CORRECTION OF THE CYCLOTRON RIC-30 MAGNETIC FIELD

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Abstract

Cyclotron RIC-30 (development of SPA" D.V.Efremov Scientific Research Institute of Electrophysical Equipment" is in operation from 1993. RIC-30 is isochronous cyclotron with sector's focusing and one-dee (180 degree) RF system. Compact magnet has 150 cm pole diameter. Cyclotron is used for the production of the PET-isotopes using internal and extracted beam with maximal energy of protons ~28 MeV. At earlier periods of exploitation some parameters of cyclotron (beam intensity and energy) were in disagreement with designed ones. It was decided to carry out the magnetic field measurements to understand the causes of such misalignment. This was done in 2006.

The results of the magnetic field measurements as well as dynamics characteristics of the accelerated beam are presented in the paper. Central steel plug with one unsymmetrical hole for the ions source was replaced by the same one with two symmetrical holes. The new plug doesn't cause a presence of the 1st harmonic of the magnetic field in the cyclotron center. This leads to the beam energy grow up at the extraction radii due to decrease of the coherent amplitudes in the accelerated beam. Change of the magnetic field parameters in the cyclotron center for the beam intensity increase is under discussion as well.

INTRODUCTION

Scheme of RIC-30 cyclotron and its technical parameters as well as beam characteristics and service conditions of the machine are presented in [1]. Maximal beam current and its energy are less than ones in technical documentation of the accelerator and there are no data about magnetic field of cyclotron. That is why it is necessary to carry out measurements of the RIC-30 magnetic field.

MEASUREMENT DEVICE

Cyclotron magnetic field measurements were carried out by means of device which was used in forming of the magnetic field of "CYTRECK" cyclotron [2].

The device consists of:

1) Mechanical automatic system which allows to move Hall-probe in azimuthal direction using step motor. Azimuthal step is fixed on the magnetic system period or whole circle in minimal axial gap of 40 mm. Radial movement of the probe is realized manually.

2) Personal computer with software for on-line processing and control of getting data. Measured magnetic field maps were used for detailed beam dynamics analysis by means of other codes.

CYCLOTRON MAGNETIC FIELD MEASUREMENT RESULTS

Dependence of measured average magnetic field and isochronous one versus radius are presented in Fig. 1. One can see that average magnetic field formed close to isochronous one. Calculated phase shift of the beam during acceleration is not more than 20°RF..

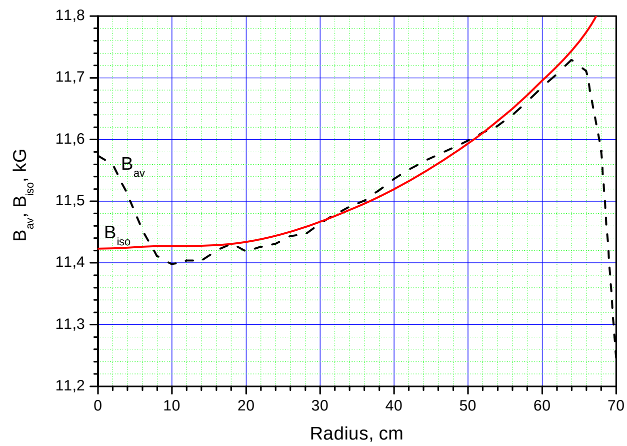

Fig. 1. Average magnetic field B_{av} and isochronous one B_{iso} for the resonance frequency of protons f=17.415 MHz

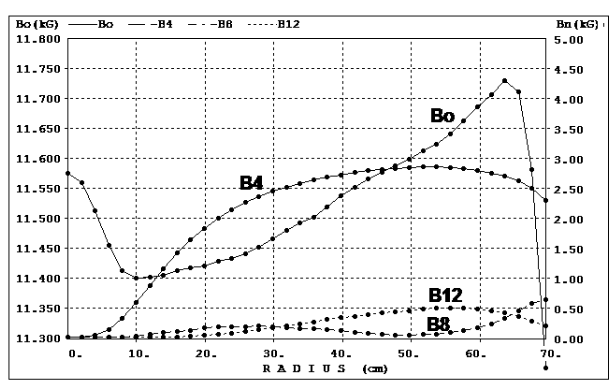

Fig. 2. Average magnetic field *Bo* (smoothed) and amplitudes of harmonics *B4, B8* and *B12* (not smoothed) which were used in the beam acceleration calculations

Measured amplitudes of the harmonics are presented in Fig. 2, 3.. Amplitude of 1st harmonic equals ~50 Gauss in its maximum.

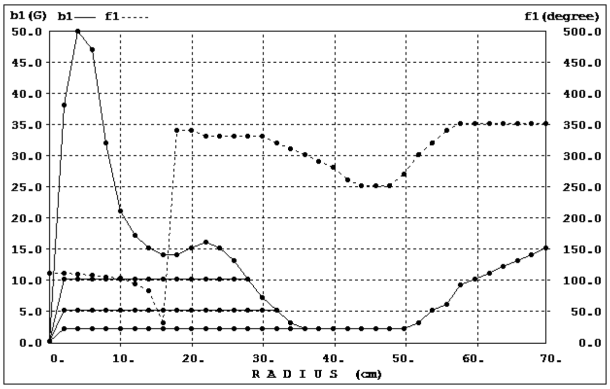

Fig. 3. Amplitude *B1* and phase f1 (smoothed) of 1st harmonic of the magnetic field that were used in the beam dynamics calculations. Three dependences *B1(r)* were used in range of radii 0-30 cm: experimental, *B1(r)=10 Gauss*, *B1(r)=5 Gauss.* Phase of the harmonic was the same in all calculations.

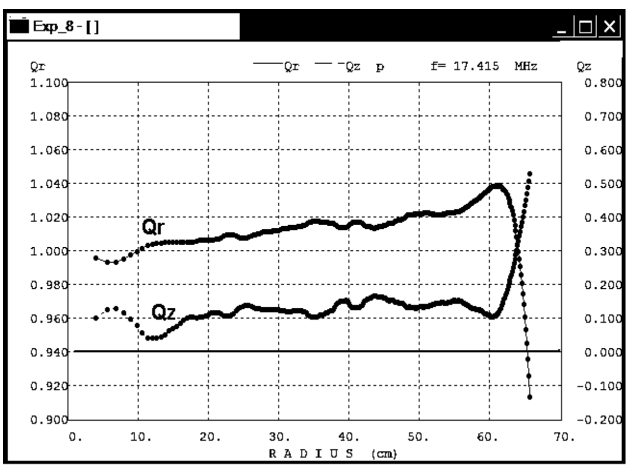

Fig. 4. Betatron frequencies (average magnetic field from Fig. 1)

Betatron frequencies are shown in Fig. 4. One can see that there is a vertical focusing of the beam in all range of radii in absence of the field imperfections but in the region 10-14 cm value of *Qz* falls to 0.03. This can cause the vertical beam losses in case of appearance of radial component of the magnetic field in this region. Measurements of the beam current shows that intensity of accelerated beam falls in this zone to its minimum value 220 mkA and then stays at this level up to the end of acceleration. It is possible to see from Fig. 2 the reason of such a decrease of *Qz*. In range of radii 10-14 cm average magnetic field stops its decreasing. Thus, there is no vertical focusing due to such a decrease in this region while variation of the magnetic field is not enough for vertical focusing at this place. It is possible to increase the variation or continue the decreasing zone of the magnetic field in this range of radii to avoid this. Forming of the average magnetic field seems simpler than increasing of the variation. Calculations show that steel ring of 5 mm thickness and 10 mm wide in radial direction can be used to solve this problem. Technical possibility of such a modernization is under consideration now.

PROTONS ENERGY AT THE FINAL RADII

Dependence of calculated energy of protons versus an average radius of orbit is shown in Fig. 5. Results of current density via radius measurements show that maximum value of current corresponds to radius 60-62 cm (it depends on cyclotron tuning). This corresponds to protons energy of 24-26 MeV (see Fig. 5).

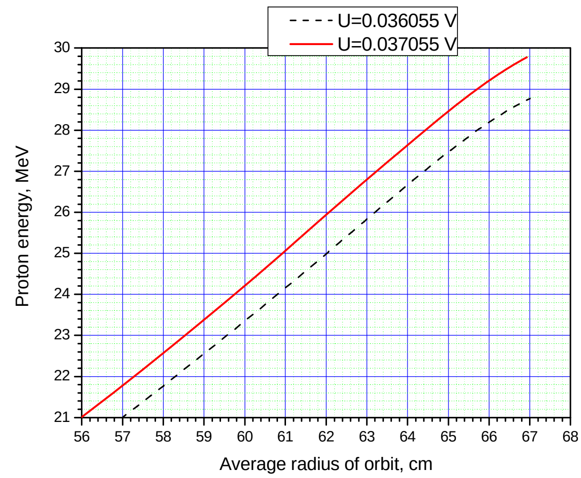

Fig. 5. Energy of proton versus average radius of the orbit for two values of the main coil current. Dash line is working regime of cyclotron with RF-frequency 17.415 MHz, red line – corresponds to possible regime with RF-frequency 17.755 MHz.

In Fig. 6 there are results of the calculations of radial oscillations amplitude of the beam forced by 1st harmonic of the magnetic field in the cyclotron center. Existing *B1(r)* causes an amplitude of radial oscillations more than 4 cm. This leads to decrease of the beam energy at the target up to 24 MeV.

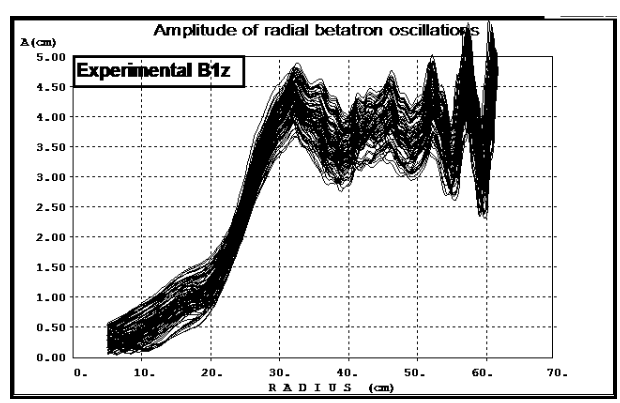

Fig. 6. Amplitudes of radial oscillations of protons versus average radius of the orbit with in the case of experimental *B1(r)*

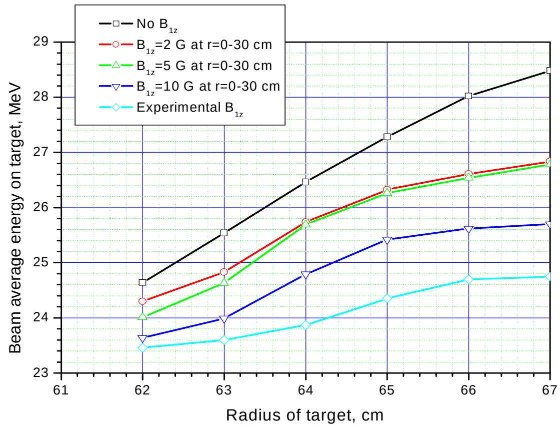

Fig. 7. Average beam energy on the target (azimuth 235°) versus its radial position for different distributions of *B1(r)* from Fig. 3

Dependences of the beam energy on inner target for the different shapes of *B1(r)* in the center are shown in Fig.7. With existing 1st harmonic of magnetic field the beam energy equals 24 MeV on radius of a 64 cm. Reaction ^{45}Sc(p,2n)^{44}Ti confirm this fact.

Central steel plug with two symmetrical relatively a center holes with diameters of 20 mm was installed into the machine. In one of the holes an ion source is arranged. The magnetic field with new plug is not measured so far, but it is possible to suppose that 1st harmonic of the magnetic field in the center is essentially decreased. Value of protons energy at the extraction radius (64 cm) was estimated by amount of ^{45}Sc(p,2n)^{44}Ti isotope and equals ~26 MeV.

CONCLUSIONS

The proton beam energy at the final radii was increased due to new steel central plug with two holes which does not create 1st harmonic of the magnetic field and essential beam radial oscillations (this plug was installed instead of plug with one unsymmetrical hole).

The intensity of the accelerated beam can be essentially increased by the change of the average magnetic field shape in the central region of cyclotron.

If the body of target is thin surface layer of any material the angle of beam hitting the inner cyclotron target becomes an important characteristic. Orbit of protons in the isochronous cyclotron is not a circle. Thus, angle of beam hitting the target depends on azimuth and radial position of the target. Technical solution of this question is under studying.

REFERENCES

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