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DEVELOPMENT OF AN -BAND ACCELERATING STRUCTURE FOR HEFEI ADVANCED LIGHT SOURCE FACILITY

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Abstract

The Hefei Advanced Light source Facility injector will choose the full-energy injection method with beam energy up to 2.2 GeV by a LINAC containing 40 S-band normal conducting traveling wave accelerating structures. A full-scale prototype of accelerating structure was fabricated and tested. Quasi-symmetric single-feed racetrack couplers were used in the design of the accelerating structure utilized for the reduction of the field asymmetry inside the coupler cavity. The RF measurement results indicated that the accelerating gradient of the prototype structure was about 23 MV/m for an input RF power of 40 MW which reached the limitation of the installed klystron.

INTRODUCTION

Hefei Advanced Light source Facility (HALF) is a diffraction-limited storage ring light source with very low emittance, reaching the level of tens of pm. The storage ring has high requirements for the injector to achieve effective beam injection and stable storage operation. Therefore, it is necessary to design and construct a high-quality injector to ensure the stable operation of HALF.

The storage ring operates in constant current mode, and the beam energy provided by the injector is designed to be 2.2 GeV, which can achieve full energy injection into the storage ring. To ensure that the storage ring has sufficiently high injection efficiency, the beam emittance of the injector at the injection point is required to be 12 nm·rad (RMS), corresponding to the normalized emittance of 51.7 mm·rad (RMS).

The injector system includes a pre-injector, linear accelerator, and transport line. The microwave frequency of the injector system is 2856 MHz. In the pre-injector, the grid-controlled gun generates an electron beam with an energy of 100 keV and beam length of 1 ns (FWHM). Then it is subsequently accelerated with the energy of 10 MeV by a standing wave pre-buncher and a traveling wave (TW) buncher, and the beam length is compressed to about 10 ps. It is continuously accelerated to about 120 MeV energy in two 3-meter accelerating structures. Then it enters the LINAC, and the beam energy is increased to the design value. The linear accelerator consists of 40 3-meter equal gradient accelerating structures, two of which are used for online backup. The average acceleration gradient for each 3-meter equal gradient accelerating structure is approximately 20 MV/m.

Although the current pre-injector design can meet the requirements of the HALF injector, it is necessary to reserve feasibility to meet potential needs such as performance improvement and multi-purpose application of HALF. The pre-injector may be replaced with other machines with much lower emittance. When the emittance is relatively low, the field asymmetry in the coupler cavity will degrade the beam's quality due to its multi-pole field components. Some coupler designs have been developed to reduce the degradation, such as dual-feed racetrack-shaped couplers [1], J-type couplers [2], and quasi-symmetric single-feed racetrack couplers [3,4].

This paper presents an S-band traveling-wave accelerating structure with quasi-symmetric single-feed racetrack couplers. We measured the RF parameters of the fabricated and tuned prototype of the full-scale accelerating structure.

ACCELERATING STRUCTURES DESIGN

Accelerating Unit

The layout of directly driving two 3-meter equal gradient accelerating structures with an 80 MW klystron was chosen in the injector with macro-pulse width of 1 microsecond and repetition rate of 10 Hz. The beam loading can be ignored because of single bunch injection. The parameters of the accelerating structure are considered as follows: based on cost, manufacturing duration, and mature technology in our laboratory, we choose the cooling method of externally welded water pipes; furthermore, we chose a working gradient of 20 MV/m for the accelerating structure by referring to other LINACs. The parameters are listed in Table 1.

Table 1: Parameters of accelerating structure in HALF injector

Parameters	Unit	Value
Frequency	MHz	2856
Type		Constant gradient, traveling wave
Work mode	rad	2π/3
Cell Number		85+2
Input power	MW	30
Gradient	MV/m	20
Iris aperture, 2*a*	mm	24.716~19.145
Disk thickness	mm	5
v_g/c		0.0184~0.0073
Attenuation	Np	0.54
Filling time	μs	0.83
Kilpatrick factor @25MV/m		1.24
Total length	m	3.14

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Coupler

Considering the low-emittance beam provided by an E-gun which might be installed at the start end of HALF injector, the emittance growth of the beam when getting through the coupler was calculated. We considered the bunch with an initial normalized emittance of 1 mm mrad, a bundle size of 0.5 mm, a longitudinal phase of 10 °, an RF phase of -3 °, and a gradient of 20 MV/m. The multipole field of the coupler, defined by the Eq. (1) and Eq. (2), were chosen as 0.001 in the calculation. According to the calculation method in [3], we calculated a normalized emittance increase of 1.27% with a quasi-symmetric single-feed racetrack coupler, which is quite acceptable.

$$\frac{\overline{\Delta E_{\mathrm{d}}}}{\overline{E_z}} = \frac{\int E_z(x=a) - \int E_z(x=-a)}{\int E_z(x=0,y=0)} \tag{1}$$

$$\frac{\overline{\Delta E_{\mathrm{q}}}}{\overline{E_z}} = \frac{\int E_z(x=a) + \int E_z(x=-a) - \int E_z(y=a) - \int E_z(y=-a)}{2\int E_z(x=0,y=0)} \tag{2}$$

The sketch of the coupler is shown in Fig. 1. The coupler, simplified based on [3] [4], is welded from three parts: a wedge-shaped waveguide, a coupling cavity, and a short-circuit waveguide. The quadrupole and dipole components are minimized by adjusting the distance between the circular arc centers of the racetrack coupling cavity and the length of short-circuit waveguide.

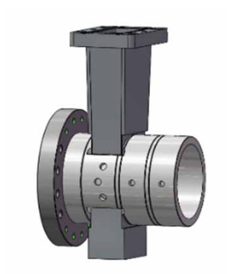

Figure 1: Sketch of the coupler.

RF MEASUREMENT

Cold Test

The full-scale prototype of accelerating structure for HALF was fabricated by National Synchrotron Radiation Laboratory, in which dozens of acceleration structures have been manufactured over the past 40 years.

The coupler and cavities were tested and tuned by using Kyhl's method and the nodal-shift method with a network analyzer, Keysight E5071C. We converted the measured frequency to the frequency for an operating temperature of 42 ◦C in vacuum. After tuning the accelerating structure, the input SWR was about 1.03, and the attenuation and filling time of the whole structure were 4.80 dB and 843 ns, respectively, compared to 4.79 dB and 834 ns in the simulation. Integral phase shift errors, measured cell by cell and shown in Fig. 2, were within ±1 degree.

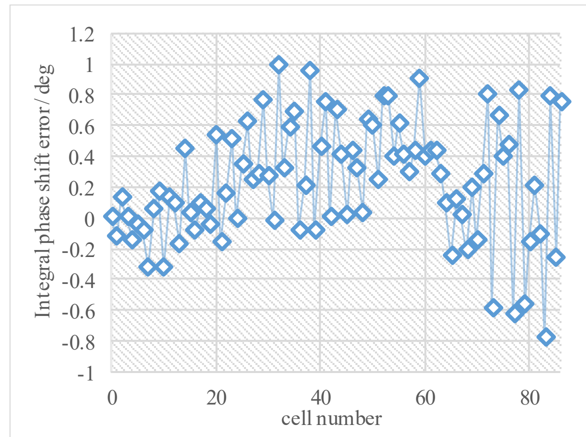

Figure 2: Integral phase shift errors measured cell by cell.

Conditioning

The conditioning process used a Canon 3730A klystron, which has an upper limit of output power of 50 MW. But due to modulator limitations, the output power could only reach about 45 MW and the repetition frequency was only 5 Hz. After about one month of conditioning, the input power could reach 40 MW, with a pulse width of 1.5 μs, a gradient of about 23 MV/m, and a 12-hour breakdown probability of about 1E-5. Figure 3 lists the output power of the klystron and the vacuum at the dummy load connecting the output coupler of the accelerating structure during the entire conditioning process, with idle time being the time for site maintenance and equipment failure repair.

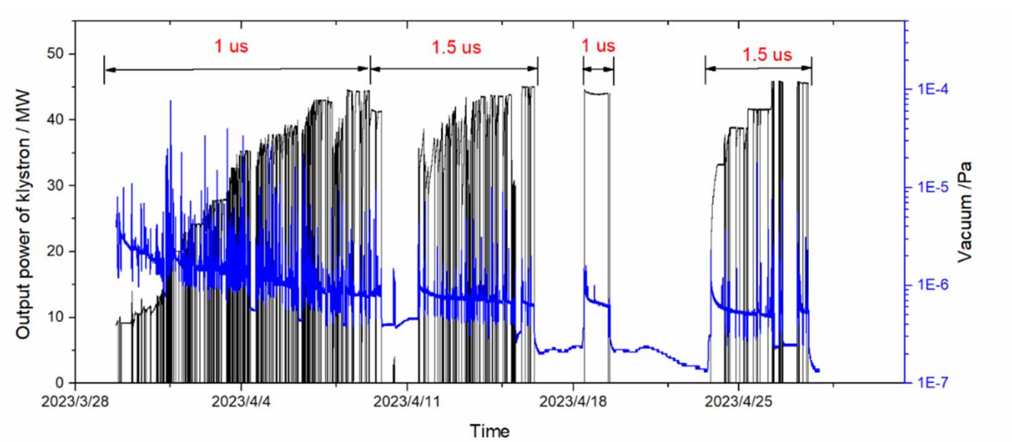

Figure 3: Klystron output power and vacuum in conditioning process.

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CONCLUSION

The full-scale prototype of accelerating structure for HALF was fabricated and tested in the past 6 months. The test results meet the design requirements, and the production and testing of the next 40 accelerated structures will be completed according to the design of this prototype.

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