Operation of the 500 MHz SRF Module: Cryogenic Considerations

A critical decision was made at NSRRC in 1999 to install a CESR-III 500 MHz SRF module as accelerating cavity by replacing the existing cavities of conventional type. The goals are to double the photon flux of the synchrotron light by doubling the maximum electron beam current and to increase the stability of the electron beam by using a superconducting cavity to exploit the well-damped impedances of high-order modes. The SRF module has been in operation since February 2005. The users at NSRRC benefit from high photon beam stability ($\Delta Io/Io$~0.05%) and smaller photon beam size that have never been available before. Last year, we reported the construction of the SRF module. In the following sections, we will discuss cryogenic aspects for a reliable SRF operation.

Superconducting devices operate at cryogenic temperature. The requirements for the cryogenic operation of a superconducting cavity differ widely from those of a superconducting magnetic device. The main differences are described in the following sections.

The superconducting cavity must be configured in a volume with partial thermal insulation to accelerate the electrons. On the other hand, a superconducting magnet is commonly operated in a complete thermally insulated volume. Recently, designs of superconducting insertion devices with cold chambers have been used to increase the magnetic field strength in a device with a small magnetic gap that does not allow sufficient space for thermal shielding. The static loss of a superconducting cavity greatly exceeds that of a supercon-ducting magnet.

The dynamic cryogenic loss of a superconduct-ing magnet can be ignored, but the RF loss of the superconducting cavity is comparable or even much larger (at higher field gradient) than the static loss in the proposed application. The cryogenic plant is commonly operated in hybrid-mode for SRF operation, to allow most of the evaporated liquid helium to return to the cold box. Hence, the pressure drop of the helium gas at the cold return in the cold box limits the lowest operating pressure of the superconducting cavity. On the other hand, the operation of the superconducting magnet in the liquefaction mode is preferable in order to reduce the operating temperature.

The superconducting cavity has to be cooled down fast enough over a certain critical temperature range to prevent generating the so-called Q-virus. Such considerations are not necessary for the superconducting magnets.

The stored energy in the superconducting cavity is much less than that on the coils of the superconducting magnet. Avoiding the boiling-off of a large amount of liquid helium during quenching is a serious concern. The operation of superconducting cavity and magnets by a single cryogenic plant is therefore challenging. Figure 1 shows the cryogenic plant originally designed for SRF operation alone but currently supporting cryo-cooling for both SRF modules and the superconducting magnets.

Two types of cryogenic plant are commonly used for large-scale superconducting devices: the piston type and the turbine type. A turbine cryogenic plant was selected to operate the SRF module at NSRRC. A turbine machine requires much less maintenance work than a piston machine, and has better performance in mean time between failures. Nevertheless, the turbine machine is less robust than the piston machine. A turbine machine is also more expensive with similar cryogenic capacity as the piston type.

At NSRRC, only one superconducting cavity will be used to operate the machine at a maximum beam current of 500 mA (Fig. 2). The required cryogenic cooling capacity for nominal operation is much lower than that required during fast cool-down and liquid helium collection. A 2000L liquid helium dewar is used to trade-off the refrigerating

Fig. 1: Cryogenic plant and valve box designed for the srf module.

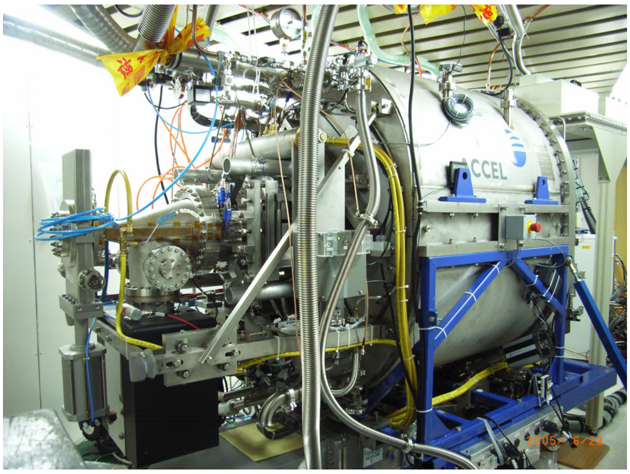

Fig. 2: 2^{nd} SRF module in rf processing area at NSRRC.

and liquefaction capacity of the cryogenic plant. Additionally, a frequency driver is implemented to adjust the capacity of the cryogenic plant to match the considerable change of cryogenic loading in various operating modes.

Similar to the case of the copper cavity where the RF frequency varies as the temperature of its cooling water fluctuates, the resonant frequency of the superconducting cavity varies with the helium gas pressure in the liquid helium vessel. The gas helium pressure and the liquid helium level must be precisely regulated to ensure the stable operation of the superconducting cavity. PID loops are implemented to regulate the gas helium pressure and the liquid helium level by manipulating the openings of the helium cold return valve and the liquid helium supply valve, respectively.

Cryogenic protection is realized by exploiting the fact that both the cryogenic plant and all the superconducting devices must be well protected in the event of quenching or other failures. The failed superconducting device must be immediately isolated from the cryogenic plant to prevent interruption of the operation of other superconducting devices. The SRF module has four external connections to the cryo-plant: liquid helium is supplied from a 2000L main dewar; the cold helium gas is returned to the cold box, the warm helium gas by-pass (only open during cool-down and warm-up) and the HEX-line, before it enters the warm suction line. Although a check-valve is installed after the HEX-line, the liquid helium supply valve, the cold helium return valve and the warm helium gas bypass valve must be completely shut off when the supply, suction or bath helium pressure is too high either because of its own failure, or the failure of the cryo-plant or some other superconducting devices. If the SRF module is cryogenically isolated, the helium gas pressure increases and the relief valve and burst disk will provide the final protection.

Prior to installation of the SRF module, a 500L test-dewar with a home-made cryogenic electronic controller was installed to simulate possible effects of the superconducting cavity on the cryogenic plant. A built-in heater performs controllable cryogenic loss. The objectives of this study were 1) to exercise cryogenic piping and insulation; 2) to master the PID tuning required to operate the SRF module; 3) to measure the static loss of the cryogenic piping and SRF valve box; 4) to improve the design of the cryogenic interlocks, and 5) to examine the maximum allowed cryogenic load at various helium gas pressures.

A turbine-based cryo-plant is normally considered to be a maintenance-free machine. However, such a cryo-plant may fail when it is first operated. The failure of a cryogenic plant may cause long-term interruption of SRF operation. Installing a back-up plant can substantially improve the reliability of such a cryo-plant. At NSRRC, a second cryo-plant will be installed in 2005 to support the operation of the superconducting magnets. In case of failure of the cryo-plant for SRF operation, the second cryo-plant can be switched via a switching valve box to support the operation of the SRF module by shutting down the superconducting magnets.

Turbine failure is the most critical failure at a turbine-based cryogenic plant. A warm turbine may be damaged by contamination with impure gas or with dust. Turbine failure will interrupt SRF operation at least for a few weeks, even if a spare turbine is available. Before the reason for the turbine failure is clarified, installing the spare turbine is risky because the replaced turbine may be damaged quickly for the same reason as the previous one was. On the other hand, if a spare turbine is not available, the impact of turbine failure on the routine SRF operation as well as on the machine operation could last for several months to enable the turbine to be repaired. NSRRC has two sets of spare turbines. Notably, the two cryo-plants at NSRRC share the same helium gas tanks. In the case of turbine failure of one cryo-plant owing to contamination, the other may be damaged in a short time. The problem of contamination must be carefully considered.

A shortage of gaseous helium can as well interrupt the SRF operation. If the safety valve on the helium gas tanks, or the cryostat's pressure relief valve is accidentally opened (e.g., because of failure of the AC power), a large amount of helium will vent into the air. All helium used in Taiwan is imported from the U.S. Hence, the design philosophy of the cryogenic plant at NSRRC involved reserving a sufficient quantity of helium in the gas tanks to guarantee SRF operation following failure/opening of the cryostat's pressure relief valve. The unused helium gas tanks are therefore strongly recommended to be separated from the operating cryo-plant at all times.

AC power failure can cause failure of the cryogenic plant. No dedicated backup electric generator is presently available to ensure the uninterrupted operation of the helium compressor, thus the liquid helium stored in the cryostat of the SRF module (about 500 liter) will be emptied in around six hours after the liquid helium supply from the main dewar of the cryogenic plant is terminated. Once the liquid helium in the cryostat has been emptied, the SRF module will begin to warm-up. During a 12-hour AC power interrupt for reasons of annual or seasonal maintenance, the SRF module will warm up to a temperature above 20K.

Nowadays, superconducting cavities are becoming the preferred choice when planning a new light source. Mastering the SRF technology at NSRRC is fundamental to ensure a highly reliable and optimal operation.

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