Beam Extraction Studies for the ORIC

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Previous papers have discussed the possibility of using the radial resonances as a mechanism for extracting the beam. This paper will consider some preliminary studies made of the 3/3 resonance, the "natural" resonance to be used in extracting particles from ORIC.

The original extraction studies for the ORIC were made with raw model magnet data as input for the equilibrium orbit and Welton's general orbit codes. It was soon recognized that although this data was capable of giving a survey of the equilibrium orbit properties, it was not able to accurately predict detailed equilibrium orbit properties, and motion off the equilibrium orbit was badly represented.

The deviation from the true axial frequency (ν_z) caused by random field errors is shown in Figure 242. This was calculated by taking the frequencies predicted by the code for an analytic field, then recalculating the frequencies using the same field with random 0.1% and 1% errors. It can be seen that 1% error causes drastic

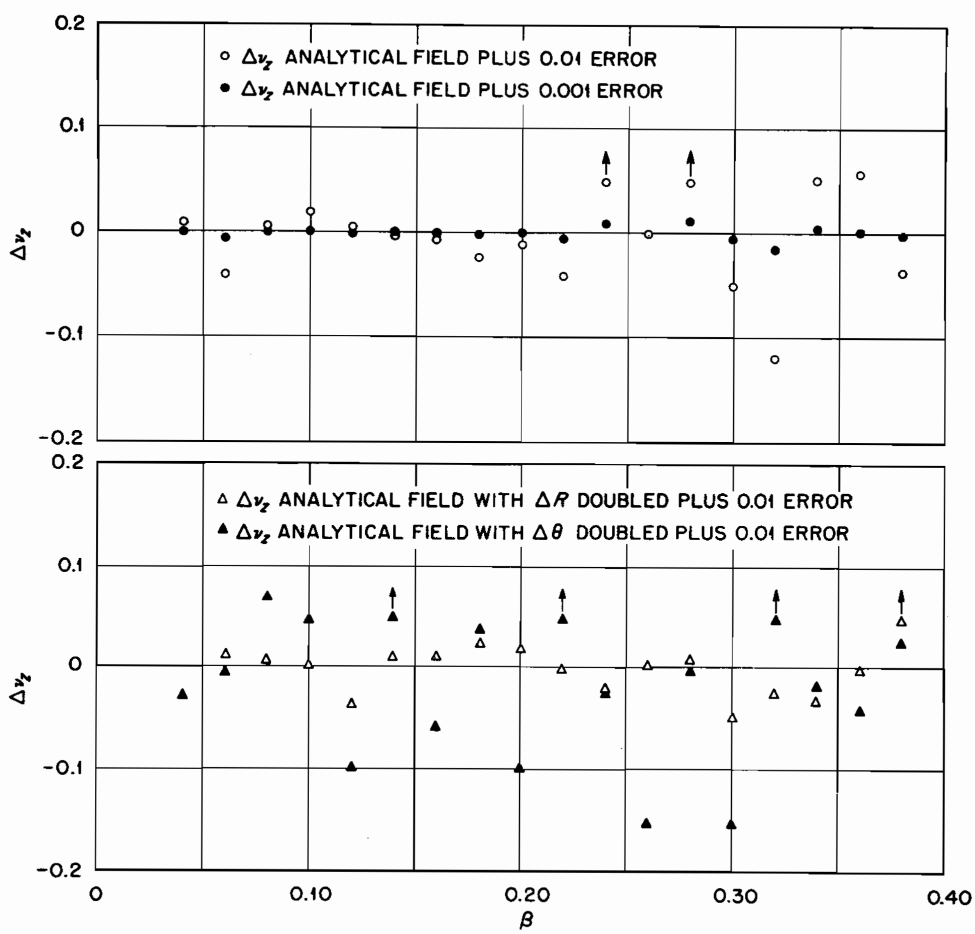

Fig. 242. The effect of random fields errors on ν_z.

shifts in the axial frequency, in some cases actually introducing defocusing. A 0.1% error is less serious and the shifts are much less pronounced. The effect of field error on the motion off the equilibrium orbit is even more pronounced. A glance at the theory [1,2] for the 3/3 radial resonance will demonstrate the origin of this effect. The invariant governing the behavior of this resonance is

$$\text{Constant} = (\nu_r - 1)A^2 + DA^3 \sin 3\psi + GA^4$$

where A is the amplitude of the oscillation measured from the equilibrium orbit, ν_r the radial frequency, and ψ the phase of the oscillation. The coefficient D supplies the driving force for the oscillation and G causes a frequency shift. The important terms in D come from the Fourier coefficients of the third field harmonics and their first and second derivatives[2], and in a less important way from derivatives of the average field. The frequency shifting mechanism has its origin mostly in the third derivative of the average field. If there are random errors in the field, the above derivatives can be incorrectly treated by the orbit codes which will then predict unrealistic ion behavior.

A plot of a model field measured on the Oak Ridge model magnet is shown in Figure 243. The bump represents misinformation to the computer. It is an error of 700 gauss and is spread over an angle of about 6 degrees. We have only shown it in one sector but it is repeated in all three sectors. The effect on deflection is shown in Figure 244. In this same figure is shown the phase plot when the field error is removed. It is seen that such a gross error totally misrepresents the ion motion. Although the present Oak Ridge model magnet is not this crude, higher accuracy than is presently available is necessary to permit meaningful studies of deflection.

Because of the lack of good model data, we felt that we could not make detailed realistic deflection studies. Instead we instituted a program of using simple-minded analytic fields to get some information about the behavior of this resonance.

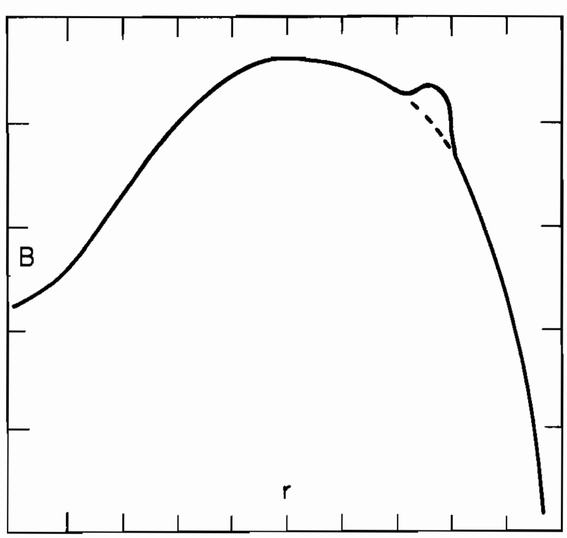

Fig. 243. Model magnetic field with error introduced.

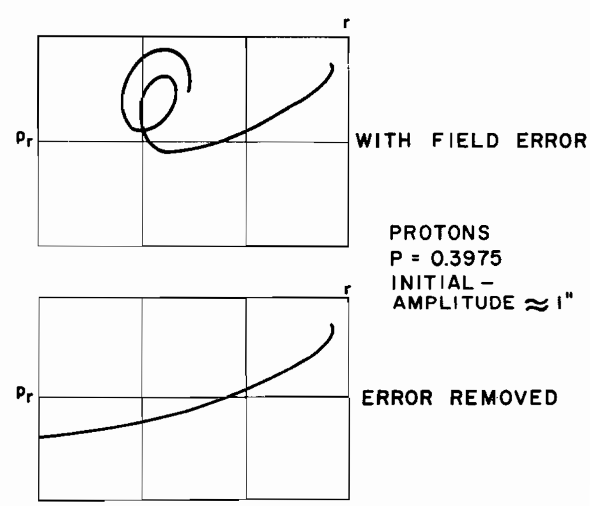

Fig. 244. Effect of field error on deflection.

The first studies made were with average fields of the form

$$\bar{B}(r) = a + br + cr^2 + dr^3.$$

As a guide, we took a model magnet run and fitted polynomials to the average field of the model magnet in the region where the deflection process will take place. We found that we could fit four polynomials, with greatly differing third derivatives, within $\pm 0.2\%$ of the average model field over a radial distance of about one model inch, (which corresponds to about 9 in. in the cyclotron). We then represent the field by

$$B(r,\theta) = \bar{B}(r) \quad (1 + f(r) \sin 3\theta)$$

where f is chosen to give a large driving term.

Figure 245 shows the phase plot for the case with the largest third derivative, $d \simeq -1{,}600$ gauss/in^3. We see the classical picture(1); the ion is driven out to a large amplitude where the frequency shifting mechanism takes over and carries the ion back toward the equilibrium orbit. Figure 246 shows the case for d - -500 gauss/in^3. Here the frequency shifting term has a much less pronounced effect. In fact the ion is out of the magnetic field before the restoring force has taken over. A field of this sort gives the required deflection properties, giving a large gain per turn which would carry the ion into a magnetic channel. The point we wish to make is that these fields, which differ at most by 30 gauss in the deflection region, give markedly different deflection properties. The first would in no way be suitable, while the second would suffice quite well. We feel, also, that this is an adequate demonstration that measuring errors must be small.

Our next studies were slightly more sophisticated, taking model magnet average field and flutter data and fitting them by a least-square fit. Then, with the

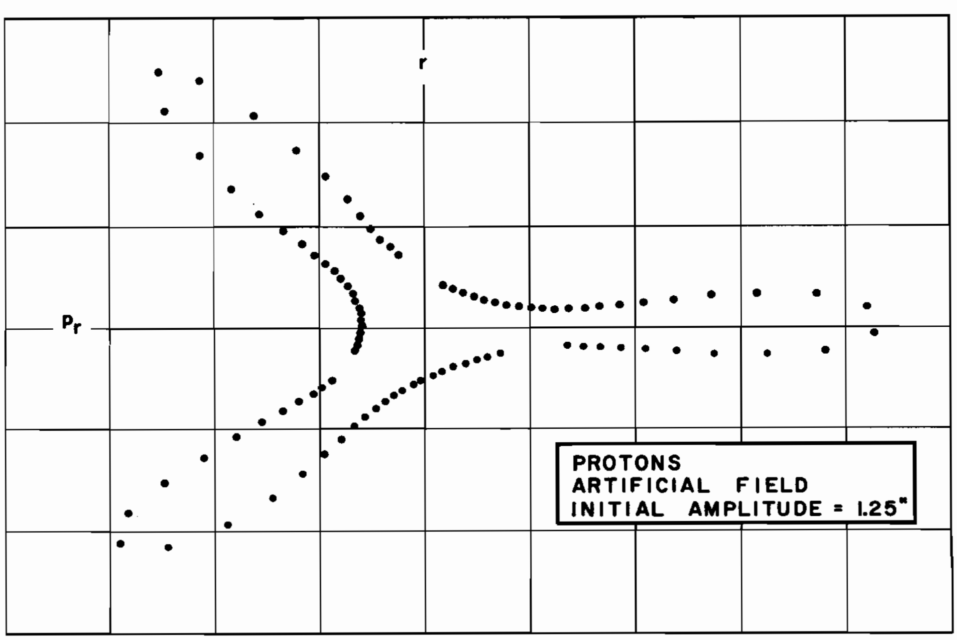

Fig. 245. Phase plot for an average field with large third derivative.

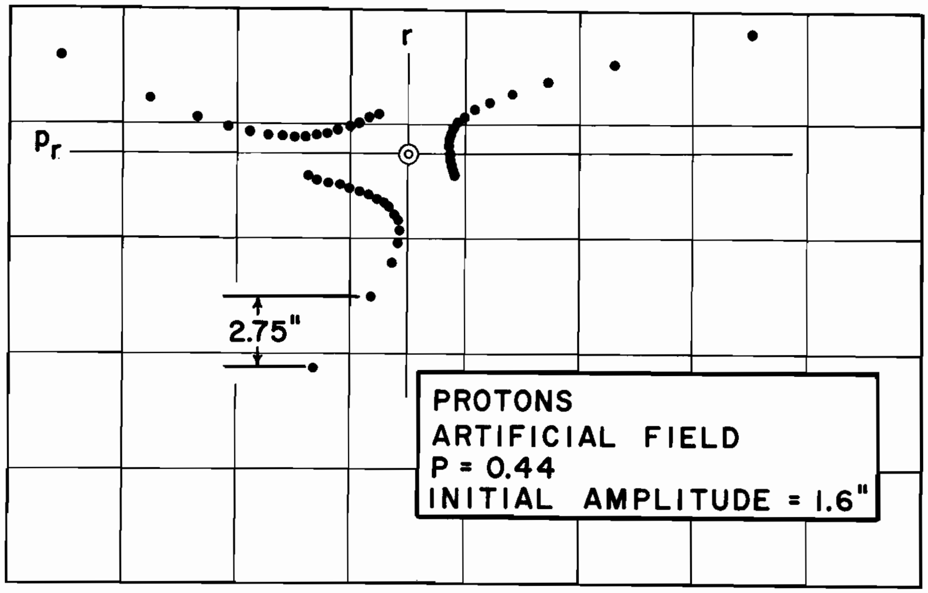

Fig. 246. Phase plot for analytic field with small third derivative.

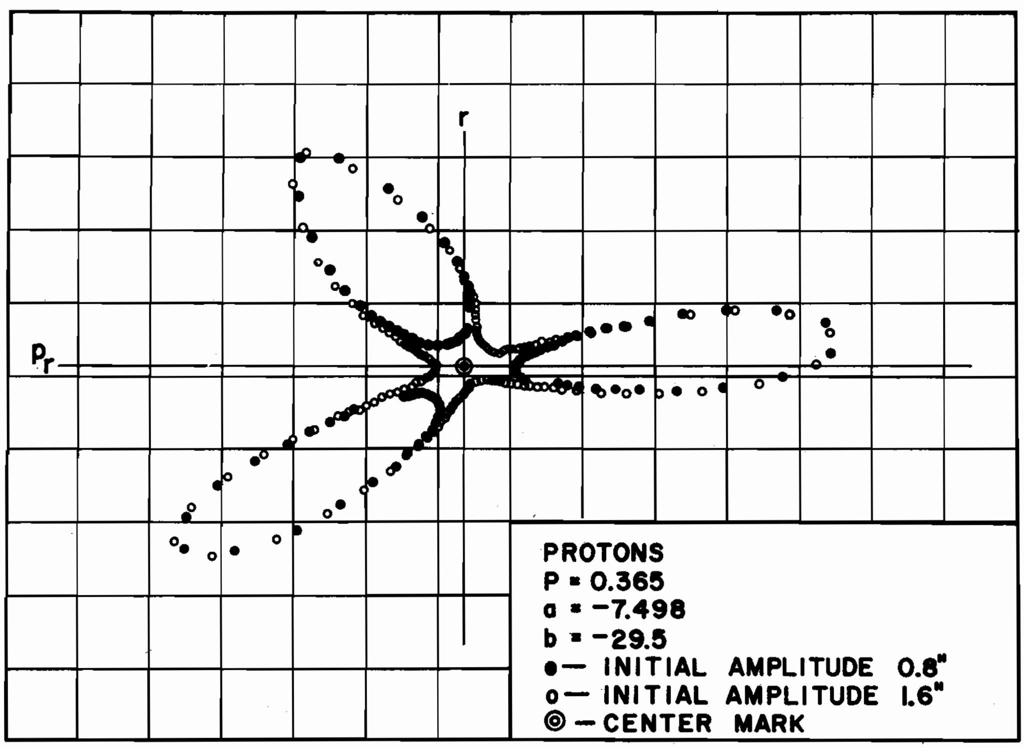

Fig. 247. Phase plot for simulated model magnet field.

field again represented by

$$B\ (r,0) = \bar{B}\ (r)\quad (1 + f(r)\ \sin 3\theta),$$

we compute the relevant phase plots. The results are shown in the next two figures. The phase plot of Figure 247 is from a model magnet field for protons. The driving

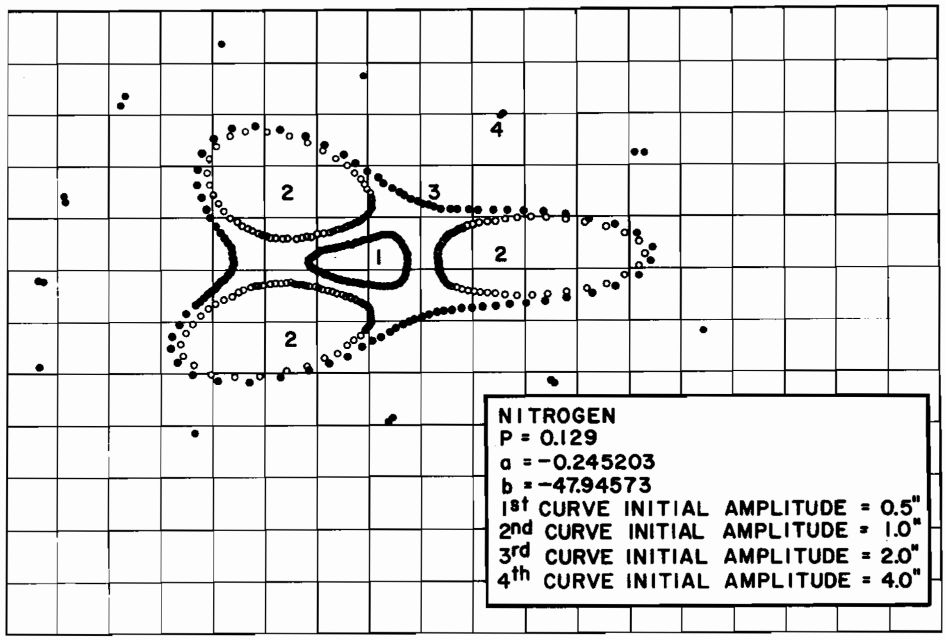

Fig. 248. Phase plot for nitrogen ions in simulating model magnet field.

term is roughly -7.5, the phase shifting term is about -30. Since the frequency is close to unity and the driving term large, the inner stable region is small and does not appear in the picture. The phase diagram is the classical diagram predicted by the usual nonlinear theory. Figure 248 represents motion of nitrogen ions in a model magnet field. The driving term is very small and the phase-shifting term very large, so that the inner stable region is relatively large. The onset of the frequency shifting mechanism is, as expected, even more pronounced than in the previous figure.

We are preparing programs to compute, as a function of the field variables and their derivatives, the radial and axial frequencies, the driving term and frequency shifting term of the 3/3 resonance, and the coupling coefficients for the coupling resonances. These, with the orbit codes, will provide a guide for the design of a magnetic field which will give good magnetic deflection of the ions.

References

(1)Hagedorn, R., Hine, M. G. IV and Schoch, A., "Non-Linear Orbit Problems in Synchrotrons," Cern. Symposium, p. 237-253 (1956).

(2)Smith, L. and Garren, A. A., "Orbit Dynamics in the Spiral-Ridged Cyclotron," (UCRL-3598) University of California Radiation Laboratory, (1959).