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Design Studies of RF Phasing System for BEPCⅡ Linac *

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Abstract In order to compensate the RF phase drift due to various factors, we will establish a RF phasing system for BEPCⅡ linac. Energy maximizing method will be used to determine the RF phase of each RF power source. A coaxial line will be used to distribute RF phase reference along the klystron gallery. The key components, such as PAD unit, IϕA units, have been developed. A minimum phasing system is established and runs successfully.

Key words linear accelerator, phasing system, low level RF system, RF phase measurement, I/Q demodulator

1 Introduction

The changes of the RF phases will change the energy gain of the beam along the linac. Consequently it will change the beam dynamics. Many important parameters of the beam, such as the beam energy, the beam optics, even the beam current, will vary at the end of the linac. So it is very important to stabilize the RF phases.

As the BEPCⅡ injector[1], the greatest challenge for the linac is to provide very stable positron beam with the injection rate of 50mA/min, which is 10 times higher than the existing linac. There isn't any RF phase feedback system running for the BEPC injector though there have been some attempts before. To meet the stringent requirement of BEPCⅡ, it is essential to establish a RF phasing system to compensate the RF phase drift due to various factors.

There are mainly three kinds of phasing method[2)] for the electron linac, namely, the beam loading method, the beam induced method and the energy maximizing method. For 1ns beam pulse, it is appropriate to use the energy maximizing method. This method is also adopted by SLAC and KEK.

2 System design

2.1 Requierment of BEPCⅡ linac

For long linacs, the fractional energy spread is

$$\frac{\Delta E}{E} \approx \frac{1}{2}\left[\frac{\alpha}{2} + \frac{1}{N}\sum_{n=1}^{N}\theta_n\right]^2, \qquad (1)$$

where N is the number of sections, θ_n is the phase error of the nth sections and α is the beam length in RF radians. The maximum phase error allowed by BEPCⅡ linac is $\pm 2°$ so that the maximum energy spread within 10 degrees of the electron/positron beam will be less than 0.4% in the worst case.

2.2 System configuration

The RF system including the phasing system is shown in Fig.1. There are 16 RF power stations installed in the klystron gallery. There are also 13 SLED systems. Part of the output power from the first klystron is coupled to a coaxial cable to drive the rest 15 klystrons. The RF power required for prebuncher and buncher is also coupled from the output of the first klystron. A phase reference signal is coupled from the output of the master oscillator. The RF phase reference line will distribute the reference signal to every phase detector.

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1) E-mail: gupd@mail.ihep.ac.cn
2) Talks given in IHEP, http://acc-center.ihep.ac.cn/miniworkshop/index.htm.

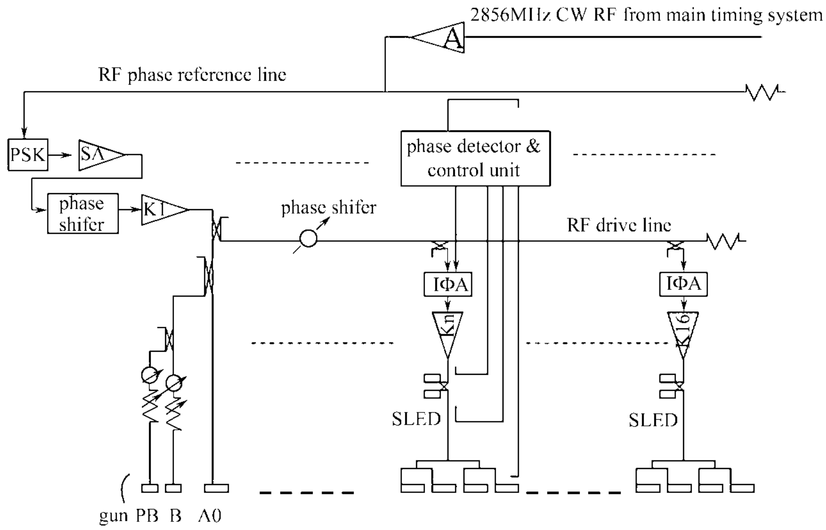

Fig.1.　The RF system configuration for BEPC Ⅱ linac.

2.3　Phasing procedure[2]

The energy maximizing method will be used to find the optimum phase of each klystron. The RF phase of each klystron is scanned and the beam energy measured using a dipole magnet and a BPM. The data will be used to fit the RF phase with respect to the energy gain. Then the desired RF phase for each klystron is sent to each phase detector and control unit and the phase feedback loop turned on. The system will compensate the phase drift but will not respond to the quick phase fluctuation in one RF pulse and the quick pulse-to-pulse variations.

3　Main issues

3.1　The master oscillator

The phase noise of master oscillator is the main source of phase noise in the whole RF system. We plan to replace the existing master oscillator with a new one. Their parameters are shown in Table 1.

Table 1.　Parameters of the master oscillator

	BEPC	BEPC Ⅱ
long-term stability	$\pm 1\times 10^{-7}$/d	$\pm 1\times 10^{-9}$/d
phase noise	≤ −100dBc/Hz @1kHz	≤ −130dBc/Hz @1kHz
power stability	≤5%	≤1%

Another very important thing is to keep the master oscillators of the linac and the storage ring synchronous. The master oscillators of the linac and the storage ring are two independent oscillators for BEPC. The electron gun is triggered by a signal from the ring master oscillator. That means the beam and the linac RF are not fully synchronous. Obviously the charge distribution between the electron bunches will change when the phase between the two master oscillators changes. And there will be different injection rates for different injections. This will be one source of instability for the linac. So it is very important that the RF signals of the linac and the storage ring should be phase locked for BEPC Ⅱ.

3.2　The RF reference[3—5]

The stabilized RF reference is a key issue for the phasing system. A phase stabilized coaxial line will be used to distribute the reference signal along the linac. The phase stabilized coaxial line selected for simplicity and easiness to maintain. We also consider installing the master oscillator in the middle of the linac instead of at the head. This will reduce the phase drift from the master oscillator at the end of the reference line. Temperature coefficients of Heliax type cable from Andrew and TCOM-1 type cable from Times Microwave are about 5 ppm/℃. We will do some tests before making the final decision. The phase stabilized coaxial line will be put in a heat jacket with a temperature stability of 0.1℃. We are also considering measuring the phase length of the reference line.

3.3　The phase and amplitude detector unit

Phase detector is a key component for the phasing system. There are many kinds of phase detectors being used on accelerators:

- Mixer type;
- Digital exclusive OR type;
- Hybrid-type phase detector (or Zero-crossing type);
- I/Q demodulator;
- Digital I/Q demodulator, etc.

The I/Q demodulator can measure the phase and amplitude simultaneously. And in theory, it is not affected by the RF power level variation when measuring the phase. The phase measurement can cover the full range of 360 degrees. So we have developed the phase and amplitude detector unit based on I/Q demodulator.

The block diagram is shown in Fig. 2. DC blocks and band pass filters are used to eliminate the strong noise from the modulators. The band pass filter is a hairpin type. Its configuration and S11 and S21 parameters are shown in Fig. 3. Its bandwidth is 300MHz. In-band insertion loss is 2.2dB. Out-band insertion loss is greater than 60dB.

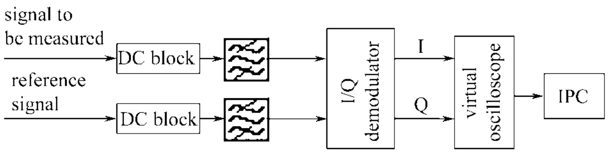

Fig.2. PAD unit.

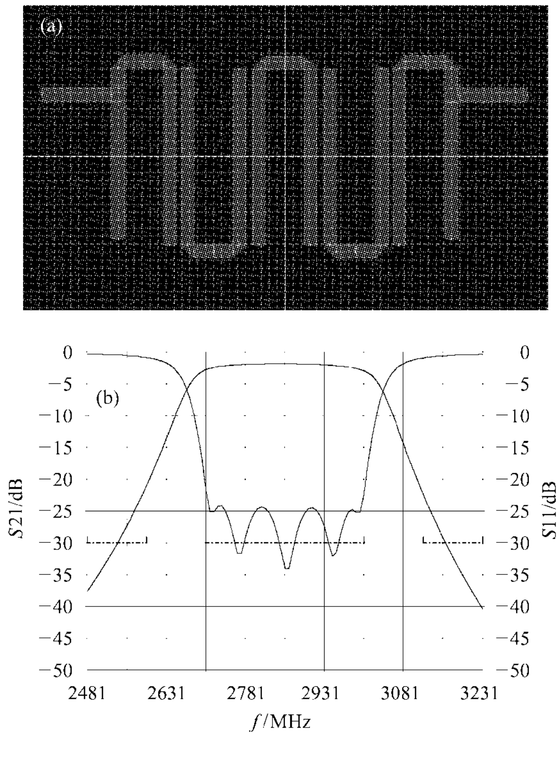

Fig.3. The band pass filter.
(a) The model; (b) The S parameter.

The working frequencies of both the RF port and LO port of the I/Q demodulator are 2856MHz. So besides the two mixers in the I/Q demodulator there are not any other active components in the detector. The virtual oscilloscope is used as a fast digitizer for sampling I and Q signal. Its sampling rate is 100Ms/s with a 12bit vertical resolution.

Software calibration[6] is used to compensate the amplitude and phase imbalance of the I/Q demodulator. Various software calibration methods for the I/Q demodulator are being studied and tested. The data before and after calibration are shown in Fig. 4. We adopted the calibration method used by SLAC in this measurement.

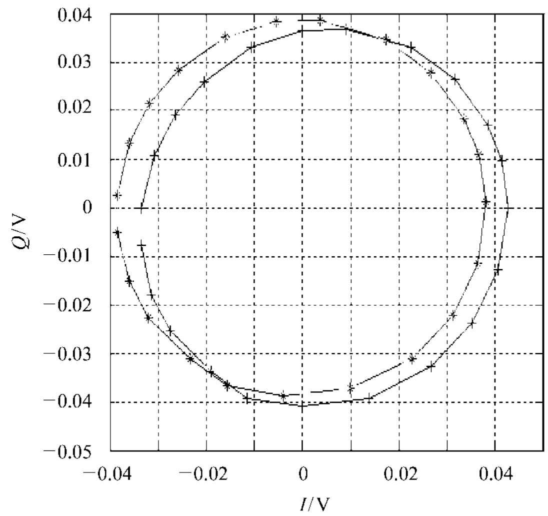

Fig.4. Data before and after calibration.

Measurements show that the I/Q demodulator has a phase resolution better than 0.2 degree and the dynamical range better than 20dB. Its repeatability is better than 0.5 degree (including the mechanical errors of the phase shifter). The industrial PC is used to process the data and as the local control unit.

After many measurements in the lab the unit is tested in the klystron gallery. From Fig. 5, we can see that the modulators produce large electromagnetic noise signals. The noise is coupled to the measurement system through various routes. We selected one part of the waveform where the noise signal is low and made average. We got the same results with modulators on and off.

3.4 The I ϕ A unit

The manufacture of the new I ϕ A units has been completed. The minimum insertion loss is less than 2.5dB and the maximum insertion loss is greater than 20dB. All the components can sustain peak power greater than 3kW. The phase shifter range is about 540° with a resolution better than ±0.5°. The phase shifter and attenuator in the IΦA unit are motorized ones from ARRA Inc.

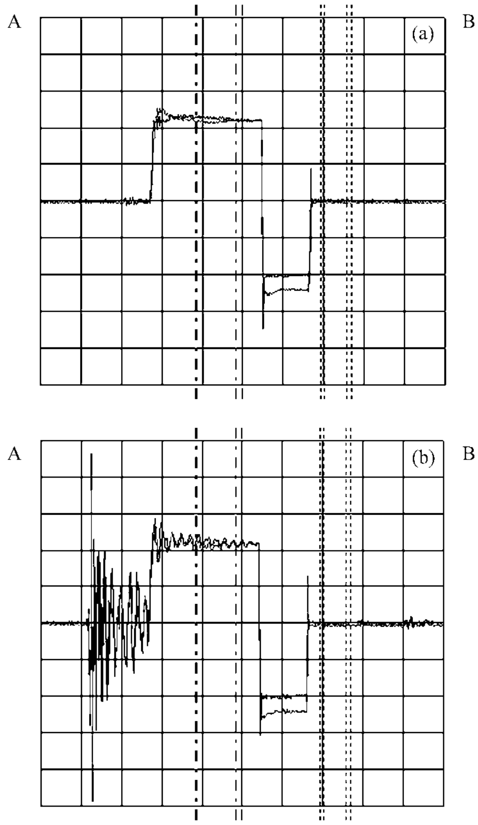

Fig.5. Field test of the PAD unit.
(a) Modulator off; (b) Modulator on.

3.5 Others[7]

The successful operation also depends on many other things. The klystron gallery will be air-conditioned to minimize the phase drift caused by room temperature variation. The cooling water for the klystron and accelerator tube will also affect the RF phase. Fluctuation of the line voltage will affect both the RF phase and amplitude. We observed 1.5 degree pulse-to-pulse phase fluctuation caused by the 3‰ modulator high voltage fluctuation. It is essential to install de' Qing circuits for the modulators to avoid this kind of problem.

4 Minimum RF phasing system

Before the shutdown of the BEPC linac a minimum phase feedback system was set up to evaluate the key techniques. The block diagram and the RF phase measurement in one day are shown in Fig. 6. We shifted the phase of the reference signal so as not to disturb the operation of the BEPC linac. We can see that the RF phase is successfully controlled within ±2° of the reference phase.

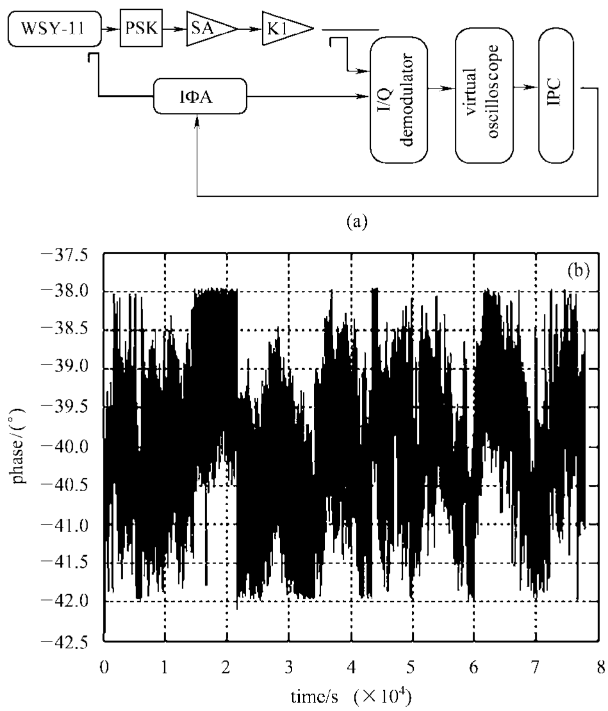

Fig.6. Minimum RF phasing system.
(a) Block diagram; (b) RF Phase in one day.

5 Conclusions

The key components of the phasing system have been developed and successfully tested. The minimum phasing system has demonstrated the feasibility of the design. The phasing system will be fully implemented soon.

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BEPCⅡ直线加速器相控系统设计研究*

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摘要 为了补偿由于各种因素引起的微波相位漂移,BEPCⅡ直线加速器需要建立微波相位反馈控制系统. 能量最大法将用来确定每台功率源的最佳相位. 沿直线加速器速调管长廊铺设相位稳定同轴线提供相位参考. 现在已经完成了关键部件,如PAD单元、IΦA单元的开发. 搭建了相控最小系统对系统进行了验证.

关键词 直线加速器 相控系统 微波低电平系统 微波相位测量 I/Q解调器

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* BEPCⅡ工程资助

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