RF SYSTEM FOR SSRF STORAGE RING

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Abstract

Superconducting RF system for the storage ring of Shanghai Synchrotron Radiation Facility (SSRF) includes 300 kW RF power source, 500MHz superconducting cavities, digitalized I/Q low lovel RF controller, and its utility etc. Status of each above is outlined, especially the achieved results in comparison to the design requirements, and scheme of superconducting cavities is presented in detail.

INTRODUCTION

The RF system for the storage ring of SSRF needs to provide an accelerating voltage and a sufficient RF power to make up for any power losses for the beam current from 200 mA to 300 mA at 3.5 GeV. Power is lost through synchrotron light emitted at the bending magnets or insertion devices, or through parasitic losses because of the vacuum chamber impedances. In calculating the RF power requirements , an estimate is made of as listed in table 1, either 5IDs installed or all the IDs* installed. Because of a waiting for the cryo-plant, on day one of operations three normal conducting cavities loan from PF of KEK were in place to for 100 mA at 3 GeV, 200 mA at 2 GeV, and 300 mA at 1.5 GeV, with being operated six months and replaced with three superconducting cavities. Each cavity is fed from its own klystron amplifier system, with a digital IQ low level RF control. A single cryogenic system supplies the liquid helium to cool and maintain the cavities at the operating temperature of 4.5 K.

Table 1: Basic RF Parameters of SSRF

Parameter	Value	Unit
RF frequency	499.654	MHz
Harmonic number	720	
Total beam power for 300mA	~491(~625*)	kW
RF voltage	≥4.5 (5.4 *)	MV
RF phase stability	≤ ± 1°	
RF amplitude stability	≤ ± 1%	

RF POWER SOURCE

The RF system at the storage ring of SSRF has 3 units of RF power sources. Each of them includes a 350 kW circulator and its 350 kW load and WR1800 waveguide components and a 300 kW CW RF amplifier, which consists of a 40 W drive amplifier, a TH 2161B-1 klystron and its HVPS.

The HVPS for the klystron is the Pulse Step Modulator (PSM) made by THOMSON. The RF amplifier based on the PSM type HVPS has been proven to be very reliable in the field, even under continuous operating and extreme ambient conditions. Such RF amplifiers have been used by many synchrotron radiation sources, e.g. SRS, SLS, DLS, CLS, BEPC II. Some light sources in construction, e.g. PLS to be upgrade, ALBA, and TPS would adopt PSM too.

As mentioned above klystron TH 2161B-1 made by THALES is chosen for the one of the main part of 300 kW CW RF amplifier at SSRF. Its curves of the output power vs. input power are showed as Figure 1. The main site acceptance tests results of three RF amplifiers are listed in table 2. [1]

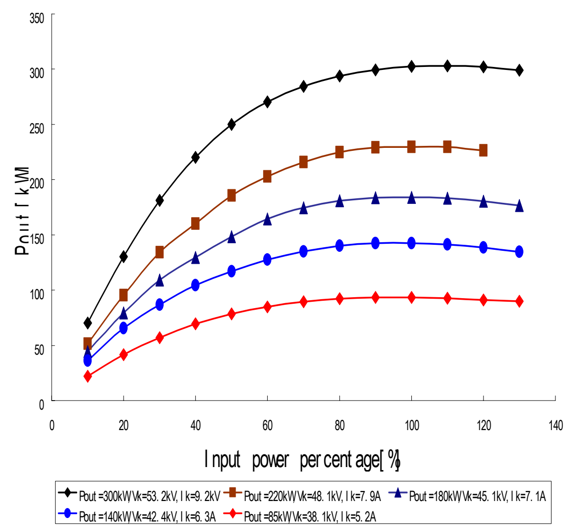

Figure 1: Pout vs drive power @ various Vk.

SUPERCONDUCTING RF CAVITIES

Since September 17, 2008, the three SRF modules had been put into the commissioning and operation. And the beam current reached 200mA with energy 3.5 GeV on Sep. 30, 2008. The superconducting RF modules is turn-key system introduced from ACCEL company. The ACCEL SRF modules are adopted by other light source such as CLS, DLS and TLS too. The fabrication of niobium cavities, high power test of RF window, vertical tests of niobium, horizontal tests of SRF module together with valve box and transfer lines, installation in the tunnel of SSRF storage ring and operation will be submitted respectively as below. [2]

Niobium Cavities

The niobium cavities were fabricated out of high quality RRR > 250 niobium and reactor grade niobium (only flanges). The niobium material was purchased from Wah Chang Company.

Table 2: Main SAT Results of RF Amplifiers at SSRF

Parameter	Design Value	Achieved value		
		#1	#2	#3
Frequency / MHz	499.654	499.654	499.654	499.654
Output power CW / kW	≥ 300	302.7	304.6	300.0
Drive power / W	≤ 31	24.9	20.2	22.6
Gain / dB	≥ 40	40.9	41.8	41.2
Efficiency of Klys.	≥ 60%	61.9	63.7	62.7
2nd harmonic / dBc	≤ -30	-43.7	-37.3	-38.6
3rd harmonic / dBc	≤ -30	-50.2	-66.1	-57.7
Attenuation (+/- 1MHz) @ 300 kW / dBc	≤ 1	-0.3	-0.97	-0.71
50 hr stability @ 300 kW output power / %		~1.20	~1.15	~0.81

High Power Test of RF Window

The high power tests of RF windows were carried out successfully to reach the specific values as follows:

- 250 kW RF power transmitted through the window in traveling wave cw operation.
- 120 kW RF power standing wave cw operation at full reflection of the power at 3 different phases with ceramics in voltage minimum and the ceramic in voltage maximum.
- 400 kW RF power transmitted through the window in traveling wave operation at >20% duty cycle.

Vertical Test

The cavities were shipped to Cornell University after BCP for vertical test. Before cool-down, careful leak check was performed on the pumpline and cavities.The pressure in the cavities were below 5.0E-10 torr at 4.5 K.

The frequency in cold state was in the range of 500.1+/-0.2 MHz. Figure 2 shows the vertical tests results of 3 niobium cavities of SSRF.

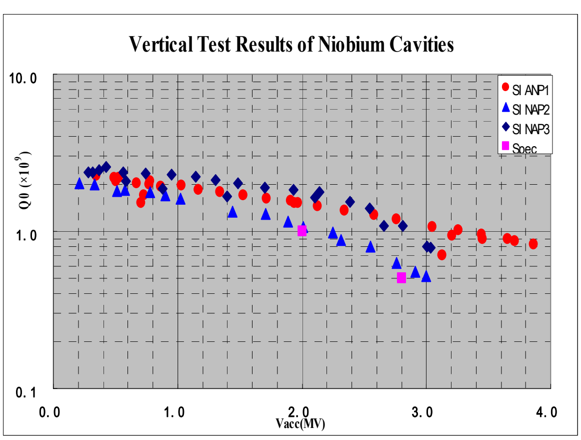

Figure 2: Vertical test results of niobium cavities.

Site Acceptance Test

The site acceptance tests took place from May 2008 to September 2008. Module #1 and module #2 were tested in the horizontal test cave in RF hall of SSRF, and module #3 was tested directly in tunnel of the storage ring. The valve boxes and transfer lines were installed and connected to SRF modules. The control electronic was taken into operation. The external quality factor was measured using Agilent E5071B network analyzer. The results reached the specified value to be in the range of (1.7 +/- 0.3) E5. The RF windows were processed with power high to 120 kW at full reflection. The site acceptance test results are shown in figure3.

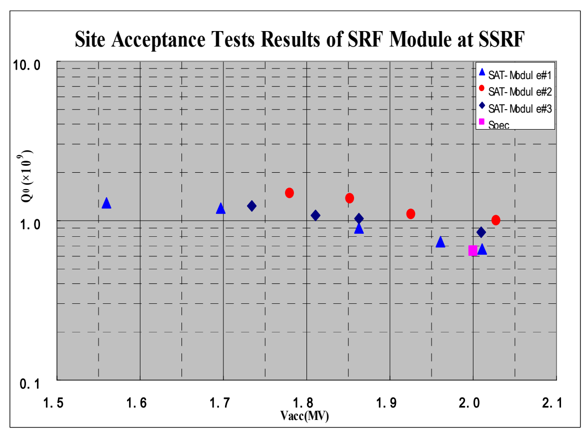

Figure 3: Site acceptance test results of SRF modules.

DIGITAL LLRF

The RF system adopts the Digital Low Level Radio Frequency (DLLRF) controller in storage ring. DLLRF [3] is based on commercial digital signal processing board, clock distribution, local oscillator board and other radio frequency elements, for example: filter, mixer and amplifier etc. Each DLLRF includes the three basic loops: amplitude loop, phase loop and tune loop. The precision of tune loop is better than 10 Hz, and for amplitude loop is better than 1%, and for phase loop is better than 1 degree.

The RF system distribution diagram block is shown in figure 4. Agilent 8663B Signal generator is the phase fundament in SSRF. It provides LINAC, booster and storage ring with phase fundament. In RF system of storage ring, the phase fundament is divided three signals and sent into LLRF controller respectively. The digital LLRF core is the DSP board which include one Altera FPGA EP2S60. In addition, it has the high speed ADC and DAC, down-converted and up-converted mixer. LLRF controller communicates with the PC though the TCP-IP. The communication between PC and center room is realized by the Share memory.

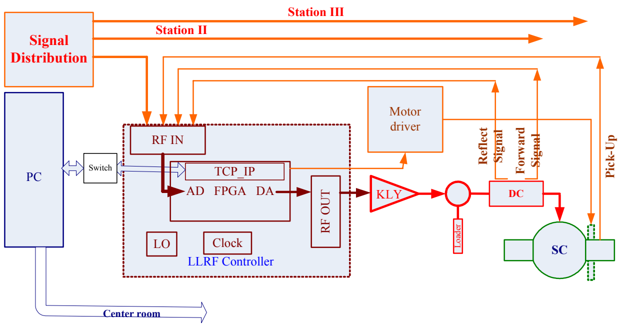

Figure 4: Digital LLRF architecture at SSRF.

LLRF controller may be divided into several features: Local Oscillator (LO) signal generation, Clock signal distribution, RF-IN (down-converted), digital signal processing and RF-OUT (up-converted). A direct digital synthesizer is adopted to obtain LO signal instead of PLL. The system has been operated successfully since Dec, 2007. Figure 5 shows the stability of amplitude loop and phase loop with 100mA beam current at 3.5 GeV energy which reached the specification values.

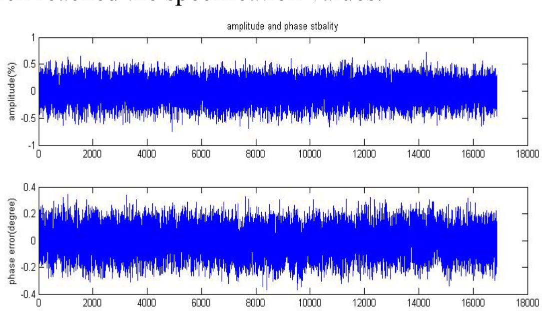

Figure 5: Stability of amplitude loop and phase loop with 100 mA beam current at 3.5 GeV energy.

CONTROL AND INTERLOCK SYSTEM

The interlock and control unit of RF system is to make the system run safely and connect the system to EPICS in reliable way. It should meet the requirements as follows:

- Correct logic.
- Fast and reliable.
- Latch fault signal and show the first fault when trip
- Provide all kinds of working modes.
- Control of six vacuum gate valves on SCCs.
- Communication with EPICS.

OPERATION

Up to now, all the three SRF modules under the digital LLRF control system are in good operation with the RF amplifier and interlock system. Operation environment of SRF modules is as following:

- All PID control loops 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 □.
- 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 180 kW mode.
- 3 sets of Digital LLRF systems are taken into operation.
- PLC interlock system is taken into operation.
- Cryogenic load leveler of each module is taken into operation with set value of 70 W.
- The beam trip diagnostic system is taken into operation to record states of monitored signals for a period ahead and behind of beam trip.

CONCLUSION AND DISCUSSION

The beam current has reached higher than 200 mA at 3.5 GeV. Further study will be carried out on the stability and reliability of Superconducting RF system aiming to maintain a stable and high quality beam current. Some issues such as improvement on the tuner control, optimization of PID parameter of SRF module need further more time to study.

REFERENCES

[1] M. Chen, Z. Feng, S. Zhao, etc, " RF power sources of the storage ring for SSRF", Chinese Physics C, 2008, 32 (S1), 197-199.
[2] Test and results of SRF modules, SSRF report.
[3] Y. Zhao, C. Yin, and T. Zhang, etc, "Digital prototype of LLRF system for SSRF", Chinese Physics C, 2008, 32 (9), 758-760.