ELECTROSTATIC DEFLECTOR AS THE HEAD ELEMENT OF THE JINR PHASOTRON EXTRACTION SYSTEM

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Abstract

The regenerative extraction system with the electromagnetic channel is used in the JINR phasotron at present time. The extraction efficiency of 50% is determined by the septum thickness which is about 5 mm. It is suggested to supplement the extraction system with an electrostatic deflector, which will provide additional orbit separation by this value, and thus to increase the extraction efficiency to 90%. The paper reports the results of the computer simulation of the beam dynamics in this system.

Two elements are now used to build-up radial oscillations of particles in the region of final radii of the accelerator - a peeler (P) and a regenerator (R). Their main parameters were chosen in |I|. The study of the regenerative extraction system showed that the necessary build-up of the radial oscillations is provided without changing the axial dimension of the beam The experimentally obtained particle extraction efficiency was $\simeq$ 50%

To increase the efficiency of beam jumping in the EMC, a new element - the electrostatic deflector (ESC) - is supposed to be added to the extraction system. The calculations for the regenerative extraction systems of synchrocyclotrons Uppsala-Sc and Orsay-Sc showed that an element like this can increase the beam extraction efficiency to $\simeq$ 95% instead of $\simeq$ 60% for radial amplitudes of not more than several millimetres. It is evident that the parameters of the electrostatic deflector and its position in the extraction system play an important part in achieving this efficiency. For example, at Uppsala-Sc it is placed in front of the peeler, its length is l=40 cm, septum thickness is δ=0.5 mm, angular length is $\Delta\theta$=20°, radial aperture is Δr=5 mm. The channel radius is R=I20 cm, the high-voltage electrode potential is V=60 kV. At Orsay-Sc the electrostatic deflector was planned to be in front of the extraction channel current section and to have the following parameters: l=40 cm, $\Delta\theta$=I6°, R=I40 cm, V=83 kV, Δr=I5 mm.

The problem of finding the parameters of the electrostatic deflector for the JINR phasotron was solved by several steps. First there were some theoretical estimations.

Let $\rho(\theta)$ be the particle trajectory in the last turn. The transverse momentum $\Delta p_\perp$ acquired by the particle at length l of the electrostatic deflector and directed along the electric field is

$$\Delta p_\perp = \frac{eEl}{\beta c}$$

where e is the electron charge, E is the electric field strength, c is the speed of light, $\beta = v/c$, v is the particle velocity. For l=43 cm, E=60 kV/cm and kinetic energy 662 MeV the particle trajectory rotation angle is

$$\alpha \cong \frac{\Delta p_\perp}{p_o} \simeq 2.6 \text{ mrad},$$

where p_o is the particle momentum at the ESC inlet. Deviation of the particle trajectory from the initial one at the ESC outlet is

$$\Delta\rho = \alpha \cdot l/2 \simeq 0.6 \text{ mm}.$$

For simplicity, it is assumed that the electric field is uniform along the electrostatic deflector.

Let us estimate possible azimuthal positions of the ESC bearing in mind that the EMC inlet is at the azimuth θ_{ch} = I° (see Fig. I), where the increase in turn separation must be $\simeq$4 mm.

Let us assume that in the first approximation the particle trajectory change after passing through the ESC is a sinusoid. Then, considering that the frequency of free radial oscillations is close to one, we obtain for the new trajectory

$$\tilde{\rho}(\theta) = \rho(\theta) + (R\alpha)\cdot \sin(\theta - \theta_o)$$

where θ_o is the unknown azimuth corresponding to the centre of ESC, R is the deflector radius.

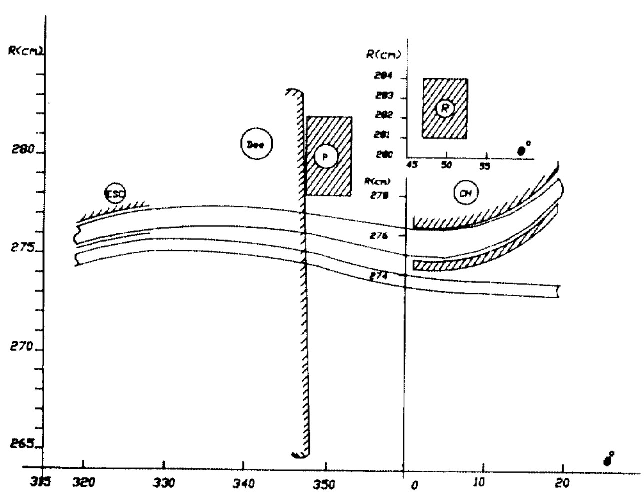

Fig. I. Lay-out of the JINR phasotron extraction system with the electrostatic deflector.

Since $\Delta\rho = \widetilde{\rho}(\theta_{ch}) - \rho(\theta_{ch}) = 4$ mm, we obtain $\theta_o^{(I)} \simeq 49.5°$ and $\theta_o^{(2)} \simeq 130.5°$ at $\alpha < 0$, and $\theta_o^{(I)} \simeq 310.5°$ and $\theta_o^{(2)} \simeq 229.5°$ at $\alpha > 0$.

The azimuth values at 0 are preferable, because they correspond to the negative potential of the deflector plates. Thus, its maximum permissible value can be increased and operation stability ensured The possibilities of installing the ESC inside the dee of the JINR phasotron was already discussed in connection with the project of electrostatic beam extraction |9|. As seen below, in our case the problem becomes much simpler owing to a much smaller azimuthal length of the ESC and the use of the existing beam build-up and deflection system without any changes. Bearing these considerations in mind we dwell upon the azimuth value $\theta_o \simeq 310.5°$.

Numeric calculation by the REGZ programme on the CDC-6500 computer confirmed the analytical estimations and allowed more precise position of the ESC to be found (see Table I).

Then the radial position of the electrostatic deflector was calculated by taking into account the behaviour of the beam envelope ($\simeq$ 70 particles) at the last and last but one turns in the range of initial radial amplitudes A_r = 0.5-2 cm with the step ΔA_r = 0.5 cm. It allowed us to install the ESC plates as shown in Fig. I and Table I. Note that trajectories of the particles lost in the deflector septum are not shown in Fig. I.

Fig. 2 shows the distribution of the particle density over the radius at the EMC inlet during regenerative build-up. There is only the interval of radii near the beam deflection system (the last 3 turns). The electrostatic deflector is clearly seen to affect the changes in the particle distribution structure which lead to smaller losses in the EMC septum owing to separation of the last turn from the internal beam after passing through the ESC.

Fig. 3 shows the effect of the ESC on beam jumping in the EMC. Noteworthy is that the beam jump in the extraction channel increases from I.52 cm to I.88 cm. Besides, the increasing dispersion in the distribution in the beam over the jump values is worth mentioning. It can be partly explained by an increase in the number of particles within the radial EMC aperture owing to the ESC. It means that the appropriate tuning of the EMC, (P), (R) and ESC to the optimum position is necessary. As expected, neither the mean calculated energy W = 662 MeV, nor the energy spread of particles at the EMC inlet $\Delta W = \pm 2.5$ MeV calculated for the given RF phase changed when the electrostatic deflector was installed. The same can be said about the ESC effect on the particle RF phases.

The extraction efficiency at the EMC mouth was calculated on the assumption that particles are equally distributed over the initial amplitudes according to the following formula:

Table I. Coordinates of the external surface of the first plate of the electrostatic deflector

θ^o	3I9	320	32I	322	323	324	325	326	327	328
(R-275) (cm)	0.20	0.3I	0.42	0.52	0.62	0.7I	0.80	0.85	0.93	0.97

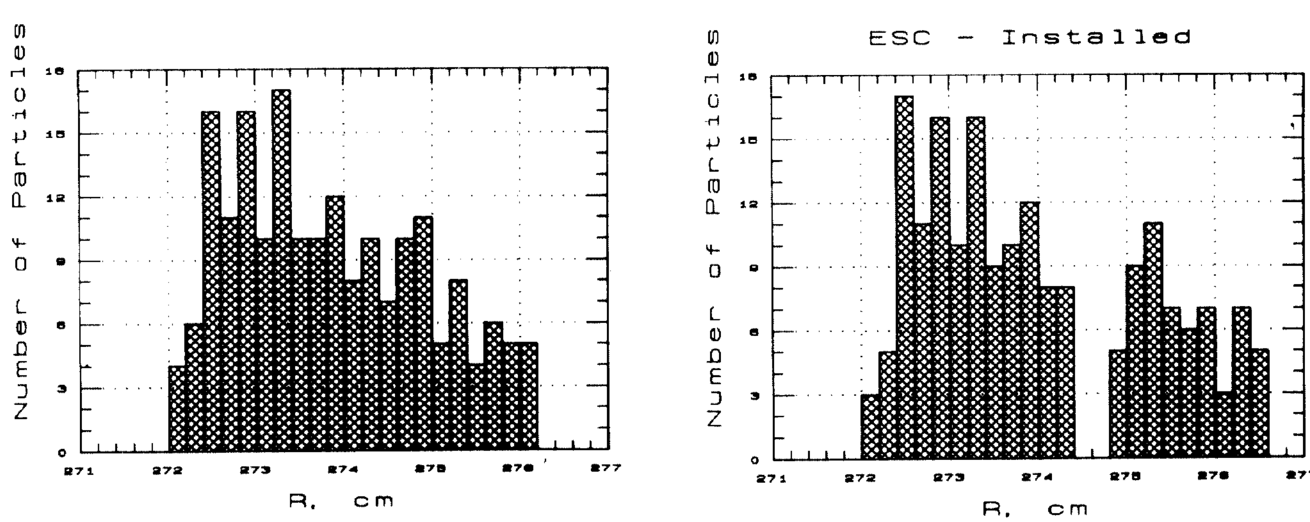

Fig. 2. Distribution of particles over the radius at the channel inlet for the last 3 turns: a) without ESC, b) with allowance for ESC.

Table 2. Parameters of the electrostatic deflector

Angular length (deg.)	I0
Length (cm)	43
Radial aperture (mm)	I4.3
Septum thickness (mm)	0.I
Effective septum thickness (mm)	0.5
Electric field strength (kV/cm)	60
Potential (kV)	86

$$\varepsilon = \frac{1}{A_{r_{max}} \cdot A_{z_{max}}} \cdot \int_0^{A_{r_{max}}} \int_0^{A_{z_{max}}} \sigma(A_r, A_z)\, dA_r\, dA_z$$

Here $\sigma(A_r,A_z) = \dfrac{n^k(A_r,A_z)}{n^\circ(A_r,A_z)}$, $n^k(A_r,A_z)$ is the number of particles with the initial amplitudes A_r, A_z which arrived in the channel without losses, $n^\circ(A_r,A_z)$ is the total number of particles with amplitudes A_r, A_z.

The values of $\sigma(A_r,A_z)$ were obtained by the REGZ programme with $A_{r_{max}}$ = 2 cm, amplitude step ΔA_r = 0.5 cm, $A_{z_{max}}$ = I cm, step ΔA_z = 0.I cm.

The calculation showed $\simeq$ I.7-fold increase in the jumping efficiency. It was (80% ± 5%) with allowance for the losses in the ESC septum and EMC, the losses at the ESC being $\simeq$ I0%. Losses at the EMC inlet are the same. The injection coefficient can be further increased with the optimum tuning of the radial oscillation build-up system.

The basic ESC characteristics are listed in Table 2. The parameters of the extraction system elements remained unchanged. It is seen that the potential of the high-voltage electrode of the deflector is much higher than the actual one (60 kV with the leak current 30 μA) achieved in the experimental study of the electric strength of the 4 m electrostatic deflector in the JINR phasotron Yet, increasing the azimuthal dimension of the ESC from the optimum (Table 2) to $\Delta\theta$ =23° allows the required ESC potential to be reduced to 37 kV. According to the calculations, in this case the orbit separation at the entrance to the ESC after the main system of radial oscillation build-up is still large enough ($\simeq$ 5 mm) to allow an effective injection in the ESC. In this case the head part of the manufactured and tested electrostatic deflector for the JINR phasotron could be used as the ESC

Conclusions

I. The parameters and optimum position of the electrostatic deflector in the extraction system of the JINR phasotron has been determined by means of the beam dynamics calculations with allowance for the present characteristics of the extraction system elements.

2. With the electrostatic deflector, the number of particles which effectively jump over the EMC septum increased by a factor of I.6-I.7.

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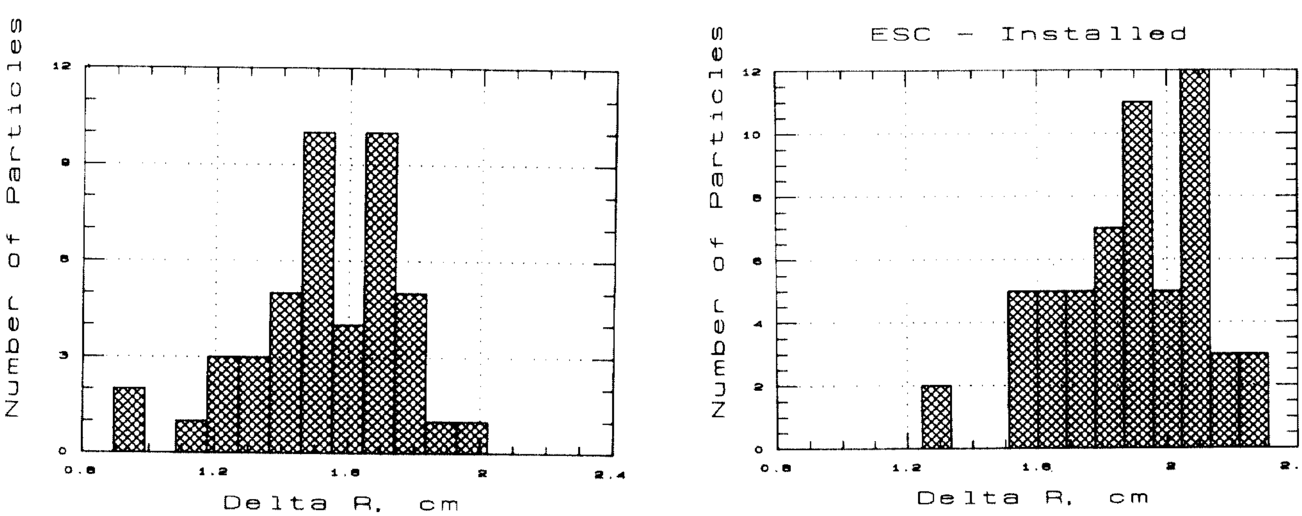

Fig. 3. Distribution of particles over the EMC septum jump values:
a) without ESC, b) with allowance for ESC.