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Preliminary Tests on the Buffer Tank for the Vented Liquid Nitrogen Flow of an SRF Module

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***Abstract*—**Since 2005, an SRF module of CESR type serves as the accelerating cavity at the Taiwan Light Source in the National Synchrotron Radiation Research Center. A 500-MHz niobium cavity is immersed in liquid helium inside this SRF module. To reduce heat load, the liquid helium vessel is thermally shielded by liquid-nitrogen-cooled copper layer, and the beam chambers are also anchored with pipes of the liquid nitrogen flow in middle of the liquid helium vessel and the vacuum vessel. A strong correlation of the movement of the cavity's frequency tuner with the temperature variation of parts cooled with liquid nitrogen was observed. A previous study on a spare SRF module with the niobium cavity cooled by liquid nitrogen instead of liquid helium, satisfactory suppression of the thermal oscillation was achieved by attaching a temporary buffer tank for the vented shielding nitrogen flow from the SRF module. In this study, a home-made buffer tank is designed and integrated to the spare SRF module with cavity cooled by liquid helium. Design, construction, integration, and preliminary test results of this buffer tank are presented.

***Keywords*—**Cryogenics, flow control, oscillation.

I. Introduction

THE Taiwan Light Source (TLS) in the National Synchrotron Radiation Research Center (NSRRC) is currently operated with 300 mA electron beam of 1.5 GeV to provide high quality synchrotron light for a variety of researches. A 500-MHz superconducting radio-frequency (SRF) module of CESR type [1] was installed as the accelerating cavity in the electron storage ring at the end of 2004. Mainly the cavity structure is made of niobium sheet, and immersed in liquid helium to achieve superconducting state. To reduce the heat load on the coolant, the liquid helium vessel is thermally shielded with both liquid nitrogen layer and vacuum vessel, whereas the multiple super-insulation layers cover both the liquid helium vessel and the liquid nitrogen shielding layer.

For the superconducting cavity of shell-like structure, its RF resonance frequency is dominated by its geometric shape and thus could be shifted by external loads. Thus there is a mechanical tuner that moves to deform the cavity shape slightly as necessary to minimize the deviation between the desired and the measured resonance frequency of the cavity, in terms of RF phase error. The residual RF phase error could disturb the feedback loops of the low-level RF (LLRF) system and eventually creates feedback instability. The tuner is highly expected to be stable at a certain region and even ideally to remain at a specific location.

For some years, TLS has been operated under the conditions that most of the possible sources of exciting an accidental movement of the cavity tuner are eliminated. For example, as being immersed in liquid helium, variation of the pressure of the liquid helium vessel certainly shifts the resonance frequency of the SRF cavity and thus requests a movement of the tuner. The pressure variation of the liquid-helium vessel is thus controlled within ±2 mbar at a nominal operational pressure of 1.24 bar abs. [2]. The electron storage ring is operated with a quasi-constant beam current of varying less than 1% [3]; the effect of beam loading variation on the tuner motion is thus also negligible. But the tuner remains busy during routing operation.

The later study [3] concluded the tuner motion clearly correlates with the temperature fluctuation of the thermal-transition beam tubes, while it was also reported by the Diamond Light Source (DLS) in UK [4]. The thermal transition beam tubes are cooled by liquid nitrogen and located in between the helium vessel and the room-temperature vessel for vacuum shielding. A temperature fluctuation on these two thermal transition beam tubes shall result in varying thermal deformation and induce an axial force on the cavity structure. Consequently the resonance frequency of the cavity fluctuates and the feedback loop drives the tuner to compensate this effect. It was thus tried to stabilize the temperature of the beam tubes cooled by liquid nitrogen.

For this SRF module, liquid nitrogen cools sequentially the thermal-transition section at the flute beam-tube (FBT) side, the copper layer that serves as thermal shielding of the liquid-helium vessel, the thermal-transition section at the round beam-tube (RBT) side, and the double elbow waveguide (WG). A 250-liter phase separator for liquid nitrogen, with function of pressure regulation, was installed in front of the cryogenic distribution box for this SRF module. The variation of supply pressure of the liquid nitrogen to the SRF module was decreased from 1 bar to 0.2 bar [5], but the tuner remained busy after this modification. The double elbow waveguide has not only a big cold mass but also a large volume for the nitrogen cooling channel, and thus becomes the best object for initial study. A separate test was then performed on a stand-along structure of double elbow waveguide [6], in which a 100-liter phase separator provided liquid nitrogen with a pressure

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variation within 30 mbar. Either the flow rate of nitrogen or the pressure in the warmer for the vented nitrogen gas was adjusted in that study. Similar to the complete SRF structure, the quasi-periodical temperature fluctuations were observed under a constant flow rate of vented nitrogen gas. However, it was found these temperature fluctuations could be diminished on either increasing the vented flow rate or regulating the pressure in the warmer.

A spare SRF module was then tested, but with liquid nitrogen filled inside the liquid helium vessel to reduce cost [7]. The test results concluded that both regulating the supply pressure of liquid nitrogen and implementing a thermally shielded buffer tank in between the test SRF module and the warmer for exhausted nitrogen ensured the suppression of thermal oscillation in that SRF module. Regulating either the flow rate of vented nitrogen or the pressure of the buffer tank with an appropriate setting eliminated the temperature fluctuation. Importantly a broader stable region was experienced with a good regulation on the pressure of the buffer tank.

A long-distance liquid-helium delivery system has been constructed and tested [8], it is thus possible to test the same scheme of installing a buffer tank for vented nitrogen but cooling the niobium cavity of the SRF module with liquid helium. A thermal-shielded buffer tank to stabilize the pressure is constructed and integrated with a passive warmer and active flow control system. Design, construction, and integration of this buffer tank, as well as the preliminary test results on the spare SRF module are presented herein.

II. Engineering and Construction

A. Design and Structure Calculation

The vented nitrogen from the SRF module is around the saturated temperature of liquid nitrogen, mostly pure gas, but sometimes companied with liquid nitrogen. The buffer tank for the vented nitrogen shall be able to keep this fluid cold to damp the pressure fluctuation effectively. Thus its nitrogen vessel shall be thermally shielded by both vacuum and multiple super-insulation layers. Experiences of previous studies [6, 7] tell that the liquid nitrogen may accumulate inside the buffer tank, which is good to hold a constant temperature. However, high-level liquid reduces the effective gas buffer volume and eventually blocks the venting port. As shown in Fig. 1, the buffer tank thus has two vent ports: one at the top to ensure gas venting, and the other slightly above the bottom of the nitrogen vessel so that only a little liquid could be remained and the redundant liquid would be expelled automatically.

A passive warmer is integrated under the buffer tank. A mass flow meter, a manual valve, and an actuated control valve are installed after the warmer, thus only room-temperature devices are required. The pressure regulation is achieved with the control loop consisted of the pressure transducer, a PID controller, and the actuated control valve, whereas the manual valve guarantees a minimum flow rate. Also installed is a temperature probe with four cryogenic linear temperature sensors (CLTSs) distributed at different heights: the lowest temperature sensor tells whether liquid nitrogen is accumulated

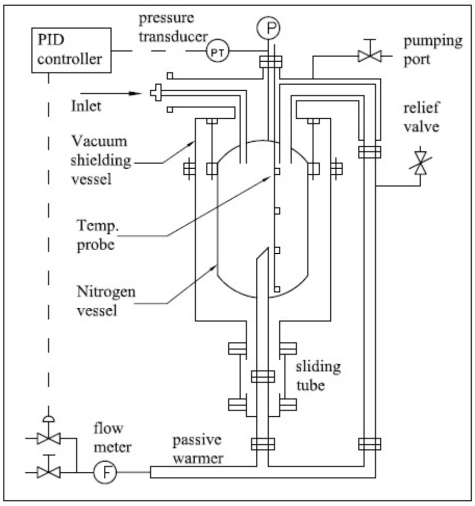

Fig. 1 Schematic layout of the buffer tank for vented nitrogen.

inside, while next highest one generates an alarm signal as it detects a temperature below 90 K.

Both the nitrogen vessel and the vacuum shielding vessel are constructed with stainless steel, with thickness of 4.8 mm and 6.4 mm, respectively. With the vacuum shielding, the vacuum vessel structure is loaded with outer pressure, while the nitrogen vessel with inner pressure. Calculations with finite element models show the maximum equivalent stress on the nitrogen vessel is 52.8 MPa under an inner pressure of 3.0 bar, whereas the vacuum shielding vessel is 20.1 MPa under an outer pressure of 1.0 bar. These are much lower than the yielding stress of stainless steel, 200 MPa.

B. Construction, Integration, and Leak Check

The nitrogen vessel was firstly manufactured with all the nitrogen pipes welded on it. Leak test is then applied as this vessel was pumped down to a vacuum of better than 1E-3 mbar. A helium detector was used to check if the leak rate of all the welds is below 2E-9 mbar-liter/sec by spraying helium gas along each weld. Then this nitrogen vessel was covered with multiple layers of super-insulation materials and hung to the top cover of the vacuum shielding vessel by four screwed rods as shown in Fig. 2.

Fig. 2 The nitrogen vessel is covered with multiple super-insulation layers and then hung to the cover of the vacuum shielding vessel

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(a) (b)

Fig. 3 The nitrogen vessel is inserted into the vacuum shielding vessel and assembled with all the instruments, pipes, and passive warmer, and then leak checked with a leak detector to examine all the welds and vacuum seals

The nitrogen vessel is then inserted into the vacuum shielding vessel as shown in Fig. 3(a). Both the connection pipes at its top and bottom, as well as the sliding tubes for vacuum sealing are assembled. Instruments such as the temperature probe, pressure gauge, and pressure transmitter are also installed. The complete set are tested with a leak detector attached to the vacuum shielding vessel as shown in Fig. 3(b), while helium gas is filled into the nitrogen vessel and sprayed along all the welds and vacuum seals of the vacuum shielding vessel. The measured leak rate is still below 2E-9 mbar-liter/sec and thus guarantees the safety for cooling down.

As shown in Fig. 4(a), the buffer tank for exhausted nitrogen locates above the radiation-shielded area for the spare SRF module. The spare SRF module is already fully assembled and ready for the cryogenic test and low-power RF measurement. But the tuner mechanism is not assembled onto it yet, which would be done later as long as this module is ready for high-power RF test. The flow control units, including the manual valve, actuated valve, and the flow meter, are integrated together with the passive warmer as shown in Fig. 4(b). The electronics, such as PID controller, monitoring meters, and temperature processing boards, as well as the wirings for meters and interlocks are also implemented and function-tested after the buffer tank is moved to this test location.

III. Preliminary Test Results and Discussions

A. Correlation of Tuner Motion to Temperature Fluctuation

The SRF module served as the accelerating cavity in the electron storage ring of NSRRC is currently operated with a constant nitrogen flow of around 60 slpm. As mentioned before, the pressure variation of its liquid helium vessel is controlled within +/- 2 mbar. A bump of 6 mbar on this vessel pressure P_{HE} is once produced as shown in Fig. 5. Comparing with the temperatures at the thermal-transition beam tubes T_{FBT} and T_{RBT}, it is obvious that the beam tube temperatures have much more significant effect on the tuner position S_{TU}. And the tuner moves to the positive direction when T_{FBT} and T_{RBT}

(a) (b)

Fig. 4 Integrated with the passive and the flow control units, the buffer tank for vented nitrogen is located above the radiation-shielded area, in which the spare SRF module is cooled and tested

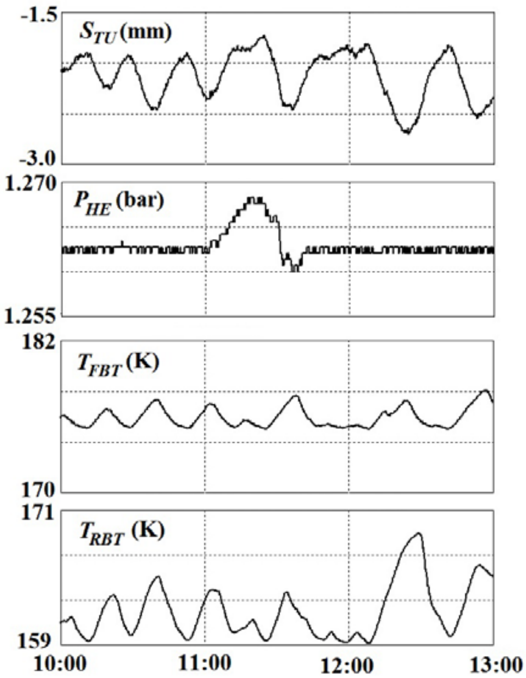

Fig. 5 Even with a 6-mbar pressure bump at the liquid helium vessel of an SRF module operated for the electron ring of NSRRC, the variation of tuner position S_{TU} is not significantly changed, while the temperature variations on the temperatures of the thermal-transition beam tubes

drive the tuner to move correspondingly.decrease, i.e., out of phase. The tuner motion is in phase with the pressure bump of the helium vessel but with a relatively small quantity. Due to the flute beam tube (FBT) is cooled by the nitrogen flow prior to the round beam tube (RBT), its temperature variation of 3 K is about one third of, and slightly prior to, that of RBT. This temperature fluctuation behaves a slow period, about 20 to 30 minutes. Notice that variation of the air temperature inside the electron storage ring tunnel is controlled to within 1 ^{o}C, and thus contributes not much on the periodic fluctuation of T_{FBT} and T_{RBT}. Take the T_{RBT} as the reference, a temperature change of about 9 K makes the tuner move 0.9 mm as observed during the last hour shown in Fig. 5, roughly a sensitivity of -0.1 mm/K to the tuner movement is thus concluded.

B. Test with the Spare SRF Module

The spare SRF module has no tuner yet, thus only the temperature fluctuations are demonstrated and discussed herein. First of all, the liquid helium vessel of this SRF module is filled with liquid helium. Various operation conditions of the liquid nitrogen shielding flow are then applied. Illustrated in Fig. 6 are the temperature of the thermal-transition beam tubes T_{FBT} and T_{RBT} of the spare SRF module, pressures of the phase separator P_{PS} and buffer tank P_{BT}, as well as the temperature distribution of the temperature probe inside the buffer tank T_{BT1}, T_{BT2}, and T_{BT3}, within a test period of 6 hours. A 100-liter phase separator accumulates the liquid nitrogen of being transferred through the 200-m cryogenic transfer system [8] and behaves as the liquid nitrogen source to the SRF module. Its pressure P_{PS} is controlled within a variation of +/- 30 mbar. At the first hours, pressure of the buffer tank P_{BT} are not controlled very well as shown in Fig. 6. Not only a periodical oscillation of +/- 50 mbar appears, but also spike of variation over 600 mbar occurs occasionally. The buffer tank even has a higher pressure than the phase separator at these violent pressure surges, which means the nitrogen will be pushed back from the buffer tank to the spare SRF module and even to the phase separator. As a result, corresponding temperature rises on both T_{FBT} and T_{RBT} are observed.

It is believed that too much liquid nitrogen flows into the buffer tank and contacts with the warm parts, such as the passive warmer, to vaporize immediately and produce the pressure spikes. As evidences of this suspicion, the temperatures of the buffer tank at the middle heights T_{BT2} and T_{BT3} decrease prior to the pressure spikes. The parameter adjustment on the pressure control loop of the buffer tank, mainly increasing the venting range through the actuated valve and setting the target pressure a little higher, eliminates the pressure spikes, but results even more obvious oscillation on the buffer tank pressure as shown in Fig. 6 for the last two hours.

However, except at the pressure spike periods, the temperatures T_{FBT} and T_{RBT} are generally more stable. Take the last two hours in Fig. 6 as an example, the variations of T_{FBT} and T_{RBT} are within 1.5 K and 4 K, respectively, much better than those shown in Fig. 5 for the SRF module with constant

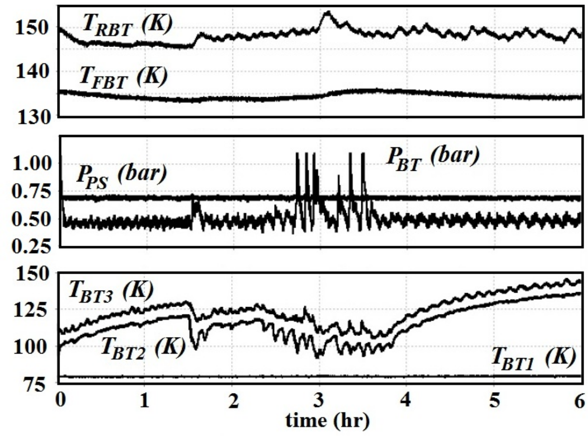

Fig. 6 Temperatures of the thermal-transition beam tubes T_{FBT} and T_{RBT} are more stable after applying suitable operation parameters on the flow control loop of the buffer tank. Variations of the pressures of the phase separator P_{PS} and buffer tank P_{BT}, as well as the temperature distribution inside the buffer tank T_{BT1}, T_{BT2}, and T_{BT3} during this 6-hour period are also presented.

nitrogen flow rate. Besides, the fluctuation period of T_{FBT} and T_{RBT} are significantly changed: long period of some hours for T_{FBT} and short period of 7 to 8 minutes for T_{RBT}. Oscillation period of this obvious difference can be used to distinguish which is the major one to affect the tuner movement. This operation parameter set is thus valuable for the future study on characteristics of the SRF module. More efforts to work out the optimal parameters of the pressure control loop of the buffer tank are still going on to reduce the variations of T_{FBT} and T_{RBT} further.

IV. Conclusion

Evidently tuner motion of the SRF module of CESR-type is strongly correlated to the temperature variation of the thermal-transition beam tubes. A home-made buffer tank is installed to stabilize the pressure of exhausted nitrogen gas from the SRF module. Most design functions of this buffer tank are tested and proven. Not only suppressing the variations, but also separating the oscillation periods of these temperatures, is demonstrated by controlling the pressure of the buffer tank. It is thus promising to keep the tuner still by this device. Further tries on the operation parameters and studies on the interacting mechanisms are in progress.

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