OPERATIONAL EXPERIENCE OF THE SUPERCONDUCTING RF MODULE AT TLS

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Abstract

An industrially manufactured CESR-type SRF module has been routinely operated at the Taiwan Light Source (TLS) at the National Synchrotron Radiation Research Center (NSRRC) since the beginning of March 2005. The original goals of doubling the electron beam current to increase the synchrotron light intensity and of eliminating the instability caused by the interaction of the electron beams with the cavity's higher-order modes have been successfully demonstrated. The greatest challenge to the operational reliability, the short mean time between failures, has been successfully overcome. This work reports the operational experience and status of the SRF module at TLS, toward a maximum beam current of 400 mA in decay mode, of 300 mA in top-up mode and of 200 mA in routine operation, over last six months.

INTRODUCTION

Since the successful commissioning of the TLS storage ring in 1993, the electron beam has suffered from strong coupled-bunch instabilities caused by the two operating room-temperature RF cavities that were designed in the 1970s. The instabilities cause a saw-tooth oscillation of the photon intensity, which raises problems in experiments that use the synchrotron light. Many attempts have been made to improve the stability of the electron beam. These include improving the cavity cooling system, adding a higher order mode (HOM) tuner, and applying RF modulation. Acceptable photon stability was attained by applying amplitude modulations of the accelerating RF voltage, but with degraded undualtor spectral intensity because the energy spread of the electron beams was increased.

In 1999 a major accelerator upgrade project [1] has begun with the goals of doubling the TLS photon flux by increasing the electron beam current to 500 mA and markedly improving the stability of the electron beams by eliminating the coupled bunch instabilities caused by the HOMs of the room-temperature RF cavities. After a detail comparative study of new normal-conducting versus superconducting RF system, the CESR-type SRF was chosen for the upgrade and TLS has become the first light source in the world to adopt superconducting RF technology. After the SRF module had been successfully installed and commissioned in November-December of 2004, routine operation of the light source using the SRF module as an accelerating cavity began in March 2005. The NSRRC thus entered a new era of SRF operation [2].

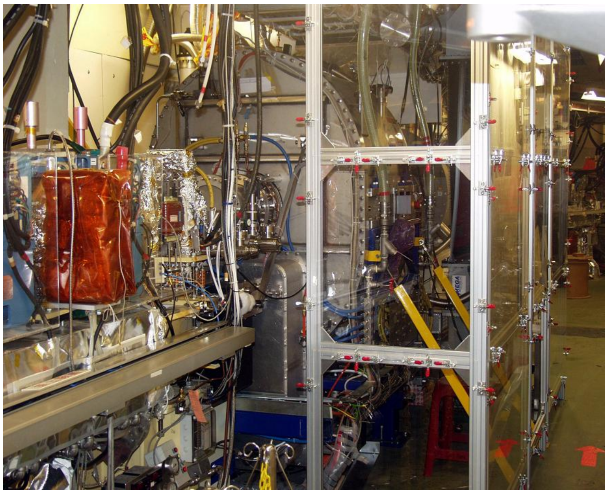

Figure 1: SRF module in routine operation at TLS.

Figure 1 presents the SRF module in operation at TLS. The operating parameters that control the operation of the 500 MHz SRF module at TLS are listed elsewhere [1]. This work reports the operational experience and development of the SRF module at TLS. The module has satisfied the requirement of high reliability with a maximum beam current of 300 mA in top-up mode and of 200 mA in routine operation, over the past six months.

SRF OPERATIONS

The SRF module features heavily damped higher-order modes. No effect of the coupled-bunch instability, caused by the SRF module, on the photon intensity has been observed, even at a beam current of 300 mA. However, transverse feedback is required to stabilize the photon beam influenced by the other residual instabilities that were fully suppressed by the coupled-bunch instabilities before the SRF module was installed but dominate the beam turbulences now. After those residual instabilities had been properly damped and the feedback loops of low-level RF system had been carefully tuned, a highly stable photon beam, as presented in Fig. 2, is available, without applying RF modulation to the accelerating RF voltage to smear out the longitudinal motion of the electron beams.

A highly stable photon intensity at a beam current of 300 mA in the top-up mode was obtained during many test runs in the machine study shifts. Routine operation at 300 mA is scheduled for the end of 2005. Notably, even at 300 mA, coherent synchrotron oscillations caused by Robinson instability are not observed. Direct RF feedback to increase the stable margins of Robinson

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instability caused by heavy beam loading is applied if required at 400 mA. A successful test-run of up to 400 mA in decay mode was conducted. Efforts are under way to improve the stability of the photon beams.

Although the use of SRF technology in synchrotron light sources can hugely improve both the photon flux intensity and the stability, it also challenges the reliability and availability of machines, especially at higher operating beam currents. The trip rate is a measure to indicate the reliability and availability of the machine. Over the last six months, when the SRF was operated, the average trip rate throughout the complete RF plant (and only one RF plant is operated in the TLS's storage ring) at a maximum beam current of 200 mA was less than once per week during user shifts. Figure 3 displays the statistics concerning the SRF trip rate over the last 6 months of continuous operation at 200 mA. This trip rate is satisfactory for the users of TLS but not for the proposed 3 GeV light source Taiwan Photon Source (TPS), which requires four sets of SRF modules to operate the machine at its target current of 400 mA (and 720 kW beam power). At the same trip rate per module, four trips would occur weekly. The SRF trip rate must be reduced to once per month per module on average.

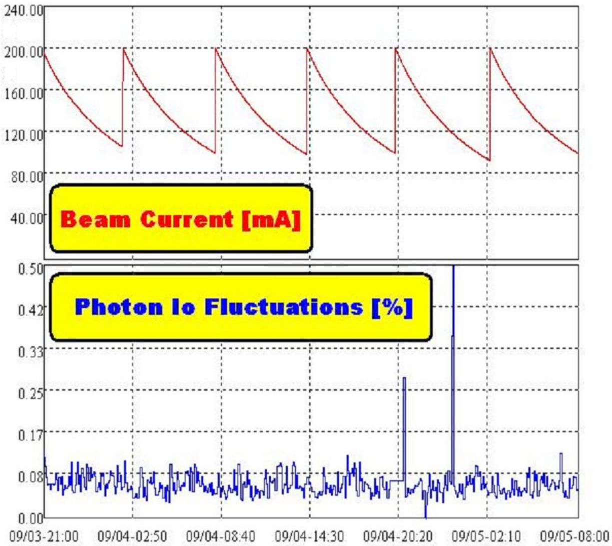

Figure 2: Typical photon stability after SRF module is used as an accelerating cavity at TLS.

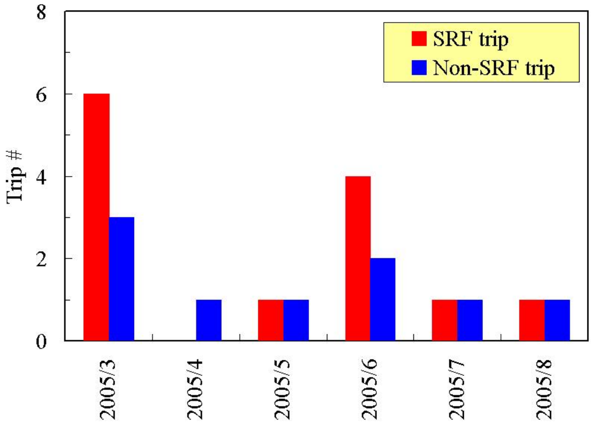

Figure 3: Statistics concerning SRF trip rate at TLS.

Of all the trip events in the user shifts, over one half are directly related to the SRF module and the rest were associated with other parts of the RF plant (called non-SRF trip hereafter). SRF trips are of two main classes: window arcing and SRF quenching. Most non-SRF trips are caused by arcing in the waveguide circulator or by the high klystron modulator current. We speculate that both window arcing (three sensors per SRF module) and circulator arcing are false alarms but a feasible method of verification is lacking. Increasing the immunity of the fast TTL electronic circuit boards against the electromagnetic interference (EMI) significantly decreases the trip rate of the window and circulator arcing. Using dual arc-sensors on individual view ports to register arcing as a coincidence of two signals provides a mechanism that helps to eliminate false alarms. The design of the next series of SRF modules should include dual arc-sensors.

A quench detector registers an SRF "quenching" when the measured accelerating voltage of the SRF cavity declines by more than 30% from its set value. Most decreases in cavity voltage are not caused by the quenching of superconductivity, but by fluctuations in the cavity voltage, when either the cavity is abruptly detuned to a substantial extent (due to, for example, beam loss) or the feedback loops of the low-level RF system become extremely unstable (because of microphonics, for example).

Fluctuations of the LN2 supply pressure to the SRF module or/and the acoustic thermal oscillations that develop along the LN2 cooling channels around the double-elbow waveguide inside the SRF module, are among the most likely origins of microphonics. Notably, microphonics can be excited by mechanical vibration modes of the niobium cavity or the in-vacuum waveguide section. Figure 4 illustrates strong relationship between the motions of the cavity tuner and the temperature variations of the thermal transition beam tubes of the SRF module due to cooling with LN2. The fluctuation period is around 30 min. The tuner loop is therefore under a heavy working load, to compensate for the detuning of the cavity frequency by the variation in the length of the thermal transition beam tubes on both sides of the niobium cavity.

The excitation of microphonics can be driven by the individual driving pulses of the stepping motor, which was observed when the tuner loop was operated at a high gain, as presented in Fig. 5. The development of amplitude loop instabilities due to internal cross talk between the feedback loops has been observed at high beam current. In the top-up mode, the tuner loop becomes relatively quiet, but the feedback loop instabilities develop at high gain, too. Various attempts have been made to overcome this operational difficulty. Currently, such "quenching" is minimized by reducing the tuner loop gain and bandwidth. A tuner loop with an extremely low gain, however, causes a slow drift of the resonance frequency of the cavity. The operation

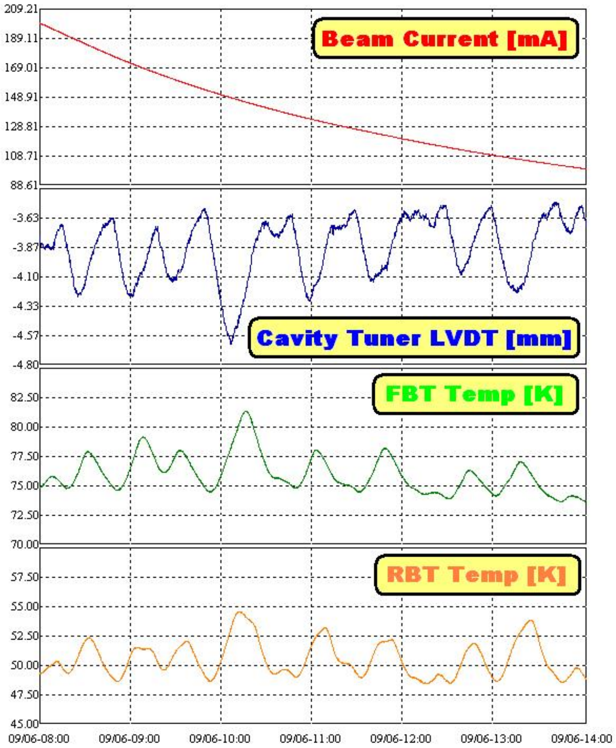

Figure 4: Strong relationship between the displacement of the cavity tuner (Tuner LVDT) and the variation in temperature of the thermal transition beam tubes (FBT and RBT) on both sides of the niobium cavity in the SRF module. Cryogenic temperatures were measured using CLTS without careful calibration.

parameters of the tuner loop must be tuned further to enable SRF to operate at high currents. A potential solution may involve a fast tuner loop and a well-designed piezo tuner. The existing low-level RF system, based on a 1980s design, is currently being upgraded.

OPERATIONAL CHALLENAGES IN HIGH-CURRENT TOP-UP MODE

The top-up mode of the light source is associated with much better spectral intensity and stability than the conventional decay mode. It minimizes the spectral fluctuations caused by thermal effects. However, the top-up mode raises new challenges that affect machine reliability. Unlike decay mode, top-up mode requires that the electron beam be injected at a very high repetition rate - once every few minutes rather than the once every few hours in decay mode, although the injection takes only a few seconds in the top-up mode. Highly stable injection kickers are required in top-up mode, especially at high beam current. Partial loss of the beam current caused by the misfiring of a kicker at high beam current causes a substantial mismatch between the cavity and the beam current. Extra RF power is required during the transient to maintain the desired accelerating RF voltage, and typically this transient causes quenching.

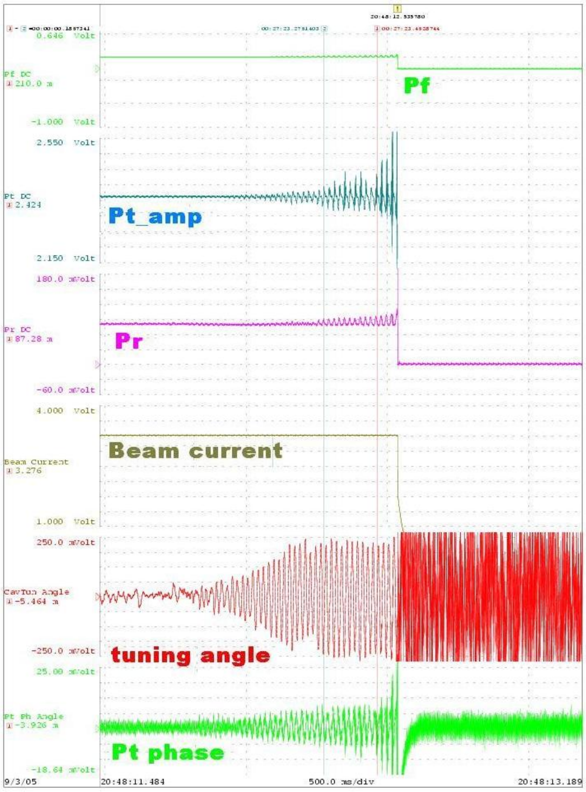

Figure 5: Development of instability in the amplitude loop caused by microphonics.

CONCLUSION

In 1999 a bold decision was made at NSRRC to use SRF technology in a major TLS machine upgrade. Since March 2005 the SRF module has routinely operated at the light source at NSRRC. The SRF cavities are now preferred around the world in building or planning new light sources. As pioneers in using an SRF module as an accelerating cavity at a third-generation light source, we are pleased to report that the users are satisfied with the performance of SRF. Mastering the SRF technology in-house is critical to realizing the highly reliable and optimal operation of the SRF module in an accelerator. Bridging the SRF technical gap rapidly remains a serious challenge for our technical staff and requires ongoing and intense effort.

ACKNOWLEDGMENTS

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REFERENCES

[1] Ch. Wang *et al.*, “*Superconducting RF Project at the Synchrotron Radiation Research Center*,” 10th SRF Workshop, Tsukuba, Sept. 2001, p. 34.

[2] Ch. Wang *et al.*, “*Successful Operation of the SRF Module at TLS*,” to be published in Proceedings of the 2005 Particle Accelerator Conference.