The wavegui system of the HLS 800 MeV Linac Postprint

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Abstract

To upgrade Hefei Light Source (HLS) Linac, eight accelerating units have been constructed to realize full-energy injection of the storage ring. Each of the units consists of two 3-m accelerators driven by one klystron. The input cavity detuning method was developed to measure and correct the phase length of the RF power distribution waveguide system. The design of the waveguide network and the principles of the detuning method are presented in this paper. After correction, the phase error between the waveguide of the two accelerators was less than 0.5, and the maximum electron energy of Linac reached 805 MeV, which is very near the theoretical maximum value of 810 MeV. These results demonstrate that the calibration of the waveguide was successful.

Full Text

Preamble

The Waveguide System of the HLS 800 MeV Linac

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To upgrade the Hefei Light Source (HLS) Linac, eight accelerating units have been constructed to enable full-energy injection into the storage ring. Each unit consists of two 3-m accelerators driven by a single klystron. This paper presents the input cavity detuning method developed to measure and correct the phase length of the RF power distribution waveguide system, including the design

of the waveguide network and the principles of the detuning method. After correction, the phase error between the waveguides of the two accelerators was reduced to less than $±$0.5°, and the maximum electron energy of the Linac reached 805 MeV, which is very close to the theoretical maximum of 810 MeV. These results demonstrate that the waveguide calibration was successful.

Keywords: Linac, Waveguide, Phase length

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I. HLS 800 MeV Linac

The layout of the 800 MeV Linac [?] is shown in Fig. 1 [Figure 1: see original paper]. The accelerating system comprises one prebuncher (a single standing-wave cavity), one buncher (a 1-m traveling-wave accelerating structure), and eight accelerating units (each composed of two 3-m constant-gradient traveling-wave accelerators) driven by eight klystrons. Klystrons No. 1 and No. 8 are rated at 80 MW, while the others are 50 MW. The RF SLAC Energy Doubler (SLED) [?] is installed in each 50 MW station. When all SLEDs are operational, the electron beam energy can reach 1 GeV [?, ?]. The main parameters of the 800 MeV Linac are listed in Table 1 .

TABLE 1. Parameters of the 800 MeV Linac

Parameters	Values
Operating frequency (f)	2856 MHz
Phase shift per cavity	$2\pi/3$
Range of the shunt impedance (Rs)	55-63 MΩ/m
Normalized group velocity range (Vg/c)	0.01-0.02
Attenuation parameter (τ)	0.585 Np
Filling time (tF)	0.8995 µs
Operating state	42°C, vacuum
No. of standard 3-m sections	8
No. of cavities in each 3-m section	86 + 2 coupler cavities
Distance between the inputs of two consecutive sections	31λ
No. of 6-m accelerator units	8

Fig. 1. (Color online) The 800 MeV Linac layout.

II. Design of the Waveguide Network

When one klystron drives two accelerators, a 3-dB power splitter and a phase-balanced waveguide network must be employed for power distribution. The arrangement of the waveguide network is shown in Fig. 2 [Figure 2: see original paper]. Branch A starts from the pass-thru port of the splitter, which connects directly to one accelerating section (A), whereas branch B starts from the coupling port, which connects to the opposite side of the successive section (B). The horizontal span between the two branches is 31λ, equal to the distance between the two accelerator input ports. The eight accelerating units are arranged in the sequence AB, BA, ···

To achieve phase balance between branches A and B, the geometrical phase lengths of the waveguides must be calculated, and phase changes caused by physical characteristics of the components must also be considered. In the network shown in Fig. 2, the coupling port of the 3-dB splitter lags 90° behind the pass-thru port. A phase difference of 180° exists between the E-plane right-bend waveguide and the left-bend waveguide [**?**]. The change in the direction of the electric field along the E-bend waveguide is marked in Fig. 2.

The calculated phase lengths of branch A and branch B are 15.4368λg and 15.6836λg, respectively, where λg is the waveguide wavelength. At the power splitter, the phase length of branch B physically increases by 0.25λg. Consequently, the total phase length of branch B is 0.4968λg longer than that of branch A, which exactly offsets the phase difference of the E-bend waveguides.

Fig. 2. (Color online) The waveguide network.

III. Phase Length Measuring Method

Traditional reflection and transmission methods suffer from several problems. A reflection phase measuring method based on shorting the accelerator output coupler is normally used to measure waveguide phase length [**?**]. As shown in Fig. 3 [Figure 3: see original paper], the output coupler of accelerator A is terminated with a short, while accelerator B is matched with a load. A network analyzer connected to the 3-dB splitter input port measures the S11 parameters of the signal reflected by branch A. The difference between the phase shift of the accelerator section and the reflection signal phase represents the phase length of branch A. By exchanging the short and the load, the phase length of branch B can be measured [**?**].

However, these methods have significant limitations:

1) Temperature stability is critical. The accelerator' s phase shift, which is significantly affected by temperature variations, is included in the measurement result. Typically, the accelerator temperature must be maintained within \$±\$0.5°C during phase measurement.

2) The waveguide network' s phase length is measured from the start of the network to the input port of the coupler end position, as shown in Fig. 3. The phase length of the coupler itself is not included. Therefore, even if the waveguide branches are perfectly in phase, the electron beam will still experience different accelerating phases when passing through the two accelerators if the couplers have phase errors.

The waveguide phase length can also be determined through transmission parameter measurement. In this approach, the accelerator output signal is fed back to the network analyzer, requiring a pair of coaxial-waveguide adapters. It is crucial to ensure their connector directions are uniformly aligned with the waveguide; a reversed connection would cause a 180° phase shift. The electric field changes for in-phase and anti-phase connections are shown in Fig. 4 [Figure 4: see original paper].

A major disadvantage of the transmission method is that the coaxial cable is too long to maintain phase stability when switching the measurement from branch A to branch B.

The modified reflection method applied in the 800 MeV Linac waveguide phase measurement is the input-cavity detuning method. In this technique, reflection occurs not at the accelerator output but at its input. As shown in Fig. 5 [Figure 5: see original paper], a copper rod is inserted from the beam entrance into the first cavity of accelerator A. The cavity is completely detuned, causing total reflection. The equivalent reflecting plane is very close to the cavity surface (the end position is labeled in Fig. 5). Therefore, the input coupler is included in the waveguide network measurement.

This method offers excellent temperature tolerance. The total reflection from detuned accelerator A is unaffected by temperature variations. Because the input bandwidth of the accelerator is approximately $±$1 MHz and the resonance frequency shift with temperature is 50 kHz/°C, no reflection occurs in accelerator B to interfere with the phase measurement of branch A if the temperature variation is kept below $±$5°C.

To measure the phase length of branch B, the only required action is to remove the rod from accelerator A and insert it into accelerator B. No RF component needs to be removed or reinstalled, eliminating any accidental errors due to mechanical problems.

Fig. 3. Reflection method for phase length measurement.

Fig. 4. (Color online) In-phase and anti-phase connection of coaxial-waveguide adapters.

Fig. 5. Input-cavity detuning method.

IV. Measurement and Calibration of the Waveguide Network

Figure 6 [Figure 6: see original paper] shows a photograph of the 800 MeV Linac. One accelerating unit in an AB arrangement is shown in Fig. 7 [Figure 7: see original paper]. The RF characteristics of the eight accelerating units were verified after installation, and the voltage standing wave ratio (VSWR) at the splitter input was less than 1.05, demonstrating successful installation. The measurement and correction of the waveguide network phase lengths then commenced. As shown in Fig. 8 [Figure 8: see original paper], a copper rod was used to detune the input cavity, and a special clamper was employed to deform the waveguide wall and adjust the phase. The phase measurement results before and after adjustment are listed in Table 2 . Notably, the deviation between the two branches was reduced to less than $±$0.5° after correction.

TABLE 2. Phase length measurement results

Accelerator unit	Phase length (degrees)
Initial	-17.5, -50.0, -73.1
Adjusted	-50.0, -50.0

When the Linac became operational, the electron beam energy was measured. The maximum energy reached 805 MeV, representing a deviation of only 0.6% from the theoretical maximum of 810 MeV. Assuming the energy difference is entirely caused by waveguide phase errors, the average phase error across the eight units is merely 0.7°. This result demonstrates that the phase measurement and correction are highly reliable.

Fig. 6. (Color online) Photograph of the 800 MeV Linac.

Fig. 7. (Color online) An accelerating unit in the AB arrangement.

Fig. 8. (Color online) The clamper for phase adjustment and copper rod for cavity detuning.

V. Conclusion

An input cavity detuning method has been successfully applied to measure and correct the phase length of the waveguide network in the HLS 800 MeV Linac. Compared with traditional methods, the proposed detuning method is more convenient because it does not require any waveguide or coaxial components to be removed or assembled during the phasing process. It is also more reliable because there is no possibility of accidental errors due to mechanical problems or temperature instability. Finally, it is more accurate because the input coupler' s phase error can be corrected.

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