OPERATION STATUS OF SRF SYSTEMS IN THE STORAGE RING OF SSRF

H.T. Hou[1,2,3], Y.B. Zhao[1,3], S.J. Zhao[1,3], Z.Q. Feng[1,3], D.Q. Mao[1,3], Z.G. Zhang[1,3], C. Luo[1,3], X. Zheng[1,3], Z. Li[1,3], M. Chen[1,3], J.F. Liu[1,3]
[1] Shanghai Institute of Applied Physics, CAS, Shanghai, China
[2] Graduate University of Chinese Academy of Sciences, Beijing, China
[3] Shanghai Key Laboratory of Cryogenics & Superconducting RF Technology, Shanghai, China

Abstract

The superconducting RF system has been operated successfully in the storage ring of SSRF since July, 2008. The superconducting RF modules integrated with 310 kW transmitters and digital low level radio frequency (LLRF) control are adopted to provide about 4.5 MV cavity voltages for 3.5GeV electron beam. The operation status of SRF system is mainly reported here, the problems we met are analyzed, and also the operation with normal conducting cavity systems is introduced briefly. The challenge for us is to improve the system reliability and machine performance.

INTRODUCTION

SSRF, a 3rd generation synchrotron light source, has commenced operation to users since May 6, 2009. Since the commissioning of storage ring in Dec. 2007[1-3], the RF system has been operated successfully with both normal conducting cavities and superconducting cavities. Due to the delay of cryogenic plant, the RF system was operated firstly with three normal conducting cavities which helped to commission of the storage ring and obtain beam current 100mA at 3GeV, 200mA at 2GeV and 300mA at 1.5GeV[4]. After the cryogenic plant was ready, three SRF modules were tested successfully and installed into the tunnel instead of the normal conducting cavities from May 2008 to Sep. 2008. Then three SRF modules, integrated with 310kW transmitters and digital LLRF control etc, have been operated for one year. The beam reached 200mA at 3.5GeV on Sep.30, 2008 and 300mA at 3.5GeV on July 18, 2009. The operation status of SRF system will be reported here.

OPERATION STATUS

The SRF system includes three RF stations, each is composed of SRF module, 310 kW transmitter [5], digital LLRF control[6] and its RF PLC interlock. The main operation RF parameters are shown in table 1. The SRF modules with gap voltage 1.5 MV per cavity are operated with 5 fast signals of the SRF module taken into the interlock chain to shut off the RF power source. The helium level is controlled around 67% by PID loop, and the helium vessel pressure is controlled at 1200mbar by PID loop with fluctuation less than ±0.5mbar. The HEX flow for cooling the waveguide section inside the SRF module is well in operation, and the liquid nitrogen insulation is also working well. The heater inside the helium vessel is set to 70W to achieve a constant of the cryogenic heat load. The transmitter was optimized at several modes in its output RF power, and is operated with the mode of 220 kW output power now. The digital LLRF control, developed by SSRF[5], has been taken into operation to control the cavity voltage and the RF phase in the precision of better than ±1% and ±1°, respectively. The complete PLC interlock in RF local station has been implemented to secure the RF system.

Three SRF modules were warmed up to room temperature when the SSRF machine this summer was shut down one and a half months for maintenance. And now the SRF modules have been cooled down to 4.5 K again and operated with beam up to 300mA.

Table 1: Operation Parameters of SRF System

Parameter	Value
RF frequency	499.654 MHz
RF harmonic number	720
Synchrotron radiation loss	1.44 MeV
RF voltage	≥4.5 MV
RF phase stability	≤ ± 1°
RF amplitude stability	≤ ± 1%
Number of SRF cavities	3
External Q	(1.7+/-0.3) E5

Since SSRF was open to users, the number of beam trip events with various trip sources was counted. Figure 1 shows the statistics of the ratio of break-down time caused by the different hardware systems during the users time from May 2009 to July 2009. The SRF system is responsible for about 24%. Among the RF trips, the faults from hardware of the digital LLRF control and the utility for RF were solved smoothly. However, the beam trip still came from the vacuum burst near the RF window of cavity at position #1. The other trip source is the fluctuation of cavity voltage when digital LLRF control operated with beam loading heavily. This fluctuation of cavity voltage resulted in the beam trip by the cavity quench when the voltage change was detected over the condition set in the quench detector. Beam trip was also caused by the insulation vacuum which was a jump to break the ready chain of SRF module. However, this kind of jump was sometime unreliable from the vacuum cold cathode controller. The insulation vacuum was restore after the CC gauge controller was reset. Thus it was malfunction of the CC gauge controller rather than a real increase of insulation vacuum.

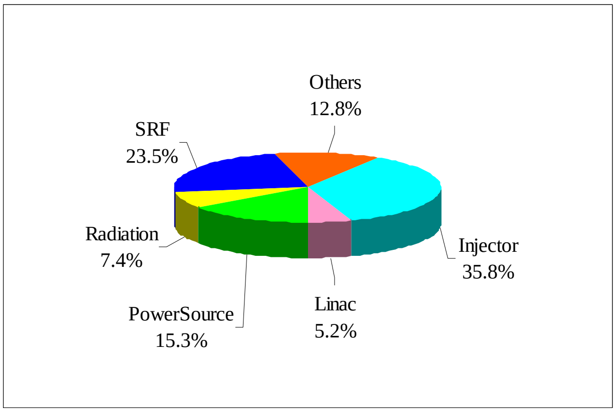

Figure 1: Ratio of break-down time of various systems.

CAVITY PERFORMANCE

After the SRF modules were installed into the tunnel and connected with valve boxes and transmitters, the operation of the modules became a challenge for RF group. Figure 2 shows the SRF modules installed in the tunnel of storage ring. Up to now, all three SRF modules with the digital LLRF control, RF transmitter and PLC interlock are well in operation smoothly

Figure 2: SRF modules in the tunnel of storage ring.

Cavity Conditioning

The SRF cavities were conditioned with cavity voltage higher than 2.0MV and the RF windows were conditioned with RF power up to 120kW when cavities were off resonance during the site acceptance tests. The vacuum burst near the RF window still happened causing a beam trip on vacuum interlocks when forward power was up to a certain range. In order to ensure the cavities were able to deliver power enough to beam, the RF windows were conditioned without beam first and with beam. The forward power of cavities at position #2 and #3 can rise higher than 160kW without vacuum trips. For cavity at position #1, the conditioning was not easy to increase the forward power due to the vacuum trip frequently. Several methods similar to Diamond light source used [7] have been tried to condition the window:

- Condition the RF window with up to 100kW RF power at about 100 kHz off resonance again under the LLRF control.
- Change the phase of standing wave to increase the forward power while keeping the cavity voltage at 1.5MV with frequency loop and IQ loop of LLRF are closed.
- Condition the RF window with beam current. One method is to increase the beam current by a slow increment, the other is to adjust the accelerating phase of the cavities slowly while keeping the same beam current.

The cavity at position #1 was conditioned to handle about 130kW forward power without vacuum trip before the machine shut down this summer. The same phenomenon happened again after a complete warm-up and cool-down operation which was different from the diamond light source experience [7], but it took a shorter time to condition to reach above 150 kW. It seems the window needs more time to condition thoroughly.

Tuner

The tuner of module at position #1 and #3 was found to move in a sudden phase jumps about several tens degrees which was a problem with strong beam loading. The sudden phase jump made the cavity off resonance to trip the beam if the frequency loop was hard to react and to flow this jump quickly enough, and the reflected power was increased. It is solved by replacing the die spring and connector between gear and bush by a new special pipe component.

Frequency Fluctuation

The helium vessel pressure of SRF modules now can be controlled within ± 0.5mbar by its PID loop. However, the cavities are found to be detuned by +/- 3 degree of the cavity phase angle during the operation. Analysis of lots of signals has been done to figure out that the variation of the cavity phase angle in a time interval of several seconds and has correlation with the venturi differential pressure or the helium vessel pressure. No correlation between the cavity phase angle and LN2 supply pressure is observed [7-8]. We will try to optimize the PID parameters of pressure loop and try to install a piezo into the tuner to expect to reduce the frequency fluctuation.

Warm Up

The SRF modules were warmed-up to room temperature during the machine shut down. The cavity vacuum variation was observed. The hydrogen gas resulted in the vacuum worst in a short time interval during warm-up. In order to ensure the ion pumps work properly, the gate valves were open again to let the NEG pumps installed on the conjunction between modules to handle the out-gassing. Figure 3 shows the vacuum variation of module at position #1 during the warm-up. The worst vacuum was up to about 1E-6 Torr. After this summer cool-down again, the vacuum was better than 2E-10 torr, and became to about 4.0E-10 Torr with cavity voltage 1.5MV.

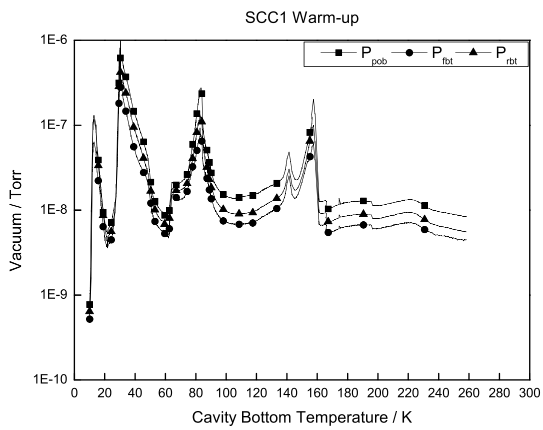

Figure 3: Vacuum variation of SRF module during warm-up. Ppob, Pfbt and Prbt are the vacuum pressure measured at cavity pump-out-box, fluted beam tube and round beam tube, respectively.

Heavy Beam Loading

When the SRF modules operated with heavy beam higher than 250mA, an instability of LLRF amplitude control was observed resulted in an activation of the quench protection to shut down the RF power. The other faults observed includes that the vacuum measured at the round beam tube became worse and the reflected power reached its limit. The fluctuation of cavity voltage was solved by tuning the parameters of IQ control loop and adjust the pre-detune angle of the cavity carefully. Kinds of quench-like above were captured as shown in Figure 4 by a fast recorder.

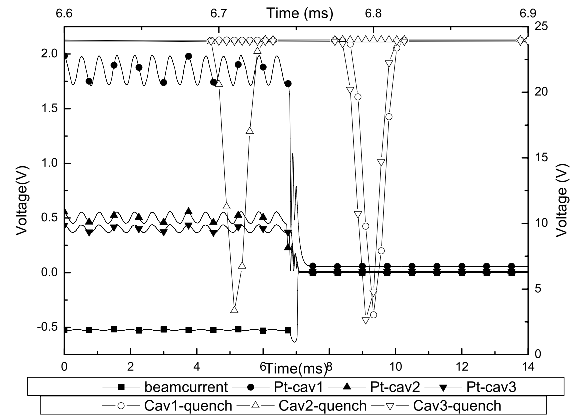

Figure 4: Quench recorded by beam trip diagnostic system. Beam current is the detected voltage from a BPM, the Pt of cavities is a detected voltage from pick-up power of cavity standing for cavity voltage amplitude. Cav-Quench is the quench interlock signal. Left vertical axis and bottom horizontal axis are for detected voltages of pick-up power, the right vertical and top horizontal axis are for quench interlock signals.

The vacuum burst at the beam exit port of cavity implied the beam hit the beam tube and then beam loss made the cavity mismatch to increase the reflected power. We speculated that the cavity reached its critical coupling and we observed the reflected power of the module had a minimum value indeed before beam trip happened. The pre-detune angle was adjusted with little help for this kind of instability. Thus the total cavity voltage was enhanced from 4.5MV to 5.1MV to suppress the instability and 300mA beam current was reached. The investigation on the instability under heavy beam current is still needed to carry out.

CONCLUSION

The 300mA beam at 3.5GeV has been reached in a decay mode at SSRF. The SRF modules integrated with transmitters, digital LLRF controls and PLC interlock are operated well. Some problems during the cavity conditioning were found and have been solved. Further study will be carried out on to minimize the fluctuation of resonance frequency, to figure out the mechanism and to reach the stability of LLRF in heavy beam loading. The most challenging thing for us is to run a heavy beam stably with the improvement of the reliability of SRF system.

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