BEAM-PHASE MEASUREMENT SYSTEM FOR HIRFL

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Abstract

The beam phase measurement system in HIRFL is introduced. The system had been improved using RF-signal mixing and filtering techniques and noise cancellation method. Therefore, the influence of strongly RF disturbing was eliminated and the signal to noise rate was increased, and a stable and sensitive phase measurement system was developed. The phase history of the ion beam was detected by using 15 sets of capacitive pick-up probes installed in the SSC cyclotron. The beam phase information was necessary for tuning purposes to obtain an optimized isochronous magnetic field, where the beam intensity was increased and the beam quality was optimized. The measurement results before and after optimized isochronous magnetic field for $^{40}Ar^{15+}$ ion and $^{12}C^{6+}$ ion in SSC were given. The phase measurement system was reliable by optimizing isochronous magnetic field test, and the precision reached ±0.5°, the sensitivity of beam signal measurement was about 10nA as well.

INTRODUCTION

The heavy ion research facility in Lanzhou (HIRFL) is composed of a sector focusing cyclotron (SFC K=69), and a separated sector cyclotron (SSC K=450), which is also the injector of the cooling storage ring (CSR). As to the isochronous cyclotron SFC and SSC, it is very important in optimization of isochronous magnetic field to get the best beam quality and efficiency of beam extraction. The information of isochronous of magnetic field could be provided by the beam-phase measurement system in beam tuning. Plate capacitive phase probe was designed and installed on SFC and SSC respectively. The signal mixing filter technology was applied and the beam signal detected by the phase probes was measured using HP8508A vector voltmeter. The frequency range of the beam phase measurement could be covered by the cyclotron frequency 6.5-14.5MHz in HIRFL, and the measurement sensitivity was about 5uV. That is when beam intensity was 10nA, the signal could be identified, and the system measurement accuracy was 0.5°.

DESCRIPTION OF BEAM-PHASE MEASUREMENT SYSTEM

The beam-phase measurement system in HIRFL mainly includes phase probe for the beam signal detection, the phase measurement signal processing system, as well as computer acquirement system.

Phase Probe

Based on many international researches of accelerator labs, plate capacitive phase probe is the best choice for isochronous cyclotron. The probes are located along the centre of one hill sector on the isochronous trim coil place of the magnet with the same distance along the radius direction. The electrode is made of non-oxygen copper plate and the voltage of induction signal is proportional to the charge of the beam pulse. Two layers of shielding outside of the electrode have been designed to protect the electrode from being attacked by beam and reduce the interference of RF-frequency. To avoid any signal reflection, the probes have an impedance of 50 ohms, the beam signal detected on the probe feed through by double shielding coaxial connector SWH.1S ensure the requirement of vacuum. The 6 sets of phase probes have been installed on the centre of SFC with the size of electrode 50mm × 100mm and the distance of 35mm between upper and lower and the 15 sets of phase probes have been installed on the centre of SSC with the size of electrode 100mm × 100mm and the distance of 40mm between upper and lower. The state of isochronous of magnetic field in cyclotron could be reflected by the results of beam phase measurement fully.

Phase Measurement Signal Process

The detection signal on the phase probe is transformed to voltage by the phase measurement processing system which is related to beam phase. The beam pulse signal with the cyclotron frequency ω_d is shown:

$$u(t) = \frac{1}{2}\sum_{n=0}^{\infty} A_n \cos(n\omega_d t + \varphi_n)$$

While A_n and φ_n are the magnitude and phase of harmonics n respectively. Capacitive phase probes installed on the centre of cyclotron not only detect the beam signal, but also the interference of RF-frequency. Generally the signal to noise rate of the beam to RF-frequency interference increases with the adding of the harmonics, however, the intensity of beam signal decreases with the reducing of harmonics. Therefore, considering the two factors of beam intensity and signal-noise ratio, the second harmonic component is selected as the measurement signal of the beam phase:

$$u_2(t) = A_2 \cos(2\omega_d t + \varphi_2)$$

The structure of beam-phase measurement system in HIRFL is shown in Figure 1.

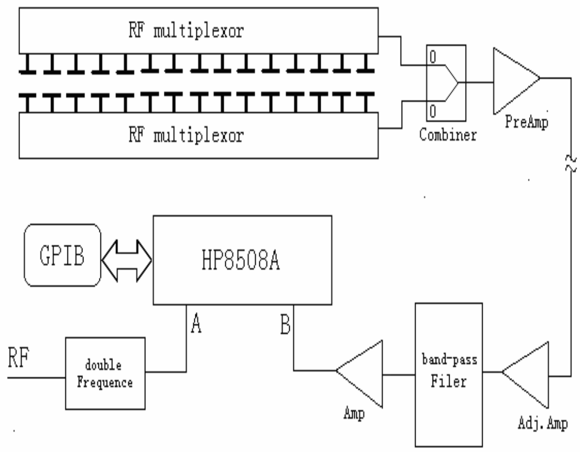

Figure 1: The diagram of beam phase measurement structure.

The signal is processed in the phase signal pre-selector including the signal combiner, noise filter, channel selection, and pre-amplification. The signal is transmitted by the double shielding coaxial cable with the equal electronics length to get the equal phase shift. The signal detected from upper and lower electrode with the same phase is added by the combiner, while the interference of RF-frequency with the contrary phase is subtracted. The coaxial switch VAS-316D with less than -70dB of crosstalk is selected to eliminate the disturbing between the channels. The signal is sent to preamplifier and filter, and then is transmitted by the 70-meter long double shielding coaxial cable to the phase measurement system located in the control room. The phase measurement system used to take the delay filter and phase meter made by self based on double balance mixer principle. However, it has been improved because of its big interference and low sensitivity. The band-pass filter has been designed to reduce the fundamental harmonic magnitude and improve the sensitivity and reliability of the system. The HP8508A vector voltmeter has been used to beam-phase measurement which is controlled by the GPIB interface. The RF-frequency voltage signal coupled on cavity of SFC and SSC is processed by doubled-frequency, which produces the RF signal with the same frequency of second harmonic of beam signal. The amplitude A_n, A_b as well as phase φ_n, φ_b are measured under the condition of with beam and without beam respectively, after calculation of vector subtraction are shown:

$$a = \tfrac{1}{2} A_2^{'} \cos \varphi_2$$

$$b = \tfrac{1}{2} A_2^{'} \sin \varphi 2$$

Therefore, the beam phase is got:

$$\varphi_{beam} = \varphi_2 = arctg\,\tfrac{b}{a}$$

SOFTWARE DESIGN OF PHASE MEASUREMENT SYSTEM

The software system is the core of beam-phase measurement, which coordinates the running of each part of the hardware. The object-oriented programming with Win 32 dynamic link library technology is used, and the human-computer interaction graphic interface is designed to accomplish the adjustment, control, and acquirement of equipment in the system. According to the principle of opening-closure, modular control software with bus structure is designed, the data is transmitted on the data bus, as well as sending messages on the control message bus, the software respond to the requirement from clients at anytime, which is not only realizes the distributed control of the system, but is also convenient to maintenance and update of the software later. The software design of the system is shown in Figure 2.

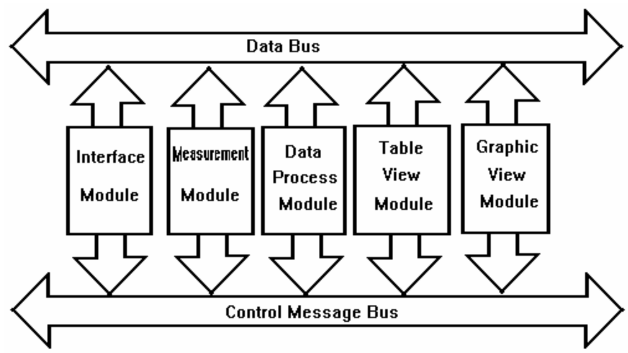

Figure 2: The diagram of system control software structure

The software has the function of automatic phase measurement of SFC, SSC and beam transport line; there is manual measurement as well as the self-check by the system. The phase information can be shown in graphs or in digitals. Generally, the system is controlled to scan all the probes getting the beam signal of phase measuring, any one of the probes can also be selected respectively. The measurement phase could be shown continuously for analysis of the isochronous of magnetic field.

MEASUREMENT RESULTS AND ANALYSIS

The beam-phase measurement system in HIRFL had been improved in the hardware and software. Various kinds of particles (Ar, C, O, N, S) had been used to the phase measurement experiment in SFC and SSC. The sensitivity of the measurement was the function of the probe size and beam intensity. The sensitivity was restricted by the interference signal caused by RF cavity to the phase probe. When the beam intensity was over 100nA, the phase accuracy was better than 0.5°. It was difficult to the absolute measurement because of many systematic errors and the weakly beam intensity. The method of background deduction was used in the software processing, which the beam intensity from 5nA to 10nA could be measured for beam phase.

The Figure 3-1 and Figure 3-2 are the results of the beam phase measurement for $^{40}Ar^{15+}$ and $^{12}C^{6+}$ respectively.

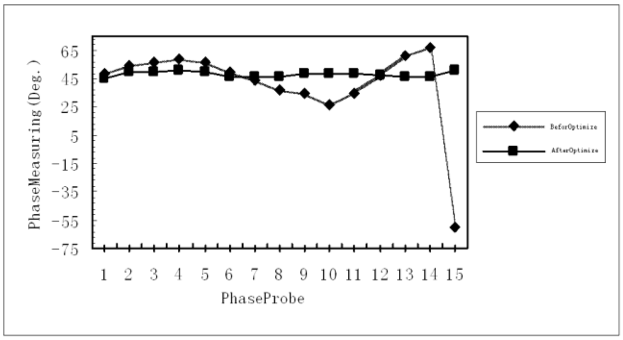

Figure 3-1: The result of the beam phase measurement for $^{40}Ar^{15+}$.

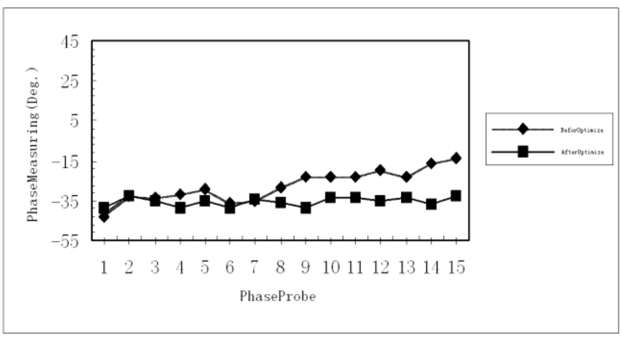

Figure 3-2: The result of the beam phase measurement for $^{12}C^{6+}$.

The results demonstrate the beam phase change before and after optimization of isochronous magnetic field on SSC. There was large difference of beam phase on 15 sets of phase probes before optimization, which showed that the isochronous of magnetic field was not better. According to the phase of measurement from each probe, changing the power current of isochronous trim coil at corresponding diameter over and over, until the difference of phase tended to be identical and the isochronous magnetic field be optimized. It could be seen from Figure 3-1 and Figure 3-2, the highest difference of phase was less than 7° . It had improved the beam intensity and the efficiency of extraction, as well as the beam quality. The total efficiency of beam intensity was over 50% when the 25 MeV/u $^{40}Ar^{15+}$ extracted from SSC in beam tuning.

CONCLUSION

At present, the beam phase measurement system in HIRFL has been put into operation; the optimization of isochronous magnetic field had been done in SSC beam tuning. The measurement data of beam phase has been proved reliability and the errors of repeated measurement less than $\pm 0.5^{o}$. The programming design is considering the integration of beam phase measurement and automatic optimization of isochronous magnetic fields to solve the problem of the human intervention when changing the isochronous trim coil, which will improve the optimizing efficiency of optimization of isochronous magnetic field and save much time for beam tuning of cyclotron.

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