OPERATION OF SRF IN THE STORAGE RING OF SSRF

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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 to 3.5GeV electron beam. The operation status of SRF system is mainly reported here, the problems we met are analyzed, and the operation with normal conducting cavity systems is introduced briefly. The challenge for us is to improve the system reliability and machine performance.

INTRODUCTION

The superconducting RF cavities integrated with 310kW transmitters and digital LLRF control etc, have been operated successfully in SSRF, a 3rd generation synchrotron light source, since July, 2008[1-5]. A series of problems have been conquered during the commissioning and operation. The beam current reached 300mA 3.5GeV and lasted more than 12 hours in Oct. 2009. Now SSRF is open to users with beam current 200mA at 3.5GeV in decay mode. The operation status of SRF system and the operation experience with SRF systems will be reported here.

OPERATION STATUS

The SRF system includes three RF stations, each is composed of SRF module, 310 kW transmitter [6], digital LLRF control [7] and its RF PLC interlock. Figure 1 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. The main operation RF parameters are shown in table 1. Operation environment of SRF modules is as following:

- All PID control loops of SRF module were taken into operation. The helium level was allowed to stability of 67% +/- 1%, and pressure stability of 1200mbar +/-1.5mbar. The HEX low rate was 30 l/min and the temperature of HEX and N2 gas were controlled to 25°C.
- Pressure of cavity is in the range of 10-10 mbar, and the pressure of valvebox and insulation are in the range of 10-7 mbar.
- 5 fast interlock signals are connected to klystron to shut off RF power fast in case problem happens. These fast interlock signals include quench, ARC, helium vessel pressure, pressure of pump-out-box and readychain.
- 3 sets of Klystrons are taken into operation at 220 kW mode.
- 3 sets of Digital LLRF systems are taken into operation.
- The complete PLC interlock in RF local station has been implemented to secure the RF system.
- Cryogenic load leveller of each module is taken into operation with set value of 70 W.
- The beam trip diagnostic system [8] is taken into operation to record states of monitored signals for a period ahead and behind of beam trip.

Figure 1: SRF modules in the tunnel of storage ring

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

Cavity performance and conditioning

Since SSRF was open to users, the number of beam trip events with various trip sources was counted. Among the RF trips, the faults from hardware of the digital LLRF control and the utility for RF were solved smoothly. The trip came from the vacuum burst near the RF window of cavity at position#1 reported [2,8] has been conquered by complete RF window conditioning [2,9] with beam and without beam. The maximum cavity voltage was high to 1.85MV in cw mode, the maximum forward power was 110kW without beam and 136kW with beam. This kind of vacuum burst didn't happen after complete conditioning.

The SRF module at position#3 is still suffered from the quench protection [10] along with gate valves at both ends of module closed. Fig.2 shows the RF signals captured by beam trip diagnostic system [8] when this kind of quench happened. It can be seen that the cavity voltage (from pick-up power signal Pt) decreased quickly and restored only in 20 μ s, and then the cavity voltage dropped again until reached the protection threshold of quench detector or reflected power reached the threshold value, which also tripped the power source. This kind of quench should not come from thermal breakdown because there was not found increase of helium vessel pressure or venture differential pressure either. Sometimes the first fault signal on interlock system of power source was reflected power instead of quench protection but with the same cavity voltage waveform as figure2. After received comments from Cornell University experts and ACCEL that this kind of quench should be caused by multipacting or an arc at the waveguide region that drains energy from cavity much quicker than that from normal quench. It was suggested to do pulse processing or a completely thermal cycle of SRF module.

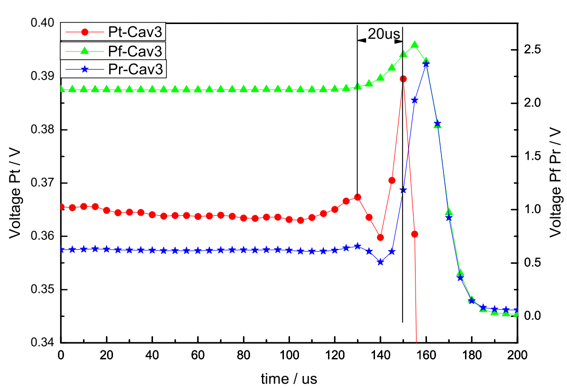

Figure 2: Forward power Pf, reflected power Pr and pick-up power (responsible for cavity voltage) Pt, captured by beam trip diagnostics system when quench happened.

For the reason that SSRF should be opened to users, we chose to do pulse processing with cavity voltage high to 2.1MV and power high to 150kW in order to deal with this problem. However, this kind of trip happened again with beam operation occasionally. It was found that the problem happened fewer with lower cavity voltage so that the cavity voltage was decreased to 1.4MV while keeping the total voltage is around 4.5MV for 210mA 3.5GeV beam operation. It is planned to do a complete thermal cycle of SRF modules and pulse processing during machine shutdown.

DLLRF system performance

The operation status of cavity voltage and phase with both 200mA and 300mA are shown in Fig.3 and Fig.4, respectively. The digital LLRF system [7] based on IQ technology and FPGA module is composed of frequency loop, amplitude loop and phase loop, which is responsible for the control of cavity voltage and phase of SRF modules with and without beam current. It can be seen that the amplitude is stabilized within +/-1% and the cavity phase is stabilized within +/-1 degree at both 200mA and 300mA beam current.

The trip came from the fluctuation of cavity voltage when operated with beam loading heavily has been conquered by adjusting the parameter of PID loops in DLLRF system and adjusting the pre-detuning angle. There ever happened the fault from LLRF system that its reference signal had fluctuation which made the cavity phase fluctuate until it tripped the beam current. After analyzing, it was thought to be hardware problem and was solved by changing the FPGA module.

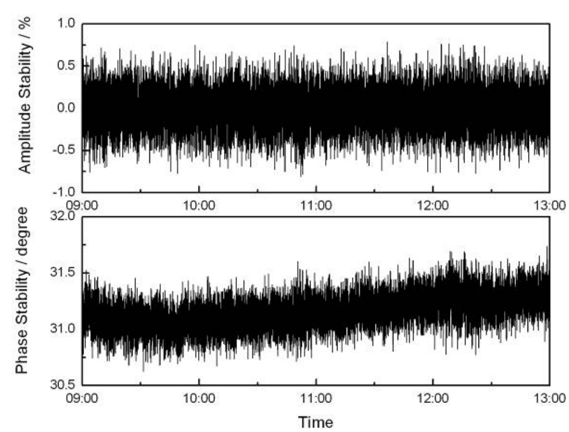

Figure 3: Operation status of cavity voltage and cavity phase of SRF module at position#1 with 200mA beam current. The upper curve is the cavity voltage recorded in four hours, and the lower is the cavity phase. The cavity voltage stabilized within +/-1%, and the cavity phase stabilized within +/-1 degree.

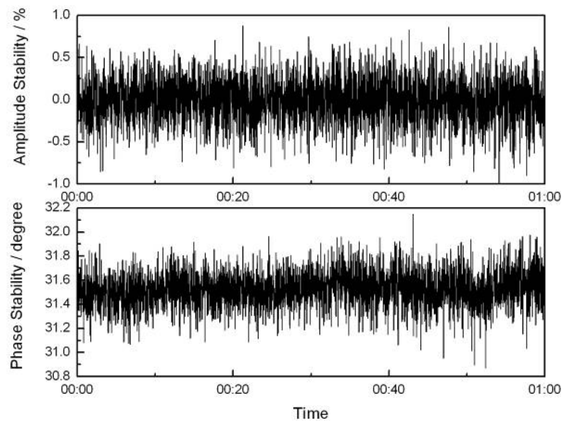

Figure 4: Operation status of cavity voltage and cavity phase of SRF module at position#1 with 300mA beam current in one hour. The upper curve is the cavity voltage recorded in four hours, and the lower is the cavity phase. The cavity voltage stabilized within +/-1%, and the cavity phase stabilized within +/-1 degree.

FUTURE PLAN OF SRF SYSTEM

SSRF plans to operate in top-up mode in the future which may bring some new operation problems to SRF modules and digital LLRF system. At this state it has to improve the reliability and stability of SRF system, including power source, SRF modules and LLRF system. For example, there ever happened arc interlock from high power circulator and 310kW water load. When arc happened, the forward power was around 100kW and reflected power is around 10kW. We don't know if it was a real arc or not. There was captured a pulse about 1s long by the fast recorder which was thought there should happen something, however, this problem should be studied further for improving the stability of SRF system.

Since there is no spare SRF module at SSRF, the study and fabrication of SRF module will be carried out. The digital LLRF system aims to make the whole system be one card, which will be more convenient for maintenance. The higher harmonic superconducting cavity for increase the lifetime and improve the stability of beam is also in consideration.

FABRICATION OF SRF CAVITIES

Based on the KEKB and BEPCII 500MHz superconducting cavities, the niobium cavity was fabricated by deep drawing method. Fig.5 shows the cavity after electric beam wilding waiting for surface processing such as BCP, high pressure water rinsing, etc. We plan to do vertical test after surface processing in SINAP. The higher harmonic niobium cavity has also been fabricated and electric beam wielded waiting for processing and test.

Figure 5: 500MHz niobium cavities after electric beam wilding. The cavity is based on KEKB type. The niobium material is from Ningxia, China.

CONCLUSION

SSRF is operating with three superconducting cavities successfully for almost 20 months and has been opened to users. The maximum beam current has reached 300mA. There have been met and solved many different kinds of problems came from SRF module, digital LLRF system, RF power source and other system. The stabilization of amplitude and phase are controlled by digital LLRF system to be better than the design specification.

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