A MEASUREMENT OF THE BEAM PHASE AT THE PRINCETON UNIVERSITY AVF CYCLOTRON

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A measurement of the beam phase at the Princeton University AVF cyclotron was recently carried out, including a measurement of the beam phase excursion as well as of the beam phase width. Prior to this phase measurement, beam turn patterns were obtained in order to achieve a beam with well centered and well separated orbits for single-turn extraction. The results of the phase measurement were analyzed and compared with the calculation. Both the methods and the results of these measurements are described in this paper.

Introduction

The beam diagonostic device in the Princeton University 64 inch AVF Cyclotron (see the Table I for the design parameters) includes a radial beam probe located along the gap of the dee (i.e. along the zero degree line). Fig. 1 shows the horizontal geometry of the end of the probe and its tip. The probe is made of copper and the tip is made of tungsten, with the currents on tip A, tip B and A+B separately measurable. When the probe sweeps out along the radius on the median plane of the cyclotron, the beam current picked upon probe B can be plotted on a chart recorder as a function of the radius from the center of the cyclotron. A close look at this plot provides information about the turn pattern of a beam, beam orbit centering, radial oscillation, effects due to resonance crossing, beam extraction, etc.. In addition, gamma rays are generated when an accelerated beam impinges on the probe tip. Measuring the flight time of a gamma ray from the probe tip with respect to the time of cyclotron RF enables us to obtain information of the phase of a beam, the phase width and phase excursion.

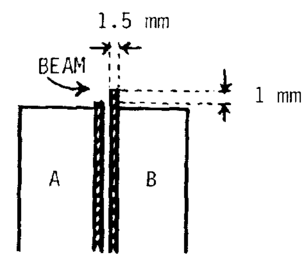

Fig. 1 Horizontal geometry of the probe and the tip (not scaled)

Table I Design Parameters of the Princeton cyclotron

Ion Source	Hot cathode internal PIG source
Magnet	64 in diameter, 3 spiral sectors
	BR(Max.)=390 kG-inches
RF accelerating system	
	Tuneable range : 14 - 23.5 MHz
	acceleration on first, second and fourth harmonics
	Dees : two 134 degree dees separated by 42 degree pie-shaped dummy dee
	Max RF voltage : 140 kV, dee to dee
	Energy gain per turn : 250 keV
Particle energies in MeV	
	protons : 19-48 (and 2-16)
	deuterons : 9-28
	3He : 56-85 (and 13-50)
	4He : 17-58
	12C4+ : 28-75
	20Ne6+ : 50-92
External beam properties for 48 MeV proton	
	Precessional extraction, 95% efficiency, 2% duty cycle, 80 keV energy spread.
	Beam emittance ;
	Radial : 40 mm mrad
	Axial : 200 mm mrad

Though such a scheme has been routinely employed in our laboratory in order to achieve successful operation of the cyclotron, a measurement that was carried out in August 1986 had a particular two-fold objective described below.

Recently, an interest was arisen at the Princeton cyclotron laboratory to do experiments utilizing polarized ions as well as high charge-state light heavy ions. Accelerating such ions means that the existing internal ion source has to be modified for external injection of ions. This led us to initiate a feasibility study for axial injection of ions into the Princeton cyclotron [1]. The core of the study was a design of the new central region, requiring a knowledge on field distribution inside the cyclotron. While the quasi-statically approximated electric field distribution can be obtained with the help of a relaxation calculation, the magnetic field distribution for the Princeton cyclotron had not been available at this laboratory. However, the magnet structure of the Princeton cyclotron closely resembles Michigan State University's (MSU) old K=50 cyclotron. Therefore, during the process of designing a new central region for the Princeton cyclotron, we adopted MSU's measured magnetic field data and then utilized the computer program SETOP [2] to extract the field distribution for a particular beam. One of the motivations of our phase measurement was to verify experimentally the validaty of such a field substitution.

The other motivation comes from the desire to restore single-turn extraction capability for a beam. Single turn extraction in the Princeton cyclotron can be obtained by placing a set of radial slit in the central region, thereby restricting the phase width of the beam. This method is based upon the mechanism of a phase-dependent orbit centering error. The required radial width of the slits and their positions were calculated based on beam dynamics studies. Direct verification of the study can be obtained by measuring the phase width with and without the slits, and comparing the results.

In the following, we present the experimental set up of the phase measurement device and then describe the results of the measurements compared with the calculations.

Apparatus and Results

A schematic diagram of the phase measurement electronics set up is illustrated in Fig. 2. The scintillator was attached to a 8575 phototube on an ORTEC 270 timing base. The pulses from the base were used as the start for a Time to Pulse Height Converter while the stop pulses were derived from a pick up on the cyclotron RF signal. What is not shown in the figure is a diode clipper between the RF and the 100 MHz discriminator, which is needed in order to avoid overloading the electronics.

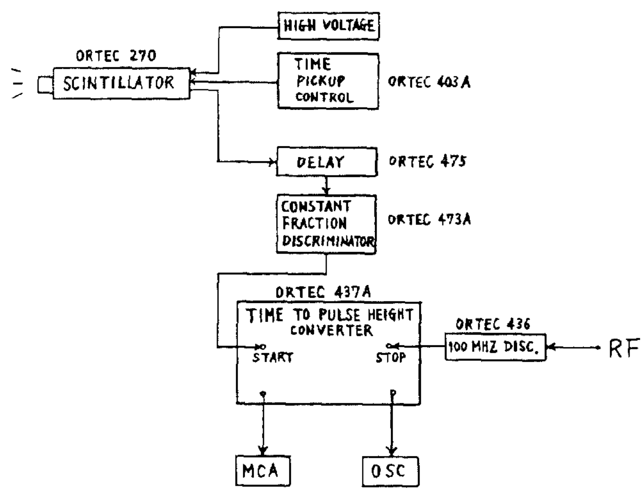

Fig. 2 Electronics set-up of the phase measurement

For the measurement, we chose a 40 MeV proton beam for which the RF was 18.520432 MHz (i.e. period=53.99 nsec) and the dee voltage was 51.01 kV. After setting the trimming coil parameters and the main magnetic field in accordance with the computer prediction, we first investigated the turn pattern of the beam.

Fig. 3 depicts a turn pattern of the 40 MeV proton beam after optimizing the amplitude and the azimuthal angle of the first harmonic field. The activation of the first harmonic field is mandatory in the Princeton cyclotron owing to the inherent asymetrical interaction between the three sector magnetic field and the two sector electric field, a phenomenon called the electric gap-crossing resonance.

Fig. 3 shows the turn pattern from the position where the first phase selection slit is in place (i.e. 18^{th} turn) all the way up to the beam extraction point. The second slit is placed at the 29^{th} turn of orbit. Both slits have a radial width of 0.5 mm. The measurement was repeated at 1 inch interval from 7 inches to 30 inches radius of the probe tip position. It can be seen from the figure that the turns are well separated all along the radius and also there is no indication of a precessional motion of the orbit center. The transmission efficiency through both slits was observed to be about 20%.

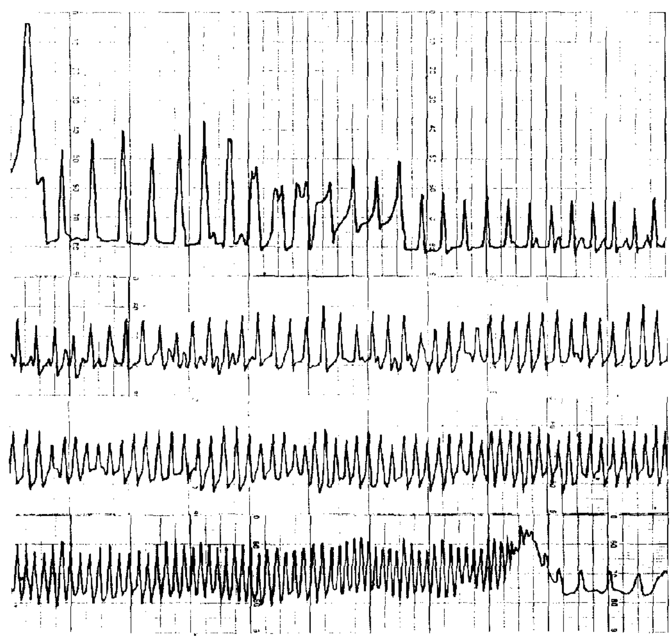

Fig. 3 The turn pattern of a 40 MeV proton beam when the cyclotron magnetic fields were exactly the same as the calculated fields. This figure shows the turn pattern from the position where the first phase selection slit is in place (18th turn) to the beam extraction point. It can be seen that the turns are well separated all along the radius and there is no indication of the precessional motion of the orbit center.

After obtaining a turn pattern of the beam, we measured the phase excursion and phase width of the beam. Fig. 4 shows the phase excursion as a function of the distance from the center of the cyclotron. In the figure, the solid curve represents the calculated phase and the boxes indicate the measured phase. With a given magnetic field configuration, the phase of a beam with respect to the RF phase can be expressed as

$$\sin\phi(E) = \sin\phi_0 + \frac{2\pi h}{E_1}\int_{E_i}^{E_f}\left(\frac{\omega_{RF}}{h\omega(E)} - 1\right)dE$$

where ϕ_0 and E_i are, respectively, the RF phase and the beam energy at the center of the first gap . ω_{RF} is the angular oscillation frequency, and $\omega(E)$ is the particle's revolution frequency at energy E. h is the integral harmonic ratio. The calculated curve in Fig. 4 was obtained by using the above equation.

Comparing the two curves in Fig. 4, we see that they are in good agreement within the experimental error. Below about

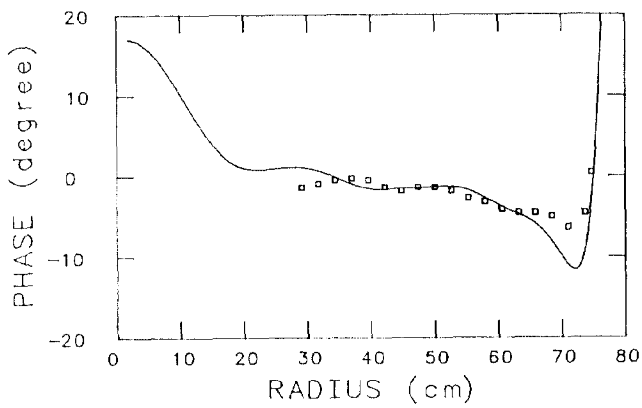

Fig. 4 The phase excursion of the 40 MeV proton beam as a function of the radius of the beam. The trim coil setting parameters were obtained from the program SETOP and considered as the most optimum field setting. The solid curve represents the calculated phase excursion and the boxes indicate the measured phase excursion. It can be seen from this figure that the two curves agree quite well.

30 cm, the Coulomb barrier of the tungsten tip prevents us from obtaining a gamma flash, therefore, to get around such a problem it would be desirable to use an aluminum tip which has lower Z, at the expense of its lower melting point.

The measured gamma ray time had a FWHM of 3.5 RF degrees when both phase selection slits were in place. On the other hand, it was about 20 degrees when slits were removed. This result is also in agreement with our prediction.

With both slits in place, we were able to extract 95% of the internal beam, resulting in as external 40 MeV proton beam of about 2 μA. We conclude that the 5% loss of beam during extraction comes from the RF ripple of the dee. We plan to reduce this ripple during the upgrade of the cyclotron.

We have also carried out a series of phase measurements for other beams at different beam energies. As expected, all results were closely in agreement with the calculations. Therefore, we conclude that the magnetic field of the Princeton cyclotron is similar enough to MSU's old K=50 cyclotron to enable us to continue our study of the central region of the cyclotron based on MSU's measured magnetic field data.

Reference

[1] Moohyun Yoon, Ph.D. dissertation, Univ. of Manitoba (1986)

[2] R.E.Berg, MSUCP-24 (1966)