DEVELOPMENT OF THE BUNCHING SYSTEM OF THE SSRF LINAC

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Abstract

As one of the most important parts of the SSRF linac, the bunching system was developed in the R&D of SSRF. It mainly consists of a re-entrant cavity (prebuncher) and 1.36m long, travelling-wave buncher. In this paper, the design of the system, the manufacture of the two components and the RF test results are described.

1 INTRODUCTION

The 300MeV linac of Shanghai Synchrotron Radiation Facility (SSRF) is used to be an injector of the 3.5GeV booster, operating in two different modes: single-bunch mode with pulse length of 1ns and pulse intensity of about 1.2nC, or alternatively multi-bunch mode with pulse length of 300ns and average macro pulse current of 180mA. In addition, it is designed as an injector for the proposed DUV FEL facility, and the energy 300MeV is therefore chosen for this purpose [1].

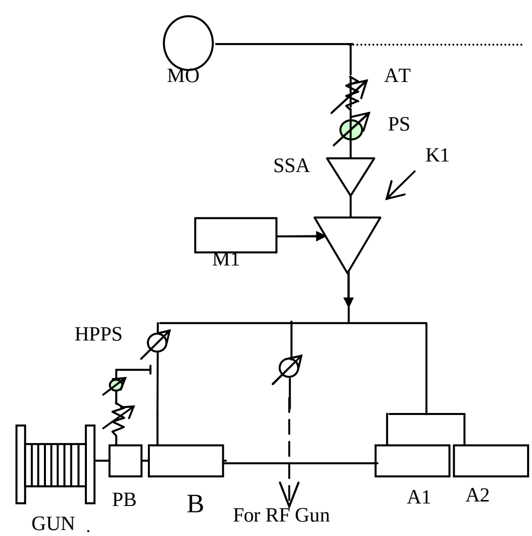
In the first phase of SSRF, to meet the requirements of the 3.5GeV booster, a thermionic cathode gun, a pre-buncher and a 1.36m long, traveling-wave buncher are employed as the pre-injector of the linac, shown in Fig.1. And they were developed in the R&D of SSRF. We describe here the design of the entire bunching system, together with the design, fabrication, and RF test results of the buncher.

2 DESIGN OF THE BUNCHING SYSTEM

To minimize the space charge effect, the bunching system of the SSRF linac was designed to be as short as possible. The total length (from the exit of the gun to the end of the buncher) is about 2m, shown in Fig.1.The bunching occurs in the prebuncher and buncher. The electrons issued by the thermionic gun enter the prebuncher with the energy of 100keV, and are bunched and accelerated to more than 10MeV within a phase interval of about 10 degree when they leave the buncher. Then, in the down-stream accelerator sections, the electrons will only be accelerated, almost without bunching.

Such kind of bunching system is selected because it is compact and independent of the rest of the accelerator [2]. And it will be convenient to adopt a RF gun as the pre-injector of the linac for the DUV FEL study.

The microwave power of the prebuncher and buncher comes from one of the three 45-MW klystrons for the whole linac, shown in Fig.2



MO: Master oscillator, AT: Attenuator, B: Buncher
PS: Phase Shifter, SSA: Solid State Amplifier
M: Modulator, K: Klystron, A: Accelerator section,
PB: PreBuncher, HPPS: High-power Phase shifter

Figure2: Schematic diagram of the RF system

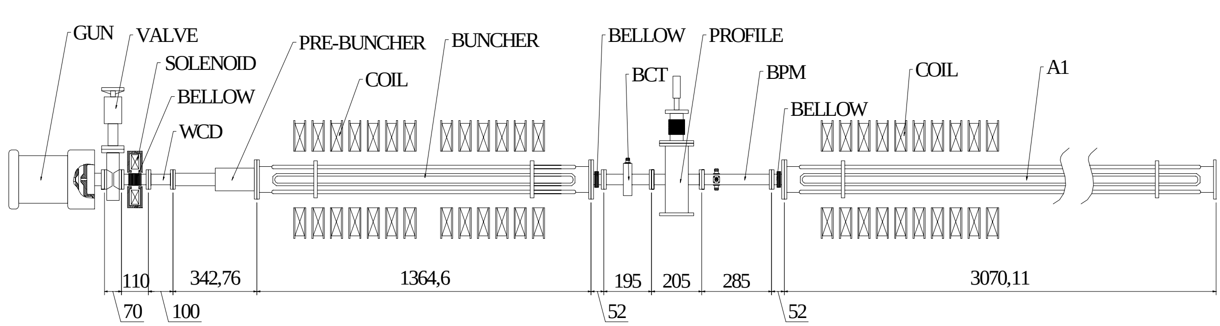


Fig.1. Pre-injector of the SSRF linac

With a commercial, rotary vane attenuator, whose attenuation range is 0.07 to 20dB, the gap voltage of the prebucner may be adjusted around 20kV, and the wave phase may be varied in a wide range using a Fox phase shifter.

The peak field of the buncher is 12MV/m at the design input power of 8.2MW. A high-power phase shifter, which can stand 15MW of pulse power, was developed in the R&D of SSRF, and will be used to adjust the wave phase of the buncher within 360 degree.

Since aside from the accelerating field, the electron beam from the gun is acted upon by its own space charge forces and radial RF fields in the prebuncher and buncher, it is necessary to incorporate steering and focusing devices into the design of the bunching system.

At the exit of the gun, a magnetic thin lens is used to locate the beam waist at the gap of the prebuncher. This location minimizes the effects of the radial fields and the radial dependence of the longitudinal fields in the prebuncher.

Between the lens and the end of the buncher, a focusing solenoid is used to introduce focusing magnetic field. The solenoid is assembled from many pancake coils. At the beginning of the solenoid, where the electrons are not very energetic, the pancakes are individually driven by separate power supplies, so that the optimum magnetic field configuration may be found experimentally.

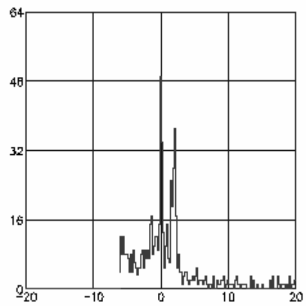
To observe the beam behavior in the bunching system, a wall current detector is installed at the exit of the gun, and a beam current transformer, a beam profile monitor and a beam position monitor are installed at the end of the buncher.

The particle dynamics of the single bunch mode is simulated with PARMELA [3]. In this mode, the pulse length from the gun is 1.0ns, and it will be bunched into three bunches by the prebuncher, whose resonant frequency is 2856MHz. Yet these three bunches will be injected into a single RF bucket in the booster and the storage ring, whose RF frequencies are 500MHz. And that's why we call it single-bunch mode.

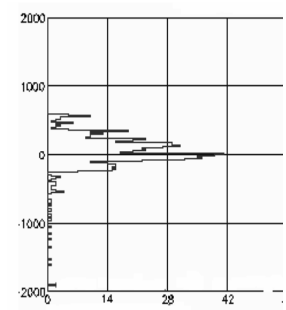
As mentioned above, the charge of the electron beam at the exit of the linac is 1.2nC. Considering the charge losses in the bunching process, we made the calculation using a beam of 2nC and 1ns from the electron gun. The parameters of the gun were calculated with EGUN, and they were used in PARMELA.

The simulations showed that by optimizing the gap voltage of the prebuncher, the wave phases of the prebuncher and buncher, and the focusing magnetic fields, the bunched beam could meet the requirements of the linac. Shown in Fig.3 are the parameters of the beam at the exit of the bunching system, with the accelerating field of 12MV/m for the buncher.

The result shows that the energy of the beam is 13.3MeV, and the normalized RMS emittance is about 60π·mm·mrad. About 70% percent of the initial charges are contained in 10 degrees around the peak.



(a) Phase spectrum



(b) Energy spectrum

Fig.3. Characteristics of the bunch for 2.0nC at the exit of the buncher. In (a), the vertical axis is the number of the particles, and in (b), the vertical axis is the energy spread of the particles with respect to the center-particle

In the multi-bunch mode, the pulse length is 300ns, the average current is 180mA, and the bunch separation is 0.35ns. Without compensation for the transient beam loading, the bunch-to bunch energy change in the buncher is about 11%.

3 PREBUNCHER

The prebuncher is a re-entrant resonant cavity machined from the material of stainless steel, Nickel plating. The stainless steel is chosen to lower the Q value to approximately 1000 so as to minimize the effects of temperature, mechanical distortions, and electron beam loading on the field in the cavity. The main parameters of the prebuncher are listed in table 1.

Table 1: Main Parameters of the prebuncher

Parameters	**Designed**	**Measured**
Total length (mm)	342.76	
Drift tube length (mm)	176.38	
Cavity length (mm)	30.6	
Gap of the cavity (mm)	8.89	
Beam aperture (mm)	19.05	
Resonant freq. (MHz)	2856	2856.1
Unloaded Q value	900~1000	880
VSWR	<1.1	1.04
Power permitted (kW)	20	
Gap voltage (kV)	~20	
Temperature (^oC)	45±0.3	

4 BUNCHER

The buncher is of copper disk-loaded, travelling-wave structure fabricated by means of the brazing technique [4]. It is about 1.36 m long, having 38 cells, including the input and output couplers, shown in Fig.4. It operates in 2π/3 mode. The phase velocities of the first five cells vary from 0.5c to 0.95c, and the dimensions and parameters are described in table 2. The other 33 cells, whose dimensions are chosen in reference to the last 33 cells (No.53 to No.85) of the 3m constant-gradient accelerator section, have the same phase velocities, 1.0c.

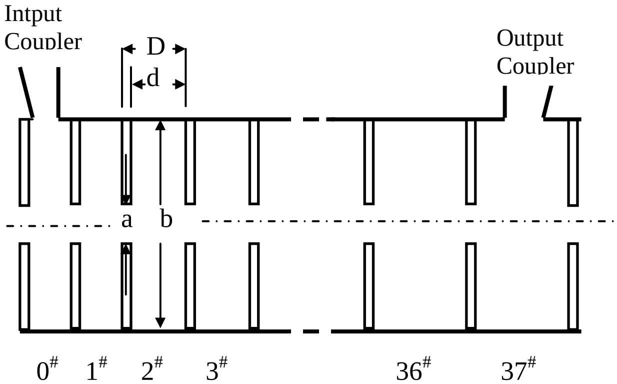


Fig. 4. Schematic structure of the buncher

Table 2: Parameters of the first five cells of the buncher

	0#	1#	2#	3#	4#
D (mm)	26.238	26.238	30.791	32.191	33.240
d (mm)	20.396	20.396	24.949	26.349	27.398
2a (mm)	19.093	22.606	22.606	22.606	22.606
2b (mm)	79.858	83.317	82.857	82.737	82.657
β_ω	0.75	0.75	0.88	0.92	0.95
β_g		0.01196	0.01235	0.01242	0.01245
1/α (1/m)		0.23	0.19	0.19	0.18
Rs (MΩ/m)		36.1	48.1	51.6	54.3
Q		10956	12495	12928	13240

The buncher was fabricated by IHEP. And, since a high-power RF source is not available to us at present, the high-power tests of the buncher and the newly developed high-power phase shifter were also performed in IHEP. Shown in table 3 are the last test results of the buncher.

The buncher is a constant-gradient structure. Its shunt impedance Rs is about 53MΩ/m, and total power attenuation τ_0 is 0.275Nepper. The input power for different accelerating filed amplitude is shown in figure 5.

Table 3: RF test results of the buncher

Parameters	Designed	Measured
Frequency (MHz)	2856	2856
VSWR	<1.1	1.1
Bandwidth (MHz)	±2	-2~0.8
Phase error of the cells (°)	<2.5	<2.0
Total Power att. (dB)	2.7	2.6
Q value of the cells	13060	
Filling time (μS)	0.4	
Input power(MW)	8.2	10

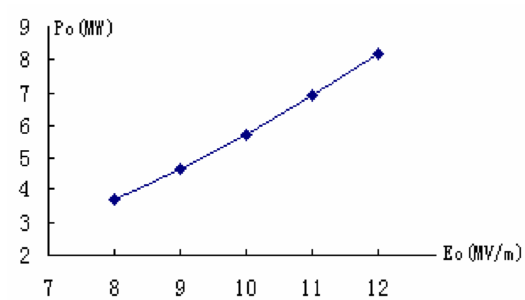


Fig.5. Input power for different accelerating field

5 CONCLUSIONS

We designed the bunching system for the SSRF linac using the simulation codes SUPERFISH and PARMELA. The prebuncher and buncher were fabricated and tested in IHEP. The results showed that this bunching system could produce the bunched beams required for the SSRF linac, and this was confirmed by an expert-group in December 2000.

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