объединенный
институт
ядерных
исследований
дубна

2312/2-81

11/5-81

E9-81-54

S.B.Vorozhtsov, V.P.Dmitrievsky

CALCULATION OF BEAM INJECTION AND MODES OF ACCELERATION FOR THE JINR PHASOTRON

Submitted to IX Conference on Charged Particle Accelerators (Washington, 1981)

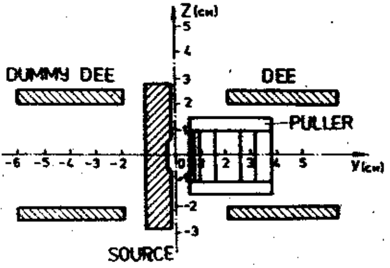
1981

INTRODUCTION

The JINR synchrocyclotron for proton energy of 680 MeV was shut down for reconstruction work in 1979. The purpose of this reconstruction is the creation of a high current phasotron with spatial variation of magnetic field. The accelerated beam behaviour together with different acceleration modes of the facility is investigated through computer simulation during the first phase oscillation. As a result, magnetic field tolerances are obtained.

INJECTION

The beam motion from the ion source up to the stationary acceleration mode was calculated using the computer code THOUR[1] modified for a high current phasotron. The accelerated beam intensity for the main variant of central electrodes geometry was estimated with taking into account synchrotron and betatron radial and vertical particle motion as well as space charge repulsion in the beam. When the extracted ion source current was as high as 100(mA)the beam intensity after the



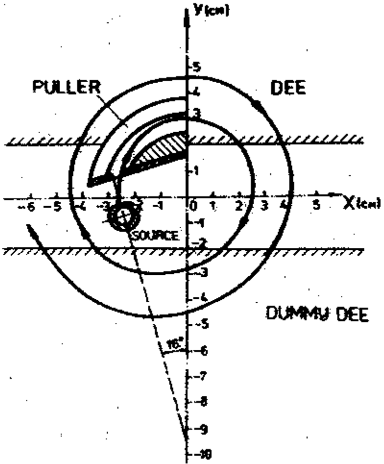


Fig.1. Geometry of the main variant of accelerator center region.

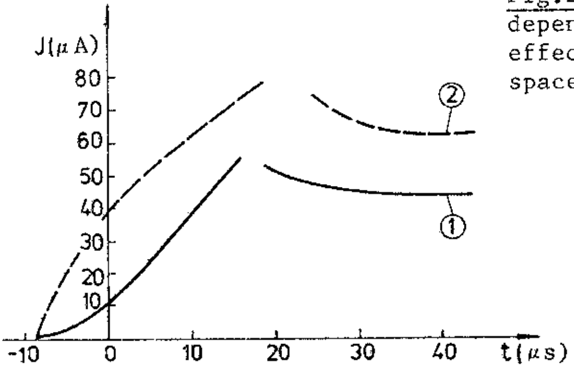


Fig.2. Beam intensity time dependence. 1 - space charge effect included, 2 - without space charge.

first phase oscillation was about 40-45μA (Fig.2) with dee frequency performance, measured at a full-scale RF-system prototype. The dee acceleration voltage was assumed to be 40-50 kV. The above mentioned intensity value could be obtained at the final radius of acceleration (270 cm) when there are no beam losses due to transversal instability or deviation of the beam from the midplane in the radius ranging from 60 to 270 cm. Even with the installed puller the proper electrical field of the beam starts to affect the value of the charge captured into the separatrice of the first phase oscillation (effect of the order of 30-35%). But the main losses of the beam are due to insufficient axial focussing in the radius range of 5-15 cm. 9% of the total beam, passing through the puller, are retained for normal acceleration. Axial motion losses are 58%; return to the center, 33%. Only particles with start phases of (-29°) ÷ (-1°) are captured at the stable mode of acceleration. The start phases range of particles, passing through the puller,was a bit wider than the above-mentioned one. Injection time was 23 μs with frequency modulation rate of 543 Hz.

MAGNETIC FIELD PERTURBATION EFFECT ON THE BEAM

A calculation taking into account a space charge requires a considerable amount of computer time, that is why the field perturbation effects have been estimated excluding collective particle interaction. Mean field perturbations lead to the instability of particle phase motion and change the frequency of axial oscillations. Figure 3 shows beam intensity performance for the mean field deviation of the form:

$$\Delta\bar{B}(R) = \Delta\bar{B}_m \frac{R_0^2}{R_0^2 + R^2} \cos\left(\frac{2\pi}{L} R\right).$$

Curve 1 corresponds to $R_0 = L = 20$ cm, curve 2 corresponds to parameter values $R_0 = 5$ cm, $L = 50$ cm. It can be seen that

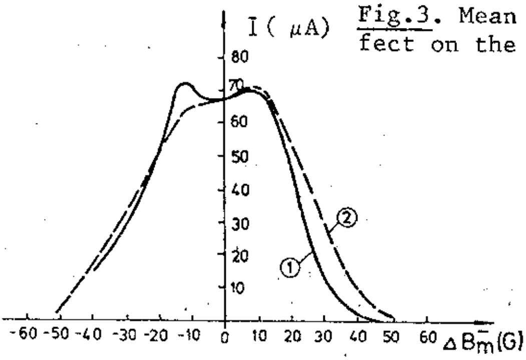


Fig.3. Mean field perturbation effect on the beam intensity.

for $|\Delta \bar{B}_m| < 10$ G beam intensity is approximately constant. Betatron radial oscillations in the center of accelerator are affected by integral($Q_R = 1$), half-integral ($2Q_R = 2$) and fourth-integral($4Q_R = 4$) resonances. An integral resonance, driven by the first harmonics of the magnetic field, is the most dangerous one. The beam behaviour analysis by the Bogolubov method[3] showed that for 3.5 cm radial amplitude spectra limitation it is necessary to keep the first harmonics amplitude smaller than 4G in the resonance region of (4–30) cm[4]. Mean radial component of the magnetic field $\bar{B}_R$ is the most dangerous as far as the beam center deviation from midplane is concerned. According to analytical predictions for the given beam deviation $|\bar{Z}| < 4$ mm, in the region 20 cm $< R <$ 40 cm the $\bar{B}_R$ value should be below 3G.

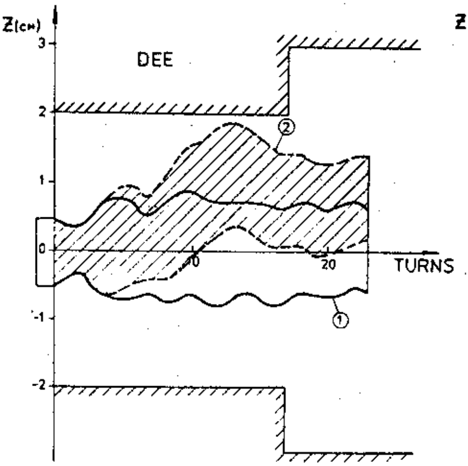


Fig.4. Beam size and position during the first turns. 1 – required field, 2 – midplane perturbation.

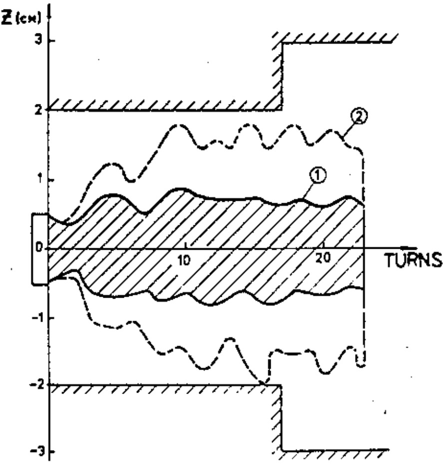


Fig.5. Acceleration field azimuthal component effect on beam axial motion. 1 – EXRZ-code, 2 – THOUR-code.

But in the radial range $R < 20$ cm the analytical appreciations are difficult to perform due to particle phase dependence of the axial focussing strength. Beam motion calculations, using complete set of equations (EXRZ-code) showed the necessity of the requirement $\bar{B}_R < a \cdot R$ for $R < 10$ cm and $a = 0.3$ G/cm and $\bar{B}_R < 3$G for 10 cm $< R <$ 20 cm. Beam deviation under the indicated condition is shown in Fig.4. The effect of neglecting the acceleration field azimuthal component in the particle axial motion equation (THOUR-code) is noticeable in Fig.5. According to Fig.5 the axial motion particle loss appreciated with the THOUR code is a little higher than in reality.

ACCELERATION MODES

As is shown in ref.[4] at the beginning of beam injection the acceleration voltage amplitude should be greater than 45 kV to enable the beam to surround the central electrode configuration. That is why for all the three modes of acceleration the initial voltage is set to be 50 kV. In addition to the mode with a separatrice area $A_b = 100$ MeV·ns a voltage linear decrease during 57.6 μs has become necessary. Other data concerning acceleration voltage amplitude time dependence are given in ref.[5]. Beam intensity performance from the initial up to the final radius is shown in Fig.6. During the first 100 μs the beam losses for 1 and 2 modes are due to dee voltage decrease from 50 kV to the value required by the respective mode. In the region $t = 200$ μs beam losses by mode 3 can be explained through the presence of separatrice area minimum in the case of time-constant 50 kV acceleration voltage amplitude. During acceleration the beam performs ≈16000 turns. Figure 7 shows the radial dependence of separatrice radial size. When betatron radial amplitude is zero the separatrice radial size corresponds to the beam radial limits.

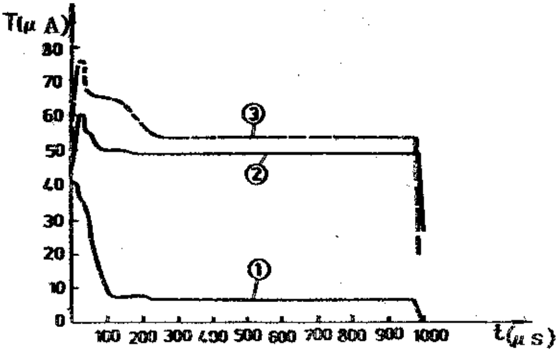


Fig.6. Beam intensity for various acceleration modes. 1 – A_b = 100 MeV·ns, 2 – A_b = 300 MeV·ns, 3 – V_D = 50 kV.

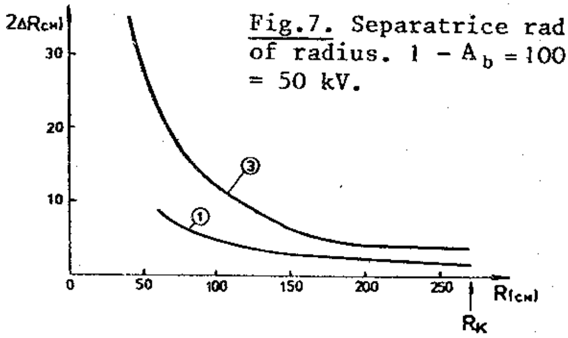


Fig.7. Separatrice radial size dependence of radius. 1 - $A_b = 100$ MeV·ns, 3 - $V_D = 50$ kV.

CONCLUSION

Computer simulation of the beam capture confirmed the earlier internal beam intensity appreciation/6/. In the first phase oscillation region magnetic field tolerances (mean field, first harmonics, field radial components) were obtained. Calculation of the beam acceleration process from injection up to the final radius made it possible to refine the required time dependences of acceleration voltage amplitude for various modes of acceleration.

REFERENCES

1. Thouroude D. MSC/PR/3995, 1975.
2. Glazov A.A., Shakun M.G. JINR, 9-11224, Dubna, 1978.
3. Bogolubov N.N., Mitropolsky Yu.A. Asymptotical Methods in the Nonlinear Oscillation Theory. "Nauka", Moscow, 1974.
4. Vorozhtsov S.B., Dmitrievsky V.P. JINR, P9-80-410, Dubna, 1980.
5. Vorozhtsov S.B., Dmitrievsky V.P., Zaplatin N.L. JINR, P9-12882, Dubna, 1979.
6. Glazov A.A. et al. JINR, 9-3211, Dubna, 1967.

Received by Publishing Department
on January 26 1981.