Superconducting RF Project: A Major Machine Upgrade

Five years ago, a critical decision was made at NSRRC to develop the superconducting radio frequency (SRF) technology for accelerator application and to install the SRF module of CESR-III design at NSRRC's storage ring. The project goal is to double the photon flux by doubling the maximum beam current and at the same time to increase the stability of the beam using a superconducting cavity by damping high-order modes. Nowadays, the superconducting cavity becomes the most desirable choice when building a new light source.

The SRF project comprises three major parts. First, the operating Doris cavities designed in the 70s are being replaced with a more recently developed SRF module of CESR-III design; second, a cryogenic plant is established to support the operation of the superconducting cavity; third, the SRF module is integrated with a new rf system developed in-house. The fabrication of the SRF module was contracted out to ACCEL in 2000 after the NSRRC received a technical transfer from Cornell University. A turbine-based cryogenic plant with a capacity of 460W will enable the SRF cavities to operate at 4.5K with sufficient safety margin on cooling power. This work was contracted out to AirLiquide in 2001, according to technical specifications developed in-house. Some difficulties were encountered during the production of SRF modules, but these have so far been overcome. The SRF module S1 at NSRRC is currently preparing to undergo a high-power acceptance test. Commissioning with the stored electron beam is scheduled for the end of 2004. A new era of SRF operation at NSRRC will then begin after 11 years of rf operation using DORIS cavities.

The most essential concern regarding the applications of superconducting rf to the light source is obtaining the high reliability and availability of the overall system. Efforts required were evaluated to substantially improve the reliability and availability at the beginning of the planning of the project. The strategy is to leave a large safety margin but not to pursue the operational performance of the superconducting rf to its frontier records. Redundant design, robust consideration and fast identification of causes of machine tripping are always the first priority in specifying the subsystem and integrating the system. Comprehensive training in SRF technology has been conducted throughout in last four years. Now, we are convinced that we can maintain our record of the lowest rf trip rate of most of operational light sources after a short learning time while operating the SRF module. Simplified Progress of the SRF project is given below.

The production of SRF modules began in 2000 and has six phases. In the first phase, two niobium cavities were fabricated by ACCEL. After chemical cleaning and high pressure rinsing with ultra-pure water, the niobium cavities were sent to Cornell for low rf power test (also called vertical test). The most difficult part of this fabrication phase is the mechanical formation of a flute beam tube. The fabrication of the cryostats by Meyer Tools was the second phase, even though the cryostats were initially fabricated in parallel with phase 1. Additional work to put a U-stamp on the liquid helium vessels has been requested. The third phase of the fabrication was the production of rf windows by Thomson and of the other beam tubes, including higher order modes, by ACCEL. The most challenging aspect of this phase was to produce ferrite tiles at a sufficiently high yield rate. In the beginning of the trial, the failure rates were very high. The fourth phase included the assembly of the SRF module and the conducting of various tests. Failure of the SRF module S2 in the high pressure test (niobium waveguide buckled at 1.8 bar in 30 min. at room temperature), undertaken as a cryogenic safety test, and the consequent failure of the rf window during the high power test due to the

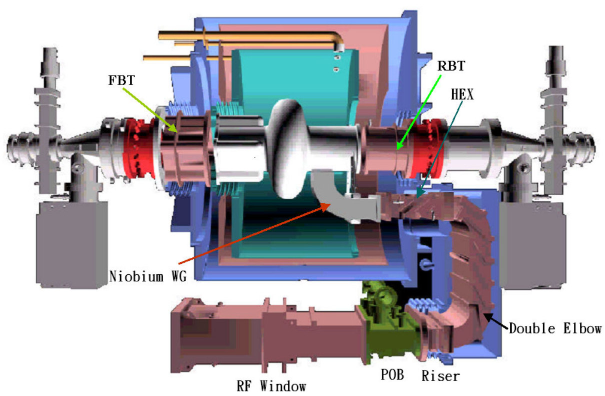

Fig. 1: Layout of the SRF module of CESR-III design.

misuse of the waveguide transformer to correct the inadequate external quality factor (Qext) caused a delay of about one-and-a-half years in the production of the SRF module S2. Subsequently, identifying the leakage between the cavity vacuum and the cryostat insulation vacuum delayed the production of the SRF module S1 by another two months. The leakage is primarily associated with the huge thermal stress on the outer flange corners of the double-elbow waveguide caused by inadequate pre-cool-down speed. The SRF module S1 preparing for high power performance test at NSRRC is shown in Fig. 2. Its high-power test is scheduled for June-July, 2004, as the fifth phase of the project. The final phase involves installation and beam commissioning.

Trouble with multipacting, microphonics, thermal loading on the cold surface by the scattering light, heavy beam loading, hydrogen adsorption and coupled-bunch instabilities must be carefully considered to ensure the highly stable operation of the SRF module at NSRRC. Some of the related problems are discussed below.

- Multipacting: Few new-generation light sources operate nowadays in top-up mode routinely rather than conventional decay mode. When the machine operates in top-up mode, the beam current will be the maximal operating beam current. Therefore, the users of the light source will benefit from the maximum photon flux. Moreover, a constant thermal effect on the beam-lines will be maintained. This will substantially simplify the beam-line tuning for optimal throughput. SRF operation may additionally benefit from the top-up mode operation. Operating the power coupler of the SRF module at the multipacting-free point is highly promising by operating the machine at a constant beam current because the effects of beam loading will be maintained.
- Microphonics may still be of concern when the machine is operated with a high beam current. A superconducting cavity is normally designed with a thin cell to ensure good thermal conduction of the rf loss on the inner surface of the cavity to the liquid helium bath. A superconducting cavity is less stiff than a normal conducting cavity. Structural deformation of the cavity varies the rf resonant frequency. However, a superconducting cavity has a higher external Q than a normal conducting cavity (a loaded Q of about 2.5E5 for the SRF module and of 0.18E5 for the Doris cavity), indicating a smaller bandwidth of the cavity resonance. These features increase the sensitivity of the superconducting cavity to mechanical vibrations.

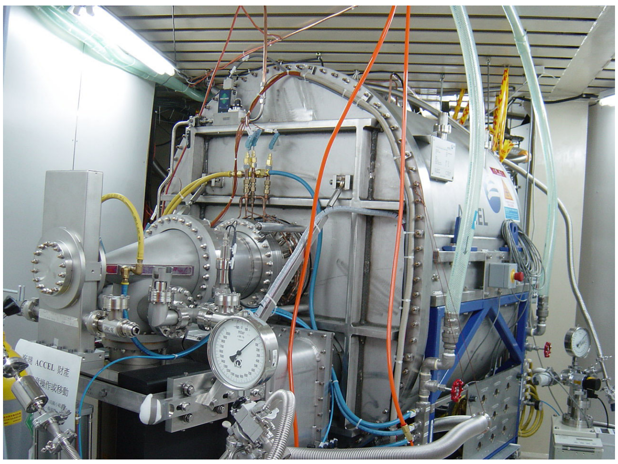

Fig. 2: The SRF module S1.

Microphonics refers to the effect of mechanical vibrations on the superconducting cavity, and the dynamically changing the cavity dimensions, and therefore, the resonant frequency of the cavity. At NSRRC, an external rf source drives the cavity at a fixed rf frequency, and the microphonics will generate low-frequency noise in the accelerating fields, eventually reducing the stability of the photon beam or disturbing the stable operation of the SRF module under heavy beam loading.

Main vibration sources include ground vibration, heavy machinery (cooling water pump, cryogenic compressor, air compressors), the turbo pumps, the cryogenic turbine, helium pressure fluctuation, and others. Mechanical vibrations can be transferred into the superconducting cavity via an rf feed-line, cryogenic hoses, vacuum chambers and mechanical contacts. Hence, the vibration sources must be suppressed or isolated. At NSRRC, the cryogenic compressor is over 100 m away from the superconducting cavity, which is therefore not a critical source of vibration in the SRF operation. The central air compressors are located on the roof of the core area near the tuner for historical reasons; these may be the most critical sources of microphonics.

Notably, the rectangular waveguide and beam chambers with large diameters are made from thin plates. The amplification factors are considerable, but may be reduced by appropriately inserting a stiffener in some cases. Electronics such as a piezo-tuner can be applied to compensate for the microphonics, which is not yet available.

Neither the direct nor low-multiple **scattered** synchrotron radiation is allowed to strike the cold surface of the SRF module. Direct synchrotron radiation from the upstream bending magnet will strike the downstream taper of the SRF module. Water-cooled radiation masks are installed to adsorb the radiation heat. Low-multiple scattered light should be prevented from hitting the cold surface. The optical paths of multi-reflected light from the upstream bending magnet have been carefully investigated. Some reflected light hits the cold surface of the thermal transition flute beam pipe. Additional radiation masks must therefore be installed just downstream of the upstream bending magnet to divert this reflected light.

Five years ago, we made a decision to build-up the application of SRF technology to accelerator in Taiwan and to install the SRF module of CESR-III design at NSRRC as our first step. In last four years, we have done our best for the SRF project. We encountered some difficulties and have overcome them so far. We are now almost ready to begin our new era of SRF operation after 11 years of RF operation with DORIS cavities. We understand well that it is much more difficult to operate the SRF module with high reliability and availability. We expect some patience from our users but we are ready to put all of our efforts to reduce the SRF trip rate so as to make our users happy!

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