A DECADE OF OPERATIONAL EXPERIENCE WITH THE 500 MHZ RF SYSTEM AT SRRC AND THE NEXT ERA OF SUPERCONDUCTING RF

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Abstract

The 500 MHz RF system at the third generation light source facility at SRRC was configured, installed, and commissioned ten years ago. Routine operation has continued since the first beam of the storage ring was stored in 1993. This article reviews the performance of the 500 MHz RF system and the experience gained from daily operation over the previous decade. SRRC has pursued a major upgrade of machine performance since 1999, by replacing the operational copper cavities with a single CESR-III superconducting RF module. Commissioning of the SRF module is scheduled for 2003. The aim is to upgrade this light source into an ultra high intensity photon factory by operating it at a maximum beam current of 500mA. Moreover, the quality of the electron beam will be significantly improved by using a high-order-mode heavily damped, accelerating cavity. The status of the SRF project is briefly provided. Highly stable operation of the superconducting cavity under heavy beam loading conditions is addressed.

1 INTRODUCTION

The operational 500MHz RF system at SRRC consists of three identical RF plants [1][2]: two of them are for storage ring operation and the left one is for booster ramping. Each RF plant includes a 70 kW, water cooled, Varian klystron powered by a 60 kW (RF power) crowbar-type high voltage power supply delivered by Mountain Technology, an EIA 6 1/8” coaxial RF feed-line from Spinner, an AFT circulator, a Byrd RF dummy load, and a Doris cavity cooled using its own secondary water cooling manifold. The individual RF plants are regulated by its own low level RF system of SLAC design to facilitate the klystron phase compensation, cavity voltage stabilization, and maintenance of cavity resonance frequency. Table 1 lists the RF system parameters in routine operation.

2 AVAILABILITY AND RELIABILITY

The RF system was originally designed for a storage ring operated at 1.3 GeV with synchrotron radiation loss of 72 keV per turn. Meanwhile, the machine has been routinely operated at 1.5 GeV with various insertion devices in response to the high demand for X-ray spectral intensity. The synchrotron radiation loss is increased to 168 keV per turn.

Only a few RF components have been faulty during the last decade of continuous operation of the RF system. Faults have included the vacuum leak from the bellows of the cavity plunge tuners, due to operation at on-resonance with the cavity higher-order modes at a higher beam current of 200mA, burning of the EIA 6 1/8” coaxial bellows causing contamination of the RF ceramic window after operation at a higher beam current up to 300mA, contamination of klystron cathode and recovery later by applying pulsed processing with an RF modulator, significant increase of the RF ceramic window’s surface temperature owing to improper overnight operation in the high power standing wave mode (30kW), and degradation of the klystron coupler owing to poor contact with the klystron port. The RF dummy loads were damaged at the very beginning of operation because of the poor resistance of desionized water. Thereafter, regular replacement has still been required after few-years of operation, due to aging.

Table 1: RF parameters in routine operation.

	Doris cavities	SRF module
Nominal machine energy	1.5 GeV	
Revolution frequency	2.49827 MHz	
RF frequency	499.654 MHz	
RF harmonic number	200	
SR energy loss per turn	< 164 keV	> 164 keV
Beam power	< 33 kW	> 82 kW
Maximum beam current	200 mA	500 mA
Number of RF cavities	2	1
Total RF voltage	0.8 MV	1.6 MV
R/Q per cell (V^2/2Pc)	~83	44.5
Ohmic Q_O	~36000	~1.0E9
Coupling coefficient	~1.3	
External Q (Qext)		2.5E5
Beam loading factor Y	~1.30	~6.95

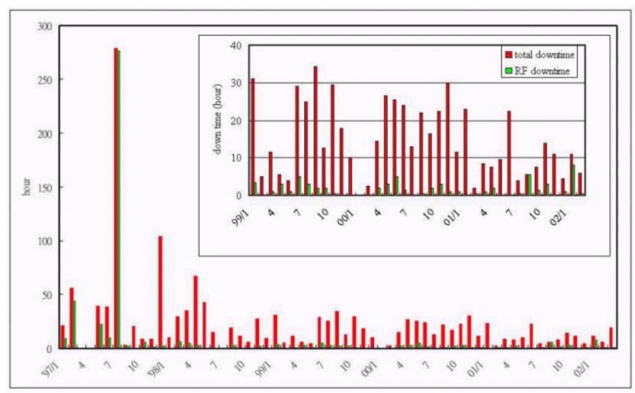

Figure 1: Statistics concerning system downtime, in hours of the light source facility at SRRC since 1997. Faults of the 500 MHz RF system (including secondary cooling water manifolds) contribute only a little.

Periodic cleaning of the circulators has been recently required, owing to the presence of unknown powders inside, causing frequent arcing after every 6 months of continuous operation. Most faults of the RF components happened only once. Carefully monitoring the coaxes' outer surface temperatures and using Teflon as support material of inner coax significantly improved the reliability of the coaxial feed-line. Enhancing the interlock protection and regularly examining the RF leakage minimizes most component damage due to human error and enables component aging to be found before they have any effect on machine downtime.

Much attention has been paid to maintaining the RF transmitters. The circuit of the transmitter's high voltage power supply includes mainly 3-phase saturable and AC reactors to regulate the voltage fluctuations of the 3-phase, 380V power lines and DC high voltage output, the 3-phase HV transformer with a Y-to-2Δ configuration, 12-phase HV rectifiers, two-stage HV inductor-capacitor filter, interlock HV circuit board with ignitron and spark gap, and other diagnostic circuits. Contamination of the high voltage circuit board due to cooling with filtered, forced air and operation of the HV rectifiers in a relatively warm environment contribute most of the residual downtime of the RF system. Replacing with over-spec rectifiers and enhancing the air-cooling capacity extend the lifetime of the HV components. However, regular cleaning of the HV circuit, and HV isolation testing of individual components are still required to guarantee reliability. Such procedures, though, use manpower.

Since the reliability of the RF plant has been improved after the lessons learned during the very first years of operation, and due to the continuous improvement of maintenance and interlock protection, faults of the RF system have contributed negligibly to the machine downtime. Figure 1 presents the downtime statistics of the light source facility since 1997.

3 SAW-TOOTH INSTABILITY

The HOM characteristics of the accelerating cavity are crucial to the performance of the synchrotron radiation. The observation and cure of saw-tooth instabilities driven by the Doris cavities' higher order modes are discussed as follows. According to the original design, the Doris cavity is equipped with a broadband damping antenna [3] to suppress the coupled-bunch instabilities caused by the cavity's higher-order modes. However, strong saw-tooth instability was observed at higher beam currents, immediately after the storage ring was commissioned, as shown in Fig. 2. The instability was primarily excited by the TM011-like mode of the Doris cavity, owing to insufficient damping of this strongest higher order mode. This instability can not easily be prevented by cleverly selecting the temperature of the cavity cooling water because the damped quality factor of TM011-like mode is not sufficiently high to

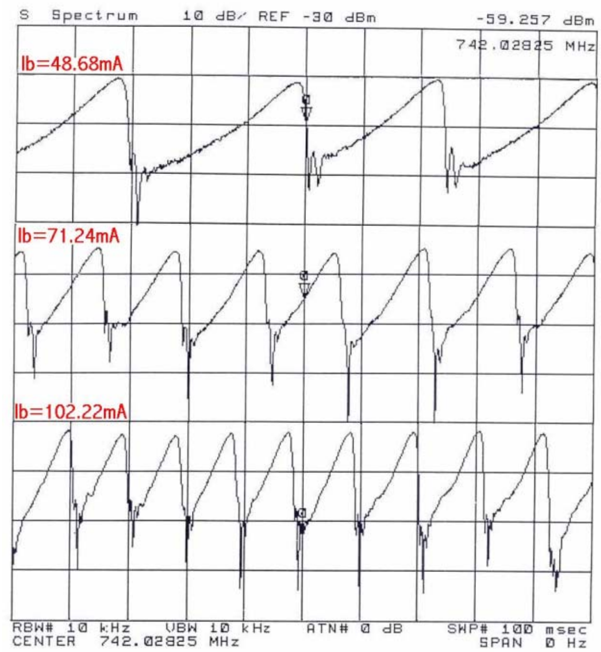

Figure 2: Saw-tooth instabilities excited by TM011-like mode of the Doris cavity in beam currents of 48.68, 71.24, and 102.22 mA, with the second tuner in its worst position. The repetition rate clearly depends on beam current.

localize its bandwidth far away from the beam modes separated by the revolution frequency of 2.5 MHz. Finally, the damping antenna was replaced by a second tuner [4] to enable the frequency manipulation of cavity's higher order modes. The synchrotron light has since been stabilized by properly selecting the second tuner position and the temperature of the cavity cooling water, and by applying amplitude modulation to RF gap voltage [5] at a frequency close to twice the synchrotron oscillation frequency, at the cost of energy spread dilution, directly affecting the undulator performance. This problem can be ultimately resolved by installing a heavily HOM damped accelerating cavity.

4 NEW RF PLANT FOR SRF OPERATION

As stated previously, a major machine performance upgrade is undertaken at SRRC by replacing the Doris cavities designed in 70's with a more recently developed CESR-III HOM heavily damped superconducting RF module [6], to double the synchrotron light intensity by operating the maximum beam current up to 500mA, and eliminating the higher order mode (HOM) effects induced by the accelerating cavity. Commissioning is scheduled for the summer of 2003. Fabrication of the SRF module was contracted out to ACCEL in 2000 after SRRC received a technical transfer from Cornell University. A turbine-based cryogenic plant with a capacity of 460W will enable the operation of the SRF cavities at 4.5K. This work was contracted out to AirLiquide in 2001, according to technical specifications developed in-house. A detailed description of the SRF project can be found elsewhere [7].

Implementing a new 500MHz RF plant to operate the SRF module is in the final stage. Single SRF module is only needed to operate the machine at a maximum beam current of 500mA or more. A 100 kW transmitter has been assembled with a spare 70kW Varian klystron and a klystron coupler re-designed in-house. An 85 kW RF output has been demonstrated by increasing the working voltage and cathode current. The delivery of 100 kW RF power is promised by further increasing the cathode current. The AFT circulator, MEGA water load, and some WR1800 type waveguide components from DIELECTRIC will be installed to connect the transmitter to the SRF module. Attention has been paid to minimizing the group delay of the RF feed line to maximize the open loop gain of the direct feedback.

5 CONCERNS ON SRF OPERATION

The first SRF module of CESR-III design was installed at CESR in September 1997. Since then, five SRF modules have been fabricated at Cornell and four of them are routinely operated at maximum RF power, delivering over 200kW each. The operation of SRF modules at CESR [8] offers invaluable lessons in performance and parameter optimisation at SRRC. Some operational concerns follow previous experience of operating the SFF modules at CESR, to develop a strategy of smooth operation at SRRC, accounting for the effects of heavy beam loading, multipacting, hydrogen adsorption, and coupled-bunch instabilities. The first of them [7] describes as follows.

The ratio of the beam-induced voltage at resonance to the cavity voltage, Y, can be considered as a figure-of-merit that reflects the impact of the Robinson instability on the RF plant, due to effects of heavy beam loading. Operating a machine with a high Y factor reduces the phase margin of the second Robinson instability. With an insufficient phase margin, the RF system becomes unstable due to RF noise, microphonics driven by mechanical vibrations, coupling between the amplitude loop and the phase loop, and other causes. An unstable RF system either fluctuates the spectral intensity of synchrotron light, trips the RF system owing to interlock protection, or causes difficulties during beam injection. A phase margin of at least 10 degree or more is convenient for highly stable operation and can be realized by detuning the cavity resonance frequency and/or by applying the direct feedback to reduce the driving impedance of the RF plant. Beam testing of the direct feedback with an open loop gain of over 20 dB has been performed with Doris cavities up to 200mA, as shown in Fig. 3. Further optimisation is in progress.

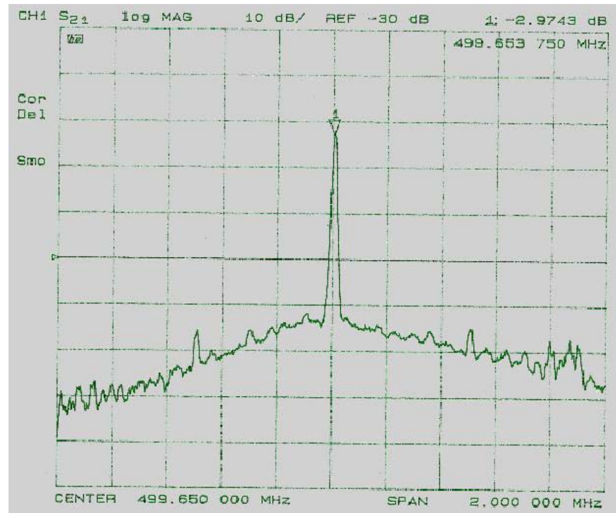

Fig. 3: Closed-loop frequency response of the RF plant with Doris cavities after applying the direct feedback at its maximum allowed open loop gain of 20dB. The frequency of the central peak corresponds to the RF frequency of the RF plant.

6 PERSPECTIVE

Outstanding operational reliability and highly stable performance of the RF plant have been achieved at SRRC using Doris cavities with second tuner. The ultimate upgrade of the beam performance, however, relies on the use of HOM heavily damped cavities and the operation of the machine at a higher beam current than currently used. This situation involves new challenges. Intensive SRF training has been undertaken, thanks to strong technical support from the SRF laboratory at Cornell. System integration of the SRF module, cryogenic plant, and RF plant has been ongoing since 1999, and is on schedule for commissioning of SRF module in summer, 2003.

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