CALCULATION OF ORBIT EXPANSION EFFECT FOR THE VINCY CYCLOTRON

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Abstract

Computation of the orbit expansion effect for the extraction from the VINCY 4-sector cyclotron is performed. The proper dependence of the main harmonic of the magnetic field on the radius is found. The turn separation increasing and the radial and axial emittances behavior are demonstrated.

It is planned to extract the ion beam from the Belgrad sector cyclotron VINCY [1] with a stripping foil or with an electrostatic deflector. In the latter case the turn separation should be increased by some method because the turn separation produced by the energy gain in the extraction region does not execed 2 mm.

The orbit expansion effect [2,3] looks like a very suitable method to increase separation between the last turn and previous one by several times. This method was first tested for the beam extraction from the electron cyclotron [4].

To use this effect it is necessary to form the radial dependence of the main harmonic of the magnetic field B_4 in a special way. The magnetic field designed for the deuteron acceleration in the VINCY Cyclotron is plotted in Fig.1.

The magnetic field of the cyclotron can be described as

$$B = B_{av}(r) + B_N(r)\cos[\beta_N(r) - N\Theta], \qquad (1)$$

where B_{av} is the average magnetic field, B_4 is the amplitude of the main narmonic, N is the periodicity of the magnetic field.

For a magnetic field like this the orbit compaction factor $\alpha = \frac{p}{r}\frac{dr}{dp}$ can be expressed with an accuracy of a few percent as

$$\alpha \approx [1 + n + \frac{1}{2N^2}(s^2 + \varepsilon d)]^{-1}, \qquad (2)$$

where

$$n = \frac{r}{B_{av}}\frac{dB_{av}}{dr} \;;\quad \varepsilon = \frac{B_N}{B_{av}} \;;$$

$$s = \frac{r}{B_{av}}\frac{dB_N}{dr} \;;\quad d = \frac{r^2}{B_{av}}\frac{d^2B_N}{dr^2}$$

If B_N does not depend on the radius, the orbit compaction factor is $\alpha = (1+n)^{-1}$. For the magnetic field shown in Fig.1 it is about 0.92 near the 82 cm radius. Introduction of the quadratic nonlinearity in the main harmonic law (it should be negative for the orbit expansion effect) allows one to increase the turn separation by several times for the same energy gain. The changed 4th harmonic dependence is plotted in Fig.1a. The corresponding dependence of the first and second derivatives as well as α dependence are plotted in Fig.2. The 4-fold increase in the orbit compaction factor is seen.

Computation of the radial particle motion in such a magnetic field was carried out with the following input parameters : the initial energy is 30 MeV, the initial radius of the equilibrium orbit on azimuth 0^o is 61.5 cm, the maximum energy gain is 0.2 MeV/turn, the RF frequency is 28.083 MHz (second harmonic of the orbit frequency). 125 turns were needed for the accelerated particle to reach the final radius. The last 10 orbits are shown in Fig.3. An increase of approximately 10 mm in the separation between the last two turns is cleary seen. In Fig.4 the radial emittances on azimuth 205^o are plotted for the initial radial oscillation amplitude of 2 mm. The empty gap between the last two emittances is about 3 mm. Hopefully, this gap is large enough for the deflector septum installation.

The behavior of the axial emittance is shown in Fig.5. In Fig.6 the radial and axial tunes for the corrected magnetic field are plotted. The phase motion is influenced by the main harmonic amplitude changing as shown in Fig.7. To compensate for this influence, a small correction of the average magnetic field shown in Fig.1b was needed.

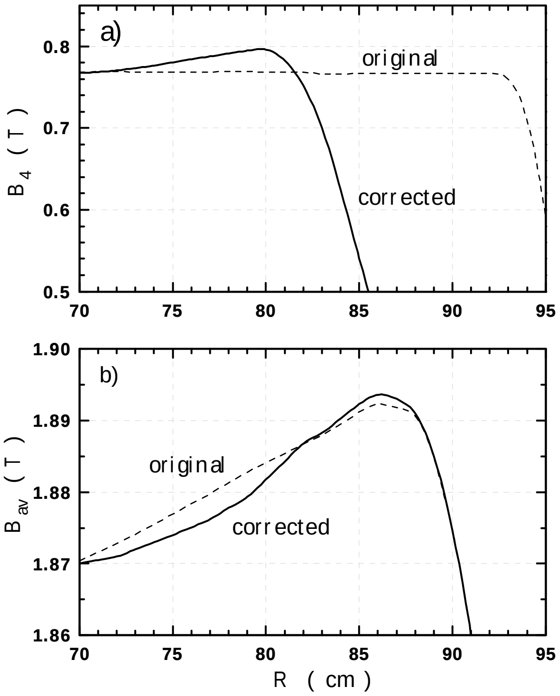

Fig.1 Average magnetic field B_{av} (b) and main harmonic B_4 (a) for D^- - ions.

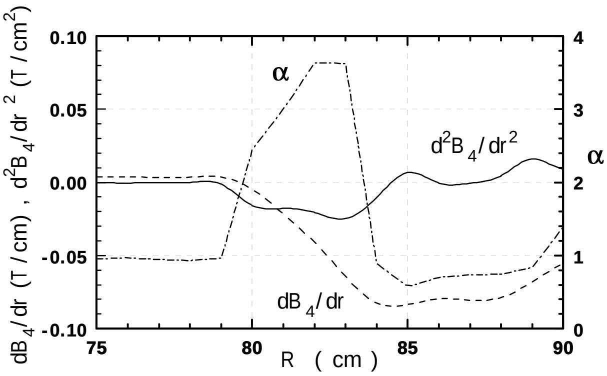

Fig.2 First and second derivatives and compaction factor α for corrected magnetic field.

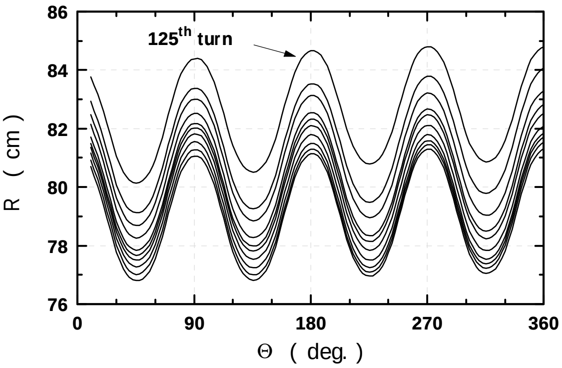

Fig.3 Last radial orbits in the expansion region.

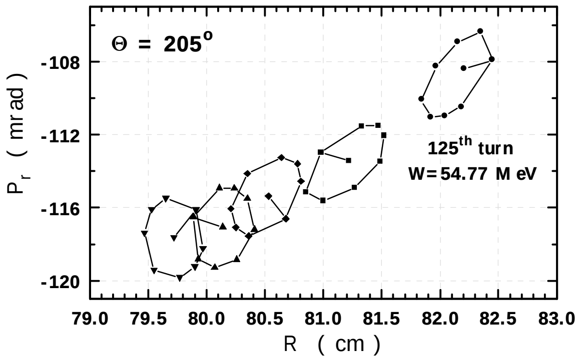

Fig.4 Radial emittances of the last 5 turns.

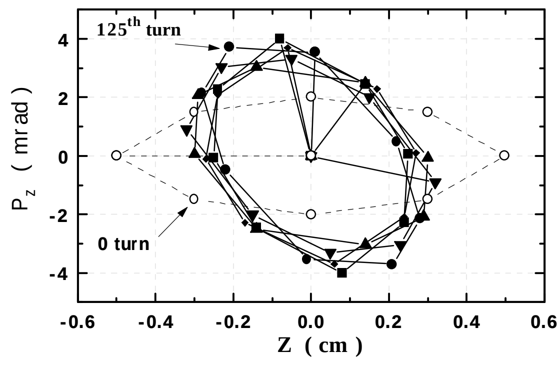

Fig.5 Axial emittances of the last 5 turns.

CONCLUSION

It follows from the above described calculation that with the properly chosen radial dependence of the main harmonic of the magnetic field in the extraction region it is possible to increase the orbit turn separation up to 10 mm conserving the beam radial and axial emittances.

Further investigation should be conducted to minimize the energy spread influence on the turn separation and to evaluate the magnetic field tolerances.

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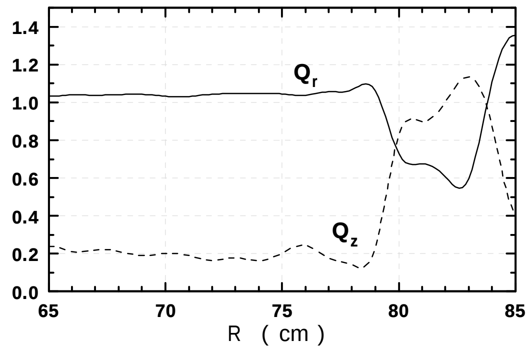

Fig.6 Radial and axial tunes for the corrected magnetic field.

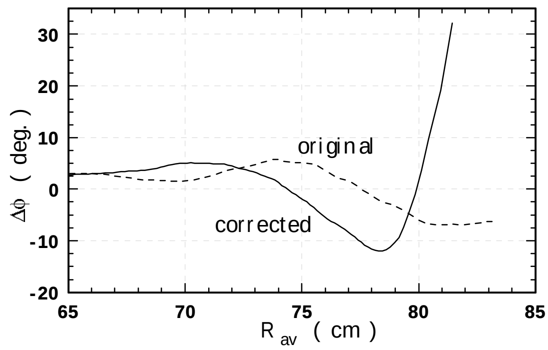

Fig.7 Phase motion for the original and corrected magnetic fields.