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MEASUREMENT OF BEAM PHASE USING PHASE PROBE AT THE NIRS-930 CYCLOTRON

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Abstract

The NIRS-930 cyclotron of the National Institute of Radiological Sciences (NIRS) has been used for production of short-lived radio-pharmaceuticals for PET, research of physics, developments of particle detectors in space, and so on[1]. The NIRS-930 has twelve trim coils for generation of the isochronous fields. Until recently, currents of the twelve trim coils had been adjusted only by monitoring the output beam intensity. In order to exactly produce the isochronous fields, a phase probe has been installed in the NIRS-930. The beam phase excursion could be reduced within 10 degree.

INTRODUCTION

The NIRS-930 (Km=110 MeV, Kf=90 MeV) has been used for radio isotope manufacturing of short-lived radio-pharmaceuticals, such as ^{64}Cu, ^{68}Ge, ^{28}Mg ^{124}I ^{211}At.

In such an operation, long hours duration of stable high intensity beam was required. And, the beam of various particles and energies were required for various experiments such as biological and physical experiments. The generation of the isochronous fields is necessary in the operation with parameter of various particle and energy. The NIRS-930 has twelve trim coils for generation of the isochronous fields. The currents of the twelve trim coils had been adjusted only by monitoring the output beam intensity before installation of the phase probe. The isochronous field was indefinite because the beam phase was not able to be measured. Therefore, a phase probe has been newly installed in order to exactly produce the isochronous fields.

PHASE PROBE FOR NIRS-930

This phase probe was a product by SHI (Sumitomo Heavy industries) with reference to design of a phase probe for cyclotron at TIARA (Takasaki Ion Accelerators for Advanced Radiation Application). This phase probe was composed of pairs of 10 upper and lower electrodes, size of which is 40 ~ 93 mm (azimuthal width) x 58 mm (radial length). The radial position of the 10 sets phase probe and radial distribution of magnetic field generated by each twelve trim coils in the NIRS-930 is shown in Fig. 1. Until now, only dispersion of beam phase was measured for adjustment of current of the trim coil. That beam phase measurement was not calibrated with acceleration phase, a zero was output of phase probe P1 that is innermost electrode in this measurement. In order to adjust the acceleration phase for an ideal phase, it is necessary to calibrate with acceleration phase.

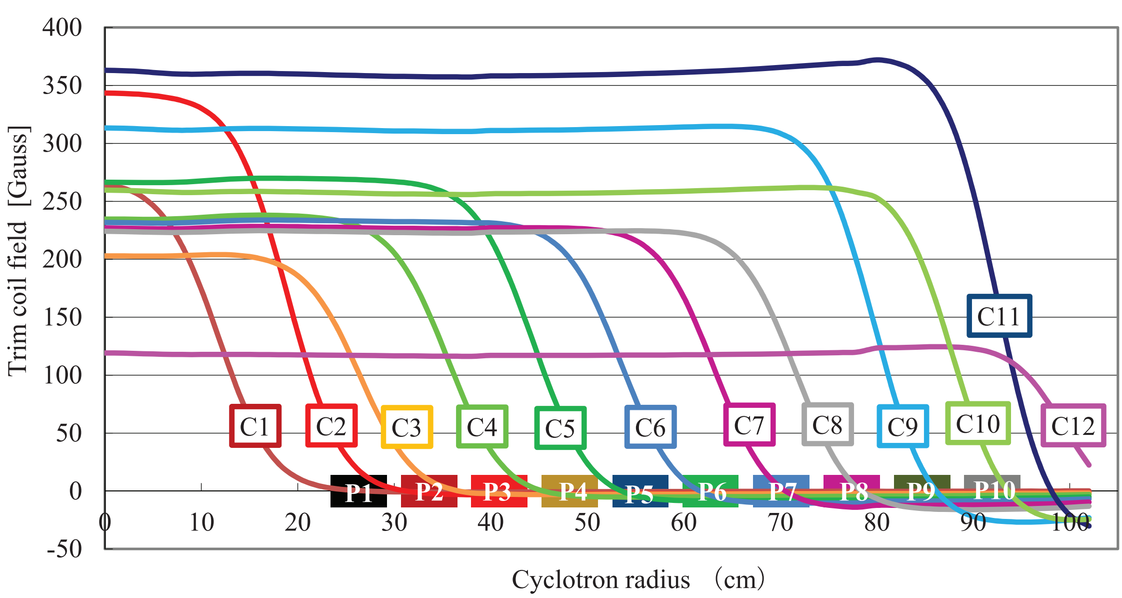

Figure 1: The radial distribution of magnetic field generated by trim coils at maximum current (in the main magnetic average field of 8.8 [kGauss]) and radial position of the phase probe.

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ESTIMATE OF PHASE DELAY FOR CALIBRATION

The ideal acceleration phase is the zero-cross point from negative to positive when a beam bunch passed through the center angle of acceleration gap in a dee electrode.

A distance between the dee electrode and the phase probe and delay difference between the signal line of the phase probe and dee voltage pick-up, must be considered for the adjustment to acceleration phase.

Delay by Azimuthal Position

The schematic layout of the NIRS-930 cyclotron at its median plane is shown in Fig. 2. The radio-frequency systems at NIRS-930 have two dee-electrodes with a dee angle of 90 degree. The harmonic mode that can be used by NIRS-930 is first and second harmonic. In this study, the beam phase detected by the phase probe was compared with pickup signal from a dee electrode at side of CH1. The angle difference between the location of phase probe and the center of dee electrode at side of CH1 is 95 degree. The beam bunch is passed through at the center of dee electrode 95 degree after the pickup in first harmonic mode, and 190 degree in the case of second harmonic mode.

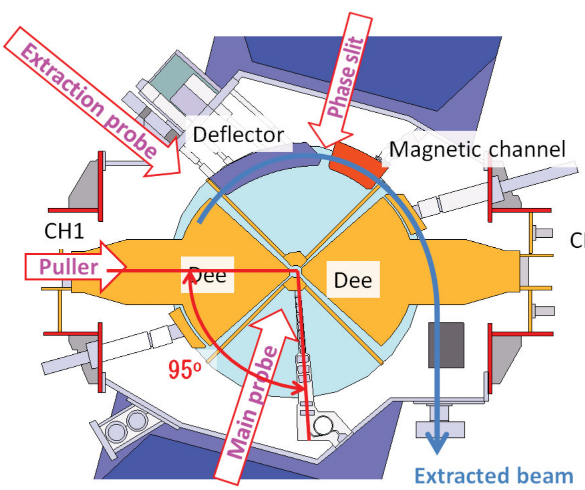

Figure 2: Schematic layout of the NIRS-930 cyclotron.

Delay by Signal Line

The delay difference of the signals between the phase probe and dee voltage pickup was measured by comparing delay of each signal line. The block diagrams of the phase probe and dee voltage pickup were shown in Fig. 3. The each signal detected by upper and lower electrode was mixed by a double balanced mixer for elimination of radio frequency noise. The output signal from the double balanced mixer was selected by a radio frequency switch in order to eliminate the delay difference to each phase probe by using one signal line. The delay in the pickup dee voltage divider estimated by circuit calculation was less than 3 degree.

Figures 4 and 5 show total delay difference between the phase probe and the dee voltage pickup line at first and second harmonic respectively.

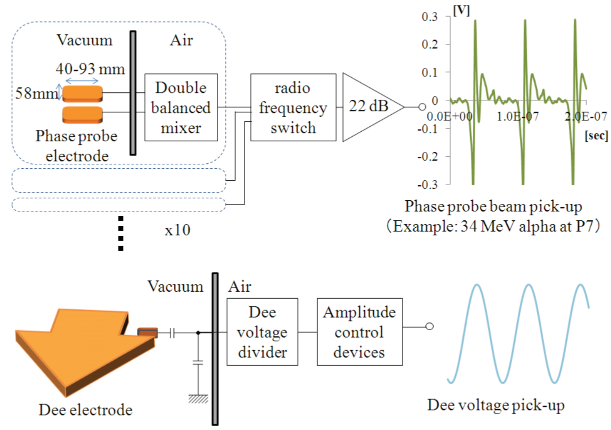

Figure 3: The block diagram of the phase probe and dee voltage pickup.

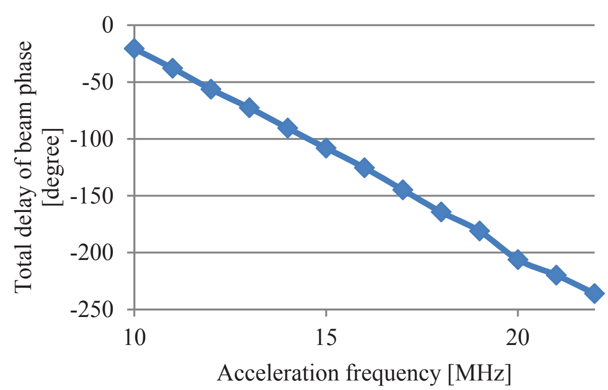

Figure 4: Total delay of beam phase from dee voltage pickup at first harmonic.

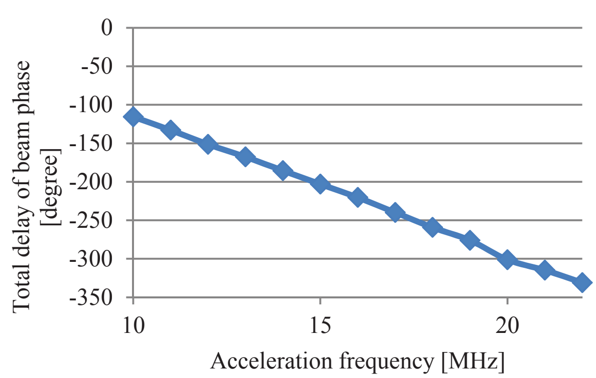

Figure 5: Total delay of beam phase from dee voltage pickup at second harmonic.

THE BEAM PHASE MEASUREMENT AND OPTIMIZATION

The isochronous field was optimized, and the acceleration phase was adjusted for ideal acceleration

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phase based on the above result. Figure 6 shows acceleration phase of 34 MeV alphas. The ordinate is beam phase (the ideal acceleration phase =0) and the abscissa is phase probe number. The blue triangles are beam phase before optimization of trim coil currents. The red circles are beam phase after optimization of trim coil currents. The beam phase excursion could be reduced within 10 degrees from ideal phase.

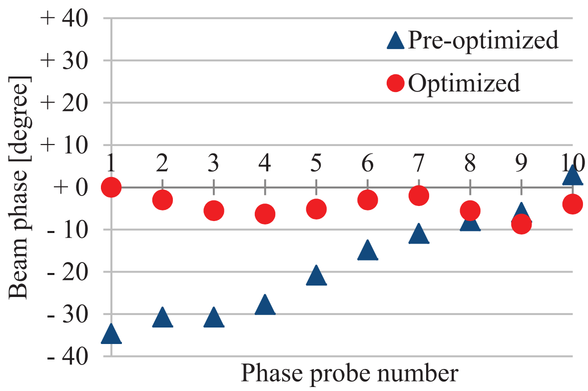

Figure 6: Beam phase of 34 MeV alphas.

RESULT OF THE BEAM TUNING USING BEAM PHASE MEASUREMENTS

Table 1 shows the beam intensity at each beam monitor when the pre-optimized trim coils current are optimized. The optimized data includes result of adjustment of the extraction elements and injection line elements and harmonic coils current.

Table 1: The Beam Intensity of 34 MeV Alphas

Beam monitor	**Pre-optimized [μA]**	**Optimized [μA]**
Inflector	31.0	41.2
Main Probe	(13.4)	21.4
Extraction Probe	15.0	19.4
Extracted beam	12.4	17.2

Main Probe: A Main radial probe set at the radial position of 100 mm.
Extraction probe: The beam probe at deflector entrance.

The detected current at the main radial probe decreases in pre-optimized data, where the main radial probe was affected by insulation failure in this probe head. The maximum extracted beam intensity was restricted by beam current at septum loss in order to protect the septum electrode. Table 2 shows the transmission efficiency of alpha 34 MeV at each beam monitor.

Table 2: The Transmission Efficiency of Each Beam Monitor at Alpha 34 MeV

Efficiency	**Pre-optimized**	**Optimized**
Extraction probe /Inflector	48.4%	47.1%
Extracted beam / Extraction probe	82.7%	88.7%
Extracted beam /Inflector	40.0%	41.7%
Septum loss /Extracted beam	17.7%	16.9%

The efficiency between the extraction probes and the inflector was decreases to 47.1% from 48.4%. The beam phase was not measured by phase probe in this central region. The optimization of the position of the electrodes such as the inflector and puller and magnetic field in the central region was required. However, the extraction efficiency that is passed through the electric deflector and magnetic channel was increased to 88.7% from 82.7%. The efficiency of extracted beam from inflector was increased to 41.7% from 40%. And, ratio of extracted beam to septum beam loss was reduced to 16.9% from 17.7%. As a result the beam intensity was increased to 17.2 μA from 12.4 μA at 34 MeV alphas.

CONCLUSION

In order to exactly produce the isochronous fields, a phase probe has been installed in the NIRS-930.The trim coil current was optimized to exactly produce the isochronous fields for 34 MeV alpha beams by the phase probe. The beam phase excursion could be reduced within 10 degrees from ideal phase.

The some further studies are required such as optimization of central regions and comparison of the turn pattern at different beam phase. The trim coils currents will be optimized at the other ions beam with different beam energies based on the beam phase measurement by the phase probe.

REFERENCES

[1] S. Hojo, et al., Proceedings of The 20th International Conference on Cyclotrons and their Applications, Vancouver, BC, Canada, MOPPT008, (2013).