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INTERNAL BEAM PHASE MEASUREMENT IN THE NIRS-CHIBA ISOCHRONOUS CYCLOTRON

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Abstract.- An internal beam phase probe of the capacitive pickup type has been developed for the correction of the magnetic field. To suppress the noise background, a heterodyne technique is employed together with compensation for rf-disturbance in the measuring circuit. In the case of fundamental mode of acceleration, the beam phases are able to be measured with a current of down to several tens nanoamperes.

1. Introduction.- For the proper operating condition of the NIRS cyclotron, it has been one of interesting subjects to verify whether the magnetic field is tuned for isochronism with adequate reproducibility. As a sensitive equipment for this verification an internal beam phase probe has been developed, which consists of six capacitive phase pickups on various radii. The correction for isochronism is easily achieved by a simple calculation using the measured phase angles. A beam phase feedback from the outmost phase pickup to the magnetic field is effective to the correction.

In this paper, we present the performance of the phase probe and the phase measuring circuit with some results of the magnetic field correction.

2. Measuring system.- The frequency range of the NIRS cyclotron is extended from 10.5 to 22MHz. Particles are accelerated by two dees of 86 degrees in two harmonic operating modes.

In the induced signal on a pickup, rf-disturbance shadows the beam signal especially when two dees are excited in the same phase, then the second harmonic component of the beam signal is utilized for the phase measurement with a heterodyne technique [1,2,3] and further, a compensator is applied to cancel the second harmonic component of the rf-signal still remaining.

2-1. Phase Probe.- A capacitive induction type beam phase probe has been built and installed in the midway between two dees. The probe consists of six pickups and a housing. The pickups are arranged such that the radial intervals correspond to an energy gain of 14% of the final energy between 20% and 90% of the energy. Fig.1 shows the construction of the probe. The openings on the housing for all pickups are the same, 10x24mm, because the charge on all pickups is constant along the radius, then the signals induced on all pickups are almost of equal amplitude. The pickup plates are of copper and placed 4mm below the housing. The housing is located 20mm below the median plane to match with the beam aperture defined by the dee gap.

The induced charge on the pickups is transformed into a voltage singnal by a high input impedance FET preamplifier connected directly to the pickup. Input capacity of the preamplifier is $\sim$5pF and upper 3dB frequency is 230MHz. All preamplifiers are adjusted to have a phase dispersion within $\pm$0.3 degree at 40MHz.

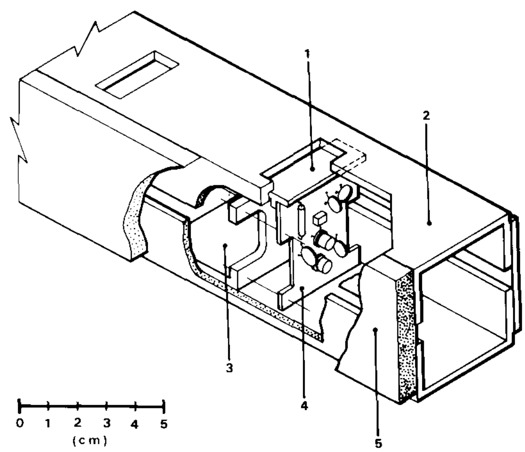

Fig. 1 : Construction of the phase probe.
(1) Pickup plate; (2) housing; (3) supporter; (4) preamplifier; (5) protector.

2-2. Circuit.- The measuring system functionally consists of three major components which are mixing circuits, compensators and a phase detector. The block diagram of the system is shown in Fig.2.

The output signal from the preamplifier is converted into a fixed low frequency of 10kHz in the mixing circuit. Local signals to the mixers are phase-locked to the output of the cyclotron master oscillator. The rf-disturbance included in this frequency is cancelled out by adding an appropriate ac-voltage which is adjusted by a variable attenuator and a 360 degrees phase shifter when the beam is switched off. As a consequence, more than 40dB of S/N ratio at the beam current of 1μA was obtained. Through an analog switch, the beam signals are fed periodically to the phase detector WILTRON-MODEL 352 in which the phase of the beam signal is compared with that of frequency-doubled rf-voltage from the dee. Dc-outputs from the phase detector are displayed on six meters through sample-hold amplifiers.

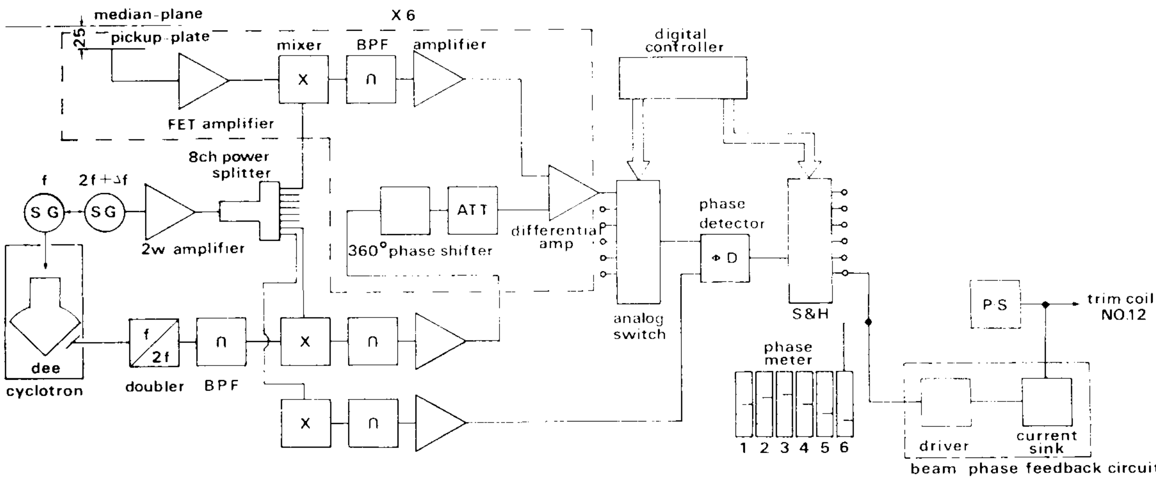

Fig. 2 : Block diagram of the phase measuring system

To fix the phase at the radius of no.6 pickup during the trimming correction as mentioned in the next section, a beam phase feedback[4)] is employed i.e. the outmost trimming coil is controlled by the error signal which represents the beam phase deviation at no.6 pickup.

3. Field Correction.- To attain the isochronous field using the observed phase angles, a new correction method has been developed in which only phase differences between adjoining pickups are used to calculate the necessary trim coil currents[5)].

Suppose that the number of observed phase differences along the radius is equal to that of trim coils which affect on the field covered by the phase probe, the following square matrix holds.

$$[\Phi] = [A]\,[I]$$

where, $[\Phi]$ is the observed phase differences between adjoining pickups and $[A]$ the phase shift in each interval caused by changes of unit current in the trim coils. By this equation, necessary $[I]$ for the correction is obtained.

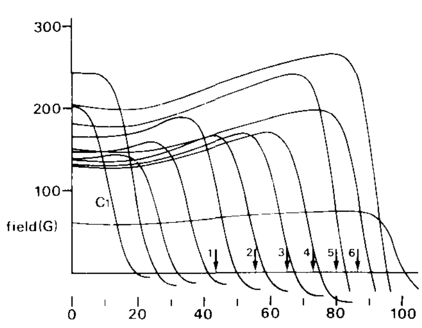

Fig. 3 : Radial distributions of the fields of twelve pairs of trim coils at the main coil excitation of 780A. Arrows indicate the positions of pickups.

In our case, although seven trim coils C5 to C11 contribute to the field of interest as shown in Fig.3, five trim coils of C6 to C10 are selected for the calculation since the number of observed phase differences is five. In the calculation, the current in C4 is also deduced to compensate a small change of the field in the inner region by new $[I]$. When the observed beam phase varies monotonously with radius, the calculation gives efficient correction factors of trim coil currents. In the case of non-monotonous phase variation, however, several iterations of phase measurement, calculation and correction are necessary. For the latter case, we tested a program which uses seven trim coil currents and seven phase differences two of which are interpolated from the observed phase history. Fig. 4 shows an example of the correction by this method. Only two iterations give the satisfactory isochronous field.

There is a possibility of missing the beam during the trim coil current correction. To prevent this, the beam phase feedback is employed, which fixes the beam phase at the outmost pickup.

The correction method was tested for a wide range of energy. In the fundamental harmonic operating mode, the beam phase could be measured with an adequate accuracy for the beam intensity down to

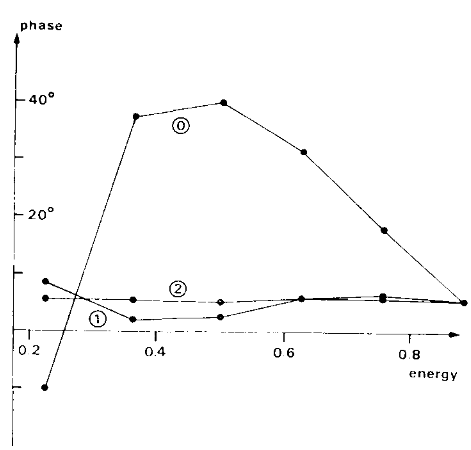

Fig. 4 : Improvement of beam phase along the radius in two iterations for 40MeV protons. (0) is the phase history before correction.

several tens nanoamperes. On the contrary, a considerable beam intensity was necessary in the second harmonic mode because of the larger rf-disturbance.

4. Conclusion.- By one or two iterations, the present correction method allows to tune the isochronous field very effectively without the calculation of absolute phase angle. The measuring system is practically useful to verify the reproducibility of isochronism. In addition, future effort is adding two pickups in the phase probe so that seven trim coils are used for the correction.

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