Measurement and adjustment of CIAE medical cyclotron magnet

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Abstract

A 30 Mev compact cyclotron used for medical radioactive isotope production is in construction.

A program controlled mapping instrument with accuracy $10^{-4}$was devoloped. Its probe moves automatically in the 30 mm gap covering a circular area more than 1600 mm in diameter. It makes the mapping efficiency and accuracy.

An iteration method was used for both hanomic and average field shimming. The results were so good that made the first hamonic from more than 10 guass reduce to about 5 guass in the most of the radius and 70 guass to about 10 guass in the central region. Meanwhile the total phase shift which represents the isochronous from more than $\pm 90°$ to about $\pm 20°$.

I. INTRODUCTION

In order to keep the most of beam accelerated to the final energy, the magnetic field of a cyclotron should be shimmed to close the isochronous and the imperfect harmonics should be kept as small as possible. There is no trimming or harminic coils in this cyclotron, the field mapping and shimming become very important.

The field adjustment was implemented by the sector pole edge modified. The aims of the field adjustment are: the first harmonic is limited to 10 guass or less except central and extracted region where 30 gauss is allowed and the total phase shift is kept in the range less than $\pm 30°$.

The full magnetic field survey of the cyclotron at CIAE was carried out based on an automatic mapping system. The sequencing of the probe movement and recording of field value is controlled from a step motor power supply and a PC286. GROUP3 Hall probe was used as the field detector with the accuracy 10^{-4}.

II. FIELD MESUREMENT

To make the measurement results more reliable following measures are taken before and during the mapping.

a, To assist in performing the measurement, check list were given for operating the system and preset control switches for each type of measurement planned.

b, Consistency check. The consistent of the rotated center of the instrument and field center is important. But the difference of the two centers exists certainly. To reduce the difference, the probe moved slightly along the radial direction to make sure the probe was located closing to the center that the differences of field value at different azimuthal positions were small enough to be considered as a same point. The limitation in our case is ± 2 guass.

c, Radial position check. A azimuthal angle is chosen as $0°$. After $0°$ fixed a serial field data acquisited and stored in the differnt radii from 0 to 84 cm steped by 2 cm. If the field value in a given field point is not the same as stored before in the mapping process, the warning would be given. Then the radial position will be checked. The data might be given up when the difference is too large.

d, The start point and the final point is a same point for each turn, so is the field. It will be checked if the two value are not the same.

e, The field curve will be displayed on the screen to show whether the shape is reasonable, and whether there is any point is out of the estimation.

III. HARMONIC ANALYSIS

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Harmonic analysis is taken on the range $[0,2\pi]$ for each given radias. A code used for Fourrier analysis computation is called after mapping. Usually the coefficients up to 40th harmonics are considered.

Fig. 1 shows the imperfect first harmonic distribution along radial direction.

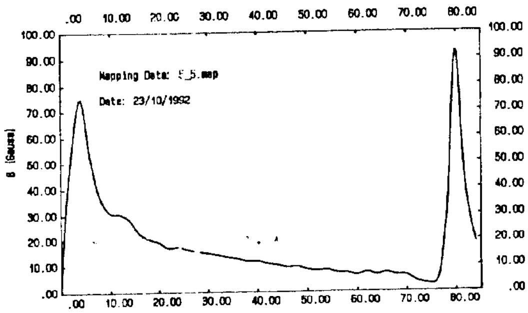

Fig. 1 The amplitude of the first harmonic distribution along radial direction

IV. BEAM DYNAMIC ANALYSIS

Fig. 2 shows the Flutter varies with the radius.

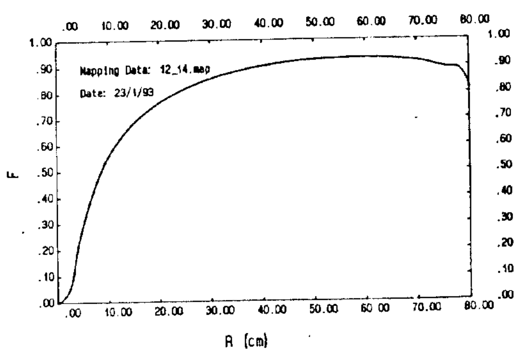

Fig. 2 The Flutter varies with the radius

Based on measured data the phase shift, betatron oscillations in radial and axial direction could be calculated. They are shown in Fig. 3, Fig. 4 and Fig. 5.

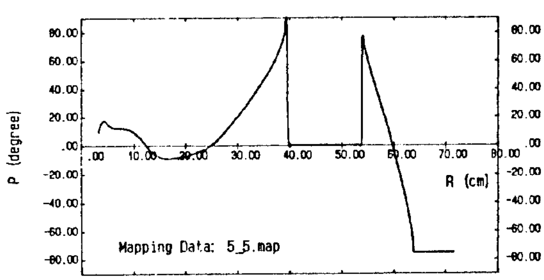

Fig. 3 The total phase shift is calculated at radius

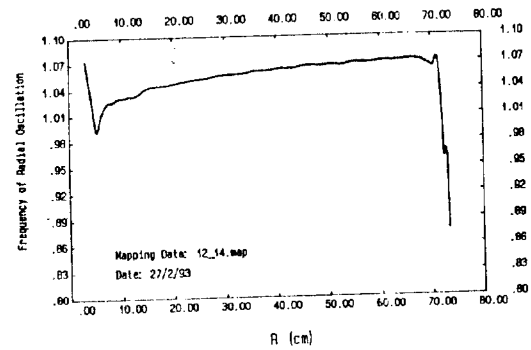

Fig. 4 The radial betatron oscillation

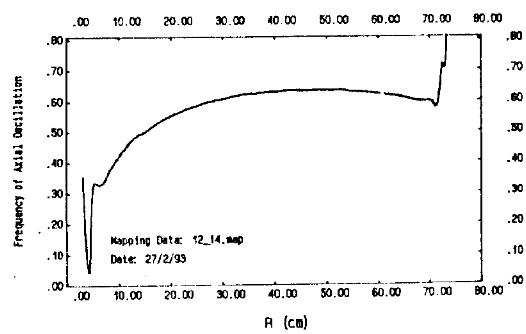

Fig. 5 The axial betatron oscillations

The diagram of data post processor of mapping is shown in Fig. 6

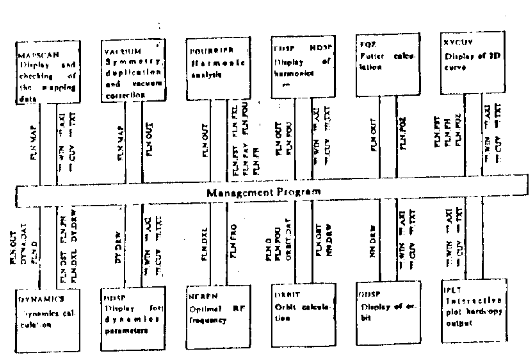

Fig. 6 The diagram of data post processor of mapping

V. FIELD ADJUSTMENT AND SHIMMING

The results show that the field is not acceptable becuase the imperfect harmonics was too large and the average field dirfted out the ischronous much more than the requisted. The reason for them was the sectors were not machined on NC machine. The sizes are slightly different each other.

The sectors could not be modified any more. What we were able to do is use the pole edges.

Fig. 7 shows the improving process of the first harmonic after 4 times of the iteration.

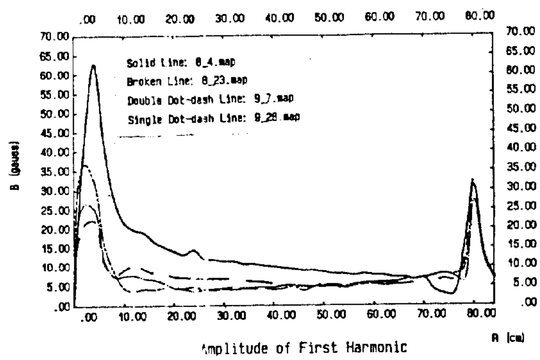

Fig. 7 The improving process of the first harmonic after 4 times of the iteration

After the field successed with an acceptable small imperfect harmonics, the average field is ready to be shimmed to meet the requirements from the isochronous. The pole edges are used again for the purpose. But an important matter must be kept in mind is the shimming should not destroy the harmonics which is in the requisted amount whenever the pole edges have to be modified to produce the field close to the isochronous. The phase shift would exest if the average field is off the isochronous in a fixed frequency. We can not add some iron to the pole edge but cut in practical modification. In order to make up for such deficiency what we have done is to reduce the frequency a small amount to make the requisted isochronous field slightly smaller. Then the modified amount would become positive using cut only.

Fig. 8 show the process how the total phase shift of the accelerated ion is improving after few times of iteration.

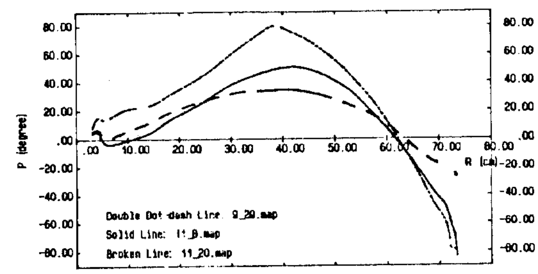

Fig. 8 The process of the total phase shift improving

To make sure the field is acceptable under the possible worst conditions, several assumptions have been added to test whether the field works. No vacuum correction and maximum possible correction have been tested. Also different initial phase angle ($\pm 30^\circ$)for the accelerated particle have been supposed. The results prove that the fields are good enough for a quite large region of the working conditions.

VI. CONCLUSION

An iteration method was taken for both hanomic and average field adjustment. The results were so good that made the first hamonic from more than 10 guass reduce to about 5 guass in the most of the radius and 70 guass to 20 guass in the central region. Meanwhile the total phase shift which represents the isochronous from more $\pm 90^\circ$ to about $\pm 20^\circ$.

The quality of the field is acceptable and it would ensure the machine work properly.