the GHe pressure is 15.75 ± 0.02 psig. The ON/OFF control mode is used to maintain the LHe level in the range 75± 1%. Figures 4 (c) and (d) plot the relationship between the LHe level and the vessel pressure in the ON/OFF control mode. The controller uses the set value and the range of fluctuation to regulate the supply valve and keep the level at 74 - 76 %. However, the pressure rises to 16.25 psig in the filling stage.

After SW6 quenching, the LHe vaporizes 10 l within 15 seconds and the LHe vessel pressure rises rapidly. The protective actions are as follows. The LHe supply valve is closed directly; the warm return valve is closed until the pressure exceeds 20 psig, and then all pressure is released via the relief valve to the atmosphere.

Figure 5 plots the relation between LHe filling in the PID or the ON/OFF control mode with respect to the variation in the LHe level of the cryogenic system's main dewar. In the test, the helium cryogenic system provides a liquefaction rate 60.5 L/h. The measured data in Figs. 5 (a) and (b) were obtained in the PID control mode; LHe is continuously supplied and the consumption of LHe exceeds liquefaction rate so the main dewar level decreases. The measured data in plotted Figs. 5 (c) and (d) are obtained in the ON/OFF control mode; the period of LHe filling is approximately 20 minutes, and the filling time is approximately three minutes. Therefore, the consumption of LHe is slower than the rate of liquefaction, and the main dewar helium level increases.

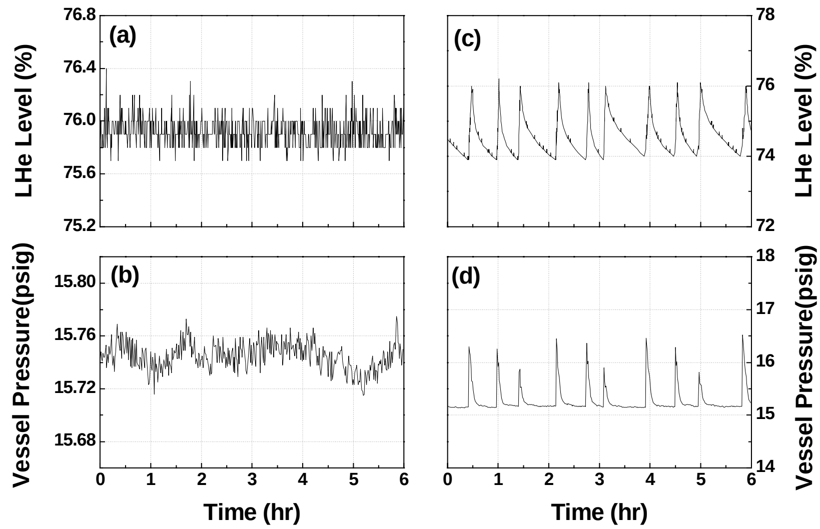

Figure 4. The relation between LHe level and vessel pressure in (a) and (b) the LHe filling in the PID control mode, and in (c) and (d) the LHe filling in the ON/OFF control mode.

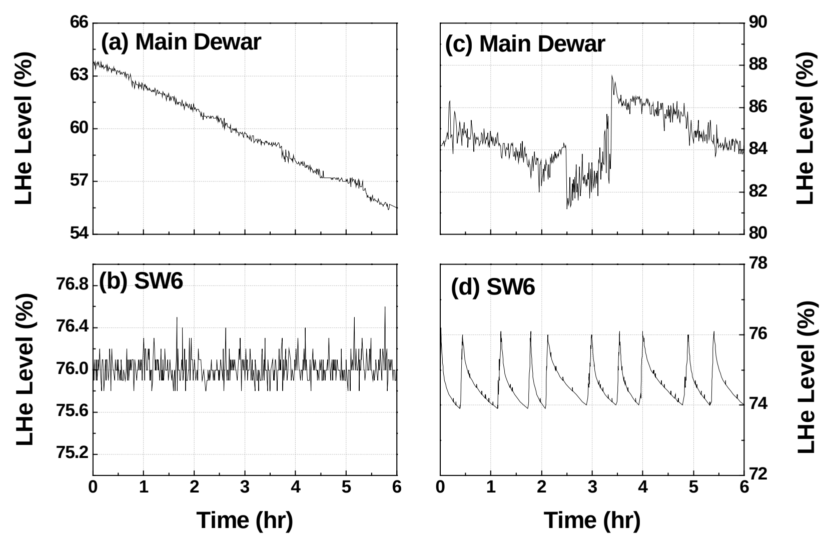

Figure 5. The relation between the SW6 and main dewar LHe level variation, (a) and (b) is the LHe filling in PID control mode, (c) and (d) is the LHe filling in the ON/OFF control mode.

CONCLUSION

The results of commissioning show that the variation in the liquid helium level can be controlled within 0.1% in the PID control mode. However, the ON/OF control mode provides lower LHe consumption than the PID control mode. Therefore, the ON/OFF control mode is selected for auto-filling the SW6 with liquid helium. Meanwhile there is no side-effect on the magnet operation when the ON/OFF control mode was performed.

REFERENCES

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[2]. F.Z. Hsiao et al., “The pilot-runs of the helium cryogenic system for the TLS superconducting cavity” Oregon USA, May 12-16, PAC 2003.