ISOCHRONIZATION STUDIES OF THE IUCF 200 MeV CYCLOTRON

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ABSTRACT

A non-intercepting movable beam phase probe recently installed in the south valley of the IUCF 200 MeV isochronous cyclotron has been used to study the relative beam phase variation during acceleration for the various beams accelerated by the facility. Small differences between the measured phase histories and the predictions of the field map data were observed and explained. Phase compression during acceleration has been measured, and a method for making rapid small energy changes (± 500 keV) while operating on a single RF frequency using trim coil adjustments at large radius has been developed. These and other consequences of the isochronization studies are discussed.

INTRODUCTION

Operation of a movable non-intercepting, charge sensitive beam phase probe in the Indiana 200 MeV main stage cyclotron was improved to allow a comprehensive study of isochronism over its entire operating range. The cyclotrons, which have accelerated protons to energies of from 27 to 200 MeV and other ions up to ²⁷Al to energies of 160 q²/A MeV, is operated with routine energy and/or particle changes occurring at an average rate of 4 per week. Acceleration over this large mass energy product requires the cyclotron magnetic field to vary from a uniform radial profile to one which increases with the relativistic particle mass by up to 25% for the limiting case of 200 MeV protons. The trim coil assemblies and field mapping data upon which initial cyclotron operation depended have been previously described.¹²³ Cyclotron operating experience has indicated that a discrepancy exists between the predicted isochronous trim coil settings based on the field maps, and those required for isochronous operation. Initial operation of the south valley phase probe has measured the discrepancies, which are now understood.¹⁴ Continued operation of the phase probe has provided a systematic study of main stage isochronism and provided a set of accurate trim coil settings which are used for cyclotron setup during energy changes. These data have improved the efficiency of the changes as well as the quality of the extracted beam, as described below.

PHASE PROBE PERFORMANCE

The main stage phase probe, shown in figure 1, is a non-intercepting, charge sensitive sampling device having a sampling frequency of 2.77 KHz. The probe sensor, a single aluminum pickup plate measuring 31 mm azimuthally by 6 mm radially, is mounted in a grounded aluminum RF shield, which also houses the Schottky Barrier sampling diode. The phase probe assembly is mounted on a multipurpose radial probe in the south valley of the cyclotron, permitting measurement of the beam phase from inflection to extraction radius. The radial probe may also be adjusted vertically through the cyclotron midplane to measure either beam phase, intensity or turn separation. The design and initial operating characteristics of this probe have been previously described.¹ A picture of the probe assembly in place in the south valley is shown in figure 2.

![Figure 1](image1.png)
![Figure 2](image2.png)
Examples of the measurements obtained using the phase probe are shown in figure 4 for proton energies from 27 to 200 MeV, which required acceleration on 3rd, 4th, 5th and 7th harmonics. The radial field profile variation over this energy range spans the design limits of the cyclotron. These isochronous phase histories were obtained by an iterative manual process in which trim coil corrections were calculated from observed phase histories until phase errors were reduced to approximately 0.05 of RF. This was usually accomplished in three to five iterations. Reduction of phase errors to less than 0.05 of RF are possible, but pointless because the field reproducibility errors are larger than this, and are dependent on magnet excitation history, in spite of a computer controlled magnet cycling procedure.

Phase compression was also tested at higher harmonics using the 75 MeV 6Li^3^- beam accelerated on the 13th harmonic. The results of this are shown in figure 6 for comparison with the 60 MeV proton measurement. For this high harmonic case, at large radius the effect of phase compression appears to be slightly

![Figure 3. PHASE HISTORY MEASUREMENTS](image)

![Figure 4.](image)

![Figure 5.](image)

This is equivalent to changing the starting phase of the inflected beam relative to the main RF. The difference in the sine of the beam phase errors observed for the two extremes of phase adjustment varies roughly as the inverse of the dee gap voltage increase with radius, as shown in figure 6a. The dee gap voltage change with radius, whose reciprocal is indicated in figure 6 by the solid curve, thus appears to be the dominant effect.

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reversed, as indicated by the deviation of the measured phase errors from that expected by the inhomogeneous gap voltage. This phase dilatation at high harmonic operation may be caused by the non-normal gap crossing, which is dependent on harmonic number. If this is the case, the effect is small compared to the phase compression resulting from the inhomogeneous gap voltage. Furthermore, the change in the inhomogeneity of the gap voltage as a function of RF frequency is not known, and this could account for some of the difference observed.

However, the gap voltage is never expected to decrease with radius at any harmonic on which we operate, which is the only other explanation for the phase dilatation observed at large radius for \( h = 13 \). The amount of phase dilatation predicted by Muller's theory for the Indiana cyclotron would be three times larger for \( h = 13 \) than for \( h = 5 \), but the absolute value predicted is larger than observed for either case we've measured. One reason for this is our imprecise knowledge of the gap crossing angle as a function of radius. It is known that this angle increases with radius because of fringe field effects, and this is consistent with observed results for \( h = 13 \) at large radius. Work is continuing to more carefully measure these effects in an effort to understand their source.

CONCLUSIONS

This work led to the development of a simple method for carrying out small, quick energy changes \((\Delta E \leq \pm 500 \text{ keV})\) while operating at a given RF frequency. Deviations from isochronism are induced by changing the current in the five outer trim coils equally. By increasing (decreasing) the field at large radius in this way, the energy of the particles arriving at the entrance to the extraction system is increased (decreased). Figure 7 shows the calculated change in phase when the energy has been changed by \( \pm 100 \text{ keV} \) for a 155 MeV proton beam. This technique has made it practical to measure nuclear reaction excitation functions routinely. The time required for a 100 keV energy change is approximately 10 minutes. This technique also makes it possible to easily reproduce the energy for a given frequency, a request frequently made by experimenters whose data are accumulated over several runs.

REFERENCES