RF SYSTEM FOR THE SSRF BOOSTER SYNCHROTRON

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Abstract

The booster synchrotron of the Shanghai Synchrotron Radiation Facility (SSRF) ramps the energy of electron beam from 150MeV to 3.5GeV with a repetition rate of 2 Hz. The guidelines of the system design are simplicity and reliability, and the ability of top-up injection for the storage ring is also taking into account. The RF system consists of a 180kW CW plant with a WR1800 waveguide line, two PETRA type 5-cell cavities and an analogue low level RF electronics with vector-sum scheme. An overview, installation and commissioning of the whole booster RF system are presented in this paper. The performance of the RF system with the beam is also given.

SYSTEM OVERVIEW

Booster synchrotron of Shanghai Synchrotron Radiation Facility has a double symmetric FODO lattice with 8 straight sections for the RF cavities, injection and extraction magnets. The RF system accelerate the electron beam from 150MeV to 3.5GeV with a repetition rate of 2 Hz. To get a quantum lifetime of more than 1 sec, the RF voltage of 1.8MV at extraction is required. The basic parameters of the booster synchrotron for the design of the RF system are listed in Table 1.

Table 1: RF system design parameters (at extraction).

Parameter	Value	Unit
RF frequency	499.654	MHz
Beam energy	3.5	GeV
Energy loss per turn	0.915	MeV
Single/Mulit-bunch mode beam current	2/10	mA
Momentum comp. factor	1.85E-2	
Natural energy spread	7.80E-4	
Longitudinal damping time	2.26	msec
Energy acceptance	3.16E-3	
Harmonic number	300	
Revolution frequency	1.67	MHz
Ramping curve of B magnet field	Positive biased sine curve	
RF voltage	1.80	MV
Beam power (Multi-bunch)	9.15	kW

Basically the RF system consists of RF power plant, cavities and low level RF control system. During R&D of SSRF, one 180kW CW, 500MHz RF power plant had

been commissioned, which would be used for the booster RF system. After comparing of different schemes by the cavity impedance, the total RF power with cavity loss, waveguide loss, and beam power, the safety margin of the RF voltage and power, and the total cost, the scheme of two Petra/Doris 5-cell cavities was adopted. Because the two cavities are driven by the same klystron, a vector-sum scheme in low level RF system is used to compensate the phase difference of the two cavities.

To avoid strong longitudinal oscillation during the injection which will cause the beam loss at injection, the starting RF voltage of ramping should be considered carefully. After calculation with the design parameter of energy and arriving time jitter of the electron beam from the linac, it shows that there is no beam loss if the starting RF voltage is lower than 600kV. On the other hand, because of the large impedance of the two 5-cell cavity and low RF voltage at injection, there will be Robinson instability limit[1] during injection, especially for multi-bunch mode operation. Calculation shows that the RF voltage should be larger than 200kV to avoid the Robinson instability.

With all the requirements above, one can finally set the ramping curve of the RF system consisting of three line, 1st line starts at the zero time (injection time) and stops at 0.04s with a constant RF voltage of 400kV, 2nd line starts at 0.04s and stops at 0.21s with a linear ramped RF voltage from 400kV to 1.8MV, 3rd line starts at 0.21s and stops at 0.25s with the RF voltage of 1.8MV. The ramping curve is shown in figure 1. With this ramping curve, the ramping tune shown in figure 2, can be calculated out.
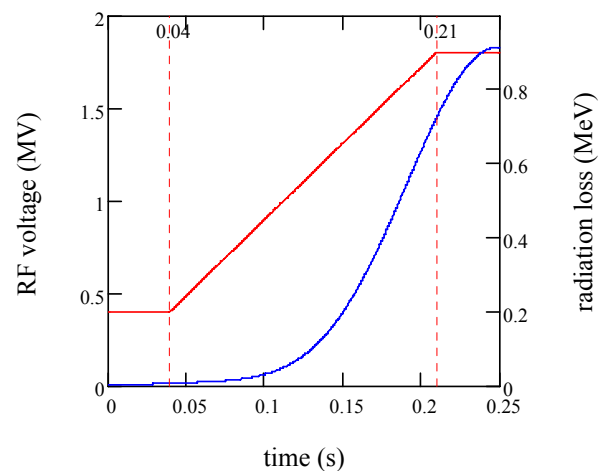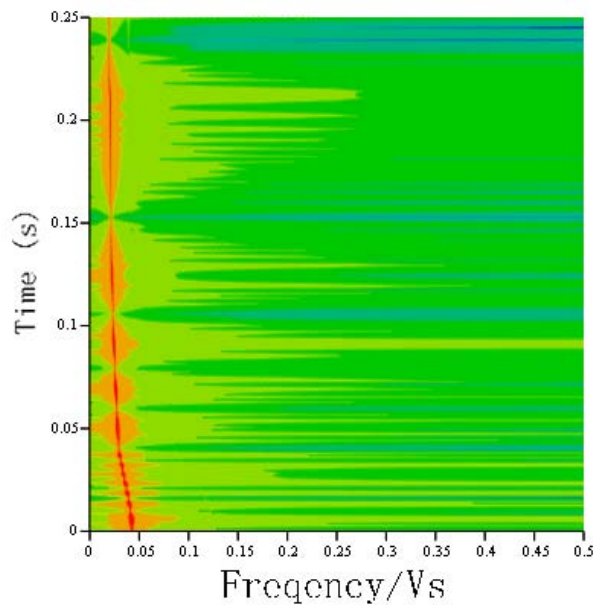

Figure 1: Ramping curve of RF voltage.

Figure 2: Ramping tune of longitudinal oscillation.

COMPONENTS OF RF SYSTEM

Cavity assembly and Low level RF system

The cavity assembly and low level RF system of the RF system are delivered by ACCEL[2]. The maximum RF voltage of the 5-cell cavity is 1MV and the coupling coefficient is set to 1.1 to reduce the reflecting power at extraction due to the low beam loading.

Table 2: RF system parameters

Parameter	Value	Unit
Number of cavities	2	
Shunt impedance	29	MΩ
Quality factor	29000	
Coupling coefficient	1.1	
RF voltage at extraction	0.9	MV
Maximum RF voltage	1	MV
Cavity power at extraction	27.9	kW
RF power at extraction	31.3	kW
Dynamic range of RF voltage	26	dB
sum voltage amplitude stability	1	%
sum voltage phase stability at injection and extraction	1	°
sum voltage phase stability during ramp	4	°

The response of the tuning loop is set to be very slow to filter out the beam loading changing with 2Hz, which is important for stabilizing the low level RF control loop. Two ramping tables are available to set both of the amplitude and phase of the ramping RF voltage, which can compensate the phase shift due to the klystron's

amplitude to phase modulation and beam loading changing during ramping. The design parameters of the 5-cell cavities is listed in table 2. The amplitude and phase stability of RF voltage for stabilizing the beam energy is also listed in the following table.

RF power plant

The RF power plant consists of one set of 180kW CW high power amplifier which was delivered by THOMCAST in 2000 and one set of WR1800 type waveguide system which divides the RF power into two branches and feeds the cavities. The RF power flow chart is shown in Figure 3. In each branch, there are two high power phase shifters to compensate the phase length difference between cavities. After adjustment, the phase different between cavities is less than 1°.
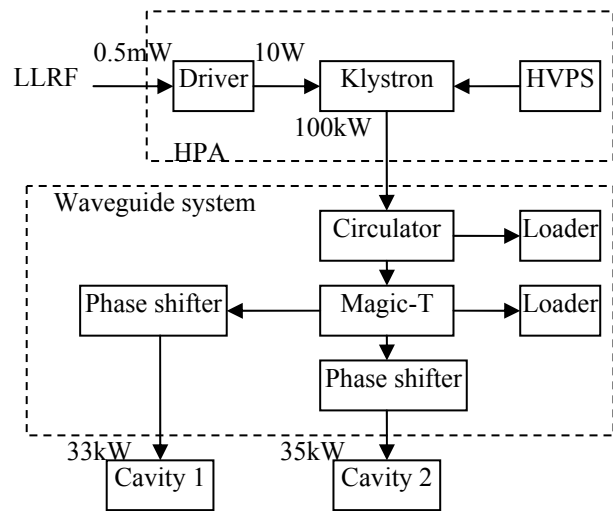

Figure 3: RF power flow chart.

Control and interlock system

The control system of the booster RF system is based on EPICS. One HPA IOC from THOMCAST and one low level RF IOC system from ACCEL have been integrated into SSRF control system via Ethernet. The RF system can be operated from the control room.

The interlock system of booster RF system is based on the ICS system of the HPA, which has high reliability, fast response, and is easy to configure. Because more than 30 digital and analogue signals from the cavities have been connected to the ICS system, new I/O cards at the filter wall, ICS and VME crate have been added during reconfiguration of the HPA. The firmware of the ICS has also been upgraded according to the modification of the hardware and operation mode.

SYSTEM COMMISSIONING

The booster RF hall has been ready by the end of 2006 with the commissioned infrastructure system. The relocation and reconfigure of the HPA started at Jan. and finished at April 2007. After the booster tunnel was ready, the cavities were installed and aligned. After that, the

waveguide system had connected from the klystron to the cavities and all the cabling work had been done at May. The commissioning of the booster RF system started at middle of May and took 2 weeks. Booster commissioning started at Oct. 1st and successfully ramped the electron beam from 150MeV to 3.5GeV within 1 week[3].

RF system commissioning

High power commissioning of the booster RF system has been finished during site acceptance test of the cavities and low level RF system and met the specification of the system design[2]. The loop delay of the whole RF system expect for the low level RF system was measured to be about 600ns. Output of the RF system was measured by HP 4396B. It showed 1kHz and its harmonics during ramping, which is the sampling frequency of the ramping table. A resonant peak was also found around 30kHz, which was the noise from the HVPS of the HPA. Although this noise is very close to the synchrotron tune at extraction, no instability was observed during booster commissioning.

Beam result

On first day of the commissioning of the booster, the electron beam with an energy of 159MeV from the linac was injected into the booster synchrotron. First turn and multi-turn beam signal has been detected on the WCM with RF system off and cavities detuned. After that, the RF system was on under the CW mode with an RF voltage of 100kV and the electron beam was stored in the booster synchrotron. Different RF voltage was applied to the store electron beam, and the synchrotron tune was measured at the same time, which is shown in the figure 4. From this figure, the momentum compact factor could be found out to be 0.01734.
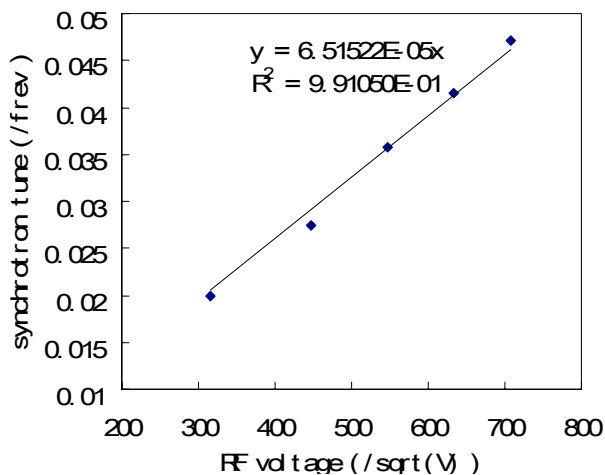

Figure 4: Synchrotron tune change with the RF voltage.

After the working point was fixed at injection energy, the ramping table of the magnets and RF voltage were set, and the trigger was synchronized, the electron beam has been ramped to 3.5GeV. The ramping tune of the longitudinal oscillation measured on a BPM at a

dispersion section was shown in figure 5. From this figure, the ramping tune of the longitudinal oscillation coincides with the calculation result shown above. Different ramping tables were tested, but no significant change of the beam parameters happened.
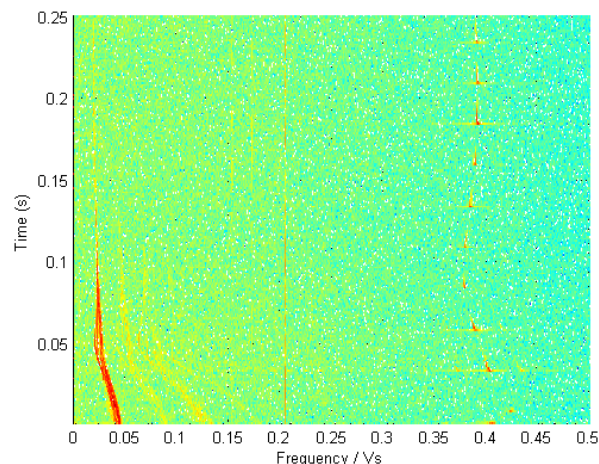

Figure 5: Ramping tune of longitudinal oscillation (curve on the left side is the synchrotron tune and the discrete curve on the right side is the horizontal tune excited by the extract kicker.)

The phase shift due to the beam loading at injection is about 10deg and 40deg under single bunch and multi bunch mode respectively. This coincides with the estimate which is 8deg and 35deg. Because the response of the tuning loop is far slower than the repetition rate of the booster, a fixed detuning angle is set to stabilize the RF system under the multi bunch mode.

CONCLUSION

The booster RF system has been successfully commissioned and tested by the beam, and met the requirements of design parameters. Because the commissioning of storage ring started 2 month later, no detailed investigations has been done. The more experiments will start in next month during the second commissioning period of the booster, while the storage ring will have the first two superconducting cavities.

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