# ANALYSIS OF THE MAGNETIC FIELD DATA AND COMPUTATION OF TRIM COIL CURRENTS FOR THE VARIABLE ENERGY CYCLOTRON

T.K. Bhattacharya, S.K. Basu and N.C. Bhattacharya
Variable Energy Cyclotron Centre, Bhabha Atomic Research Centre
Calcutta-700064, India

## Summary

Magnetic Field Data of the Calcutta 88" Cyclotron has been analyzed with the Berkeley Code CYDE to compute trial Trim Coil Settings, $\nu_r$ , $\nu_z$ and phase history Sin $\phi$ ,in order to improve the beam quality of the cyclotron.

## Introduction

Whenever a new beam, characterised by its charge-state and mass number or an already tried out beam with increased final energy is tuned, one needs in practice to set about 50 parameters for the cyclotron and about 10 parameters for a good transmission of the extracted beam on to the target. The number of beam-line parameters varies, depending on the channel in which the experiment is carried out. It is worth-noting that each cyclotron is unique in its behaviour and that the interdependence among the various parameters like, Central Region Parameters, Main Magnet Coil, Radio Frequency, Dee Voltage, the various Trim Coils, Valley Coils, Deflector settings are so complicated that it is not possible to express the dependence analytically. Hence, it is not theoretically possible to predict the optimum settings for all the parameters uniquely, so that one can immediately tune all the parameters and obtain a good beam on the target. But from a previous precise knowledge of the Magnetic Field Data, it is possible to predict a set of trial settings, with the help of a computer code such as CYDE developed at Berkeley[1] and the deflector calibration. The Berkeley 88" Cyclotron Laboratory has produced a Systematies[2] of such parameters using a personal computer which provides an efficient data management system to assist with the day-to-day operation. The motivationof the present work is to achieve such systematics for our cyclotron. Such systematics will also enable one to study the behaviour of radial and vertical oscillation frequencies ( $\nu_r$ and $\nu_z$ ). A precise knowledge of these frequencies is necessary for designing and installation of an external ECR heavy ion source[3)] funded for the Calcutta Cyclotron, as well as for injection of the present beam into a future post-accelerator facility.

## Procedure for Trim Coil Setting Calculation

The computer code CYDE in its present form obtained from LBL, Berkeley[4] was used for calculating the Trim Coil Settings for a desired beam. This code consists of several sub-programmes for undertaking the following tasks viz.,

(1) to calculate a base magnetic field. B(I,r,$\theta$ ) from the measured magnetic field maps,at a number of main field currents.

(2) to estimate the trim coil contributions at these levels for each radius.

(3) to calculate the equilibrium orbit parameters according to the main field and isochronous fields for the desired energy.

(4) to calculate trim coil currents.

(5) to calculate the equilibrium orbit properties for the final fitted fields.

A constrained least squares fitting routine TRIMCO is incorporated for optimising the settings, assuring at the same time the isochronism condition. The expected phase history of the beam is also obtained as an aid to beam diagnostics. One may opt for a trim coil solution for an average field profile other than the isochronous field profile by inputting the central "field bump" and the `edge fall off´near the extraction radius.

## Magnetic Field Mapping Data

The detailed magnetic field measurements for our cyclotron was done with a calibrated search coil fixed on a computer controlled semi-automatic gear[5]. Iron field was measured at 31 main coil excitations from 665A to 2850A with azimuthal scans of 360°/3°, 120°/12° and 60°/3° depending upon the current. The effect of each trim coil for an excitation of +3000 and -3000 Ampere-turns was measured at one azimuth for 5 principal main coil excitatiions. Measurements were also done by simultaneously exciting main and all the 17 trim coils. Raw data processing was done on BESM-6 computer at Bombay using computer codes, such as CERTFY, OMNVEC, COMPCO and MAINCO which finally generated coefficients to express the iron field B(I, r, $\theta$ ) as a polynomial in magnet current I, the trim-coil effects and DB/dI for the main magnet. The data tapes thus generated need to be converted again for our purpose to make it compatible with IRIS-80 computer of VECC, Calcutta. For that additional conversion programmes were written in FORTRAN, which provided data files according to the requirements of CYDE code.

## Results

We have calculated optimum trim coil settings and the main coil adjustments for $\alpha$ -particles in the energy range 30 to 120 MeV using the aforesaid measured magnetic field B(I, r, $\theta$) and trim-coil contribution (dB/dI). In doing so a model central field bump` and the `edge fall off` near the extraction radius, determined empirically from previous operating experience, was used as input. The trial set of trim-coil currents for each energy was obtained from the operator's log book. The trial main coil current was estimated from measured I-H Curve for the cyclotron magnet and the B$\rho$ value for the corresponding $\alpha$-beam. Table 1 gives typical results obtained for 60 MeV $\alpha$-particle beam for our machine at a main coil current of 1027 A and dee voltage of 45 KV. For completeness, the trial trim coil currents used are included. It is experienced that the least squares solution from such a procedure is very much sensitive on the bounds for trim coil currents used rather than their absolute magnitude, provided the input reference main coil current is a good approximation. Figure 1 shows the variation of the magnetic field, both with trial and calculated trim-coil currents as a function of radius for 60 MeV $\alpha$-particle. It is observed that the field is more or less isochronous between 7" to 37". It is requir- to decrease between 0" and 7" to meet the vertical focussing requirements; between 37" and the extraction radius, the field falls below isochronous values as required for efficient extraction. In the same figure, the variation of vertical and radial oscillatron frequencies $\nu_z$ and $\nu_r$-1 respectively, with radius are also shown. Figure 2 shows the variation of estimated Sin $\phi$ with radius for the same beam. It is observed that $\nu_r$ is close to 1 from centre of the cyclotron to the extraction radius and then falls below 1 as desired and $\nu_z$ gradually increases as expected from isochronism requirements. The calculated phase history shown in Fig. 2 is adequate for acceleration though not optimised for minimum phase slip.

Table - 1

| | | | |
|---|---|---|---|
| Energy | = | 60.00 | MeV |
| Mass | = | 3.97153 | Proton Units |
| Charge | = | 2 | Proton Units |
| Dee Volts | = | 45.40 | KV |
| Harm. No. | = | 1 | |
| Freq. Particle | = | 8.6600 | MHZ |
| Freq. Cyclotron | = | 8.6600 | MHZ |

| Coil | Optimum Setting (Amps.) | Trial Setting (Amps) |
|---|---|---|
| 1 | -750 | -358 |
| 2 | 660 | -340 |
| 3 | -442 | -251 |
| 4 | 0 | 0 |
| 5 | 0 | 0 |
| 6 | -89 | 0 |
| 7 | 0 | -69 |
| 8 | -46 | 153 |
| 9 | 136 | 0 |
| 10 | 0 | 90 |
| 11 | 284 | 0 |
| 12 | 25 | 149 |
| 13 | 668 | -40 |
| 14 | 263 | -300 |
| 15 | -1388 | 0 |
| 16 | -638 | 0 |
| 17 | 2000 | 474 |

| | | |
|---|---|---|
| Main Coil Adj. | = | 7.6 A. |
| Ref. Main Coil | = | 1027.0 A. |
| Calc. Main Coil | = | 1034.6 A. |

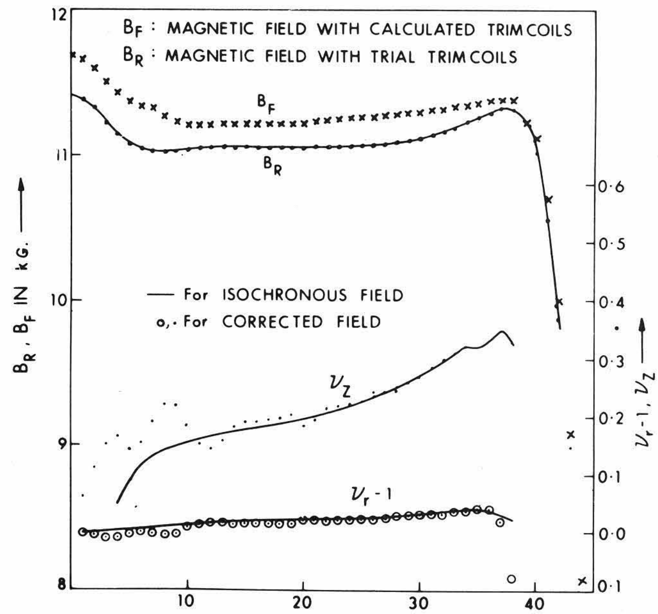


FIG. 1. R IN INCHES

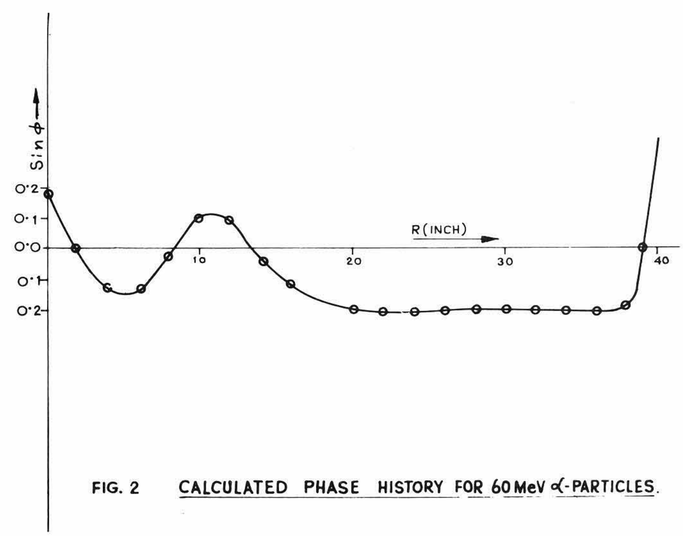


FIG. 2 CALCULATED PHASE HISTORY FOR 60 MeV $\alpha$-PARTICLES.

## Conclusion

Trial Trim Coil settings for $\alpha$ -beam has already been obtained satisfactorily. It has been found that this serves as an excellent guide for trying out a new beam. Our aim is to extend this work for the heavy ions to be accelerated in the near future and to try to improve the quality of beam extracted from our cyclotron.

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