# 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[1]. Energy maximuming 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 are under development.

## 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, 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.

## SYSTEM DESIGN

### *Requierment of BEPCII Linac*

For long Linacs, the fractional energy spread is

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

where N is the number of sections, $\theta_n$ is the phase error of the nth sections, $\alpha$ is the beam length in RF radians.. The maximum phase error allowed by BEPCII Linac is ± 2º so that the maximum energy spread within 10 degree of the electron/positron beam will be less than 0.4% in the worst case.

*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.

### *Phasing procedure[3]*

The optimum phase of each klystron must be found first. The RF phase of each klystron is scanned and the beam energy will be 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 phase feedback loop will be turned on. The system will compensate phase drift but will not response to the quick phase fluctuation in one RF pulse and the quick pulse-to-pulse variations.

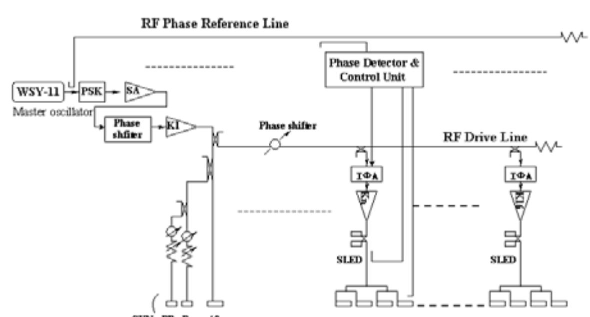


Figure 1: RF system configuration for BEPCII Linac.

## MAIN ISSUES

### *The master oscillator*

The phase noise of the master oscillator is the main source of the 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.

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 is not fully synchronous. Obviously the charge distribution between the electron bunches will change when the phase between the two master oscillators changes. And there

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will be different injection rate 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 BEPCII.

## *The RF reference[4][5][6]*

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. Phase stabilized coaxial line is 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-1type cable from Times Microwave are about 5 ppm/°C. We will do some test before making the final decision. The phase stabilized coaxial line will be put in a heat jacket with a temperature stability of 0.1°C. We are also considering measuring the phase length of the reference line.

Table 1: Parameters of the master oscillator

| | BEPC | BEPCII |
|---|---|---|
| Long –Term Stability | $\pm 1\times 10^{-7}$/day | $\pm 1\times 10^{-9}$/day |
| Phase Noise | ≤100dBc/Hz @1KHz | ≤130dBc/Hz @1KHz |
| Power Stability | ≤5% | ≤1% |

## *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 it is less affected by the RF power level variation when measuring the phase. So we will develop the phase and amplitude detector unit based on I/Q demodulator.

The block diagram is shown in Figure 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 Figure 3. Its bandwidth is 300MHz. In-band insertion loss is 2.2dB. Out-band insertion loss is greater than 60dB.

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 isn't any other active components in the detector. The virtual oscilloscope is used as a fast digitizer to sample I and Q signal. Its sampling rate is 100Ms/s with a 12bit vertical resolution.

Software calibration[7] are 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 is shown in Figure 4. We adopted the calibration method used by SLAC in this measurement.

Measurements show that the I/Q demodulator has a phase resolution better than 0.2 degree and dynamical range of about 20dB. Its repeatability is better than 0.5 degree (including the mechanical errors of the phase shifter). The industrial PC will be used to process the data and as the local control unit. After many measurements in the lab the unit now being tested in the klystron gallery.

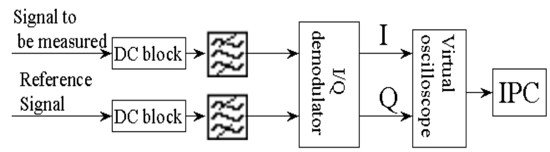
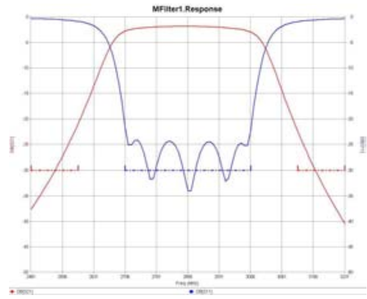



Figure 2: PAD unit.

(a) The model



(b) The S parameter

Figure 3: The band pass filter.

## *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 degree with a resolution better than ± 0.5°. The phase shifter and attenuator in the I φ A unit are motorized ones from ARRA Inc.

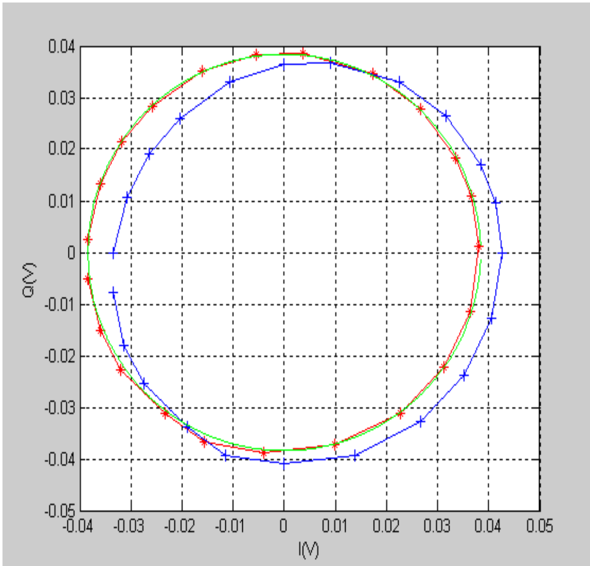



Figure 4: Data before and after calibration.

### *Others[8]*

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.

## EXPERIMENTS AND MEASUREMENTS

Many measurements must be done before the implementation of the whole system. The RF variation with respect to room temperature, cooling water, modulator high voltage etc. is being measured in the klystron gallery. The software interface of the measurement is shown in Figure 5. Before the shutdown of the Linac a minimum phase feedback system will be set up to evaluate the key techniques. After that the whole system can be set up.

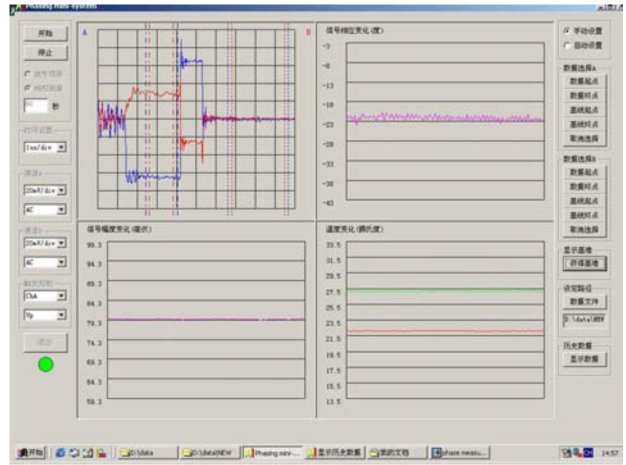


Figure 5: Measurement Interface.

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