INJECTION IN CRYRING

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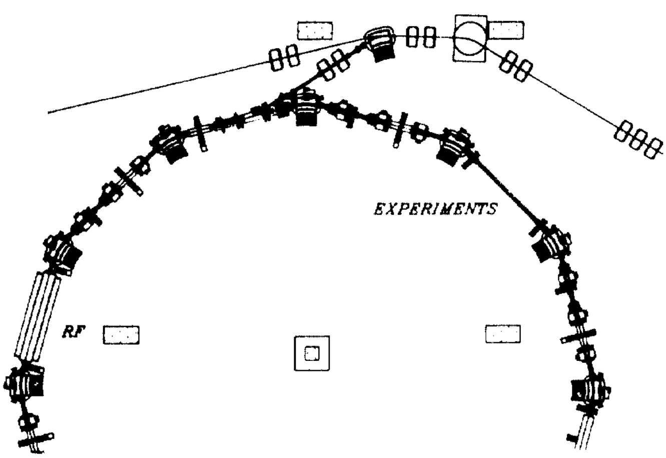
Abstract

Ten turn horizontal injection in CRYRING is studied. Computer simulations and the design of the injection section will be presented. The efficiency calculations are made with a Monte-Carlo method where the injected ions are Gaussian distributed. The injection efficiency will be about 85%. The losses depend mainly on the large dispersion, 1.6 m. In order not to exceed the space charge limit the vertical emittance might have to be enlarged. The closed orbit will be shifted locally at the injection section with electrostatic kickers.

A Bird's Eye View

CRYRING will be a 52 m long synchrotron/storage ring for highly charged heavy ions. The incoming beam comes from an EBIS ion source and is accelerated by an RFQ to 300 keV/u. q/A (charge/nucleon) is at least 0.25.

Figure 1.



Part of CRYRING with injection.

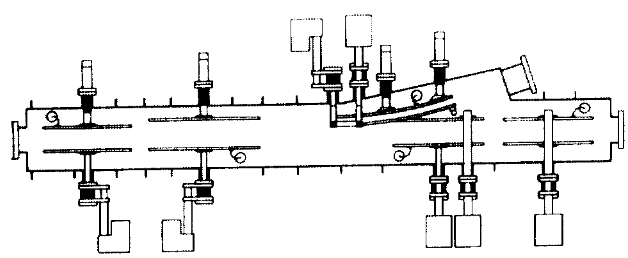
The other parameters for the incoming beam is a bit uncertain, but we assume the following values: $\varepsilon_x=5\pi\,\mu$m·rad, a 70 μs long pulse and $200\pi\,\mu$m·rad horizontal acceptance (90 mm good field in the quadrupoles, dp/p = $5\cdot10^{-3}$). 70 μs gives a 500 m long pulse. The 90 mm aperture includes field errors, $200\pi\,\mu$m·rad corresponds to 70 mm aperture without field errors.

The basic theory for multiturn injection is well known, and is found e.g. in [1]. Since the injection energy is low, it is possible to use electrostatic kickers instead of magnets. These are cheaper and easier to ramp down. We will use four kickers, all on the injection straight section. The closed orbit should be moved 30 mm when the injection starts.

Later we will inject low-charged ions from a platform. These are easier to move with electric fields than with magnetic. The magnetic rigidity for U^+ from a 400 kV platform is 1.4 Tm so large magnets would have been needed.

It is not necessary to use four kickers to guide the beam, you could manage with only one or two. One advantage with four kickers is that Q_x can be changed without problem. With fewer kickers you have to fix the phase between the kicker(s) and the injection point. Another is that the beam is not affected outside the injection section.

Figure 2.



Kickers and injection channel.

Space Charge

The maximum number of ions it is possible to have in the ring is limited by the incoherent tune shift at injection energy and is approximately $4\cdot10^{11}/A$. ($\delta Q=0.25$, q/A=0.25). This assumes that the vertical emittance is $100\pi\,\mu$m·rad. But ε_y in the injected beam is only $5\pi\,\mu$m·rad so we need to dilute the beam. We plan to do this with a vertical kicker in the incoming beam.

Another way to use this emittance asymmetry is to excite the resonance Q_x-Q_y=0 with a solenoid or skew quadrupoles. This will transfer energy, or emittance, from the horizontal plane to the vertical and will increase the efficiency. [2]

The Injection Program

This program simulates the injection and gives the user a powerful tool to study the influence from different parameters, e.g. Q-values, injected beam shape or septum thickness.

The tracking routine assumes a linear lattice, so a standard transformation [3] can be used.

$$\eta = \eta_0 \cos Q\psi + p_0 \sin Q\psi + \frac{D}{\sqrt{\beta}}\frac{dp}{p}$$

$$p = \frac{1}{Q}\frac{d\eta}{d\psi} = -\eta_0 \sin Q\psi + p_0 \cos Q\psi$$

The particle moves on a circle in η-p space.

A short summary of the program:

1. Generate 100 ions in the incoming beam with Gaussian distributed emittances and momenta.
2. Calculate the corresponding coordinates in the ring for the ions. Those which hit the outside of the septum are lost.
3. Move the closed orbit.
4. Track all particles one turn. Those which hit the inside of the septum are lost.
5. Repeat 1-4 ten times.
6. Move the closed orbit a few more turns and track until no more ions are lost.

Validity of the Model

The model of the injection which is used in the computer code is simple and neglects several effects. Here is a short analysis of the most important.

Space charge. The incoherent Q-shift is not included. We don't know how large the the intensity will be, and anyway, the space charge is largest in the end when the losses are small.

Sextupoles. The program assumes a perfectly linear lattice, which is resonable since the ions are only followed in 20 turns, and our sextupoles will be rather weak.

The intensity of the incoming beam is treated as a step function which not is correct. The intensity will be lower in the beginning and in the end. But, since we don't plan to change any parameters during the injection this doesn't matter very much. The calculated efficiencies will be too low, but because we only use the values to find the best settings this is not important.

Gaussian distributions are chosen for simplicity although the actual distribution probably will be parabolic.

Efficiency Calculations

How many ions will survive the injection and which are the optimal settings of different parameters? This problem is too complex to be treated analytically, so the computer program is used to simulate the injection.

The optimal settings depends strongly on the lattice parameters (Q_x, β-values,..) [4]

In the simulations normally 100 or 1000 particles are injected each turn during ten turns. The result is presented both graphically and numerically.

It is not easy to find the best solution, the maximum of a non-analytical function of six parameters. After a more or less systematical search the following parameters are suggested. These are values in the beamline, not in the ring.

β_x	1.3 m	
D_x	− 0.3 m	dispersion
$\frac{dD_x}{ds}$	0.3	
α_x	0.3	
dxp	−0.5 mrad	angle beam-closed orbit
dx	3.0 mm	dist. beam center-septum

The table below shows the efficiencies for some different cases. You can see that the maximum is not very narrow. In the first three cases one of the parameters is changed. In the next three the injected beam is different. Finally the last case has a different working point.

This table gives the efficiency after 30 turns. (10·1000 ions injected).

change	efficiency
none	84 %
$D_x = 0$	82 %
dxp = 0 mrad	83 %
dx = 4.0 mm	82 %
50 μs pulse	88 %
$\varepsilon_x = 10\pi$ μm·rad	72 %
dp/p = 0.25 %	92 %
$Q_x = 3.3$, $Q_y = 1.8$	91 %

The efficiency will probably be around 85 %.

The lost ions are mainly those injected early with high momentum. Due to the 1.6 m dispersion on the injection section these hit the septum after one or three turns (Q_x close to $2\frac{1}{3}$).

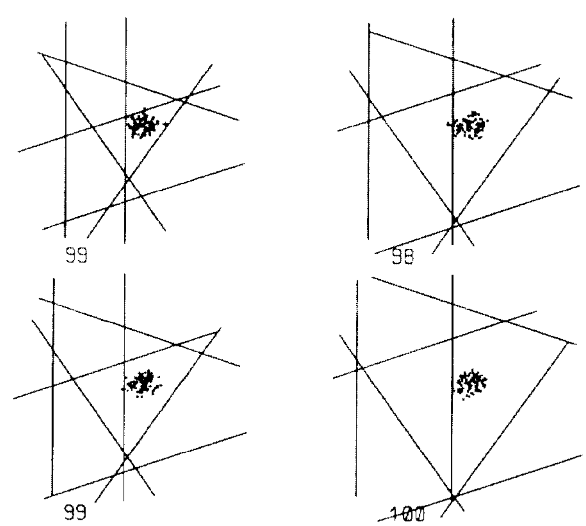
In the last case above the dispersion is much smaller (0.4 m) and so the losses.

Guide to the Plots

These phase space plots show the future for the injected particles at the point where they enter the ring. Instead of tracking the ions and plotting them at each turn the septum at each turn is projected backwards.

In these plots you can immediately see both the injected beam and the acceptance. If e.g. the angle is wrong then the particles come over or below the acceptance, or if α or β are wrong the injected beam and the acceptance have different shapes.

Figure 3.



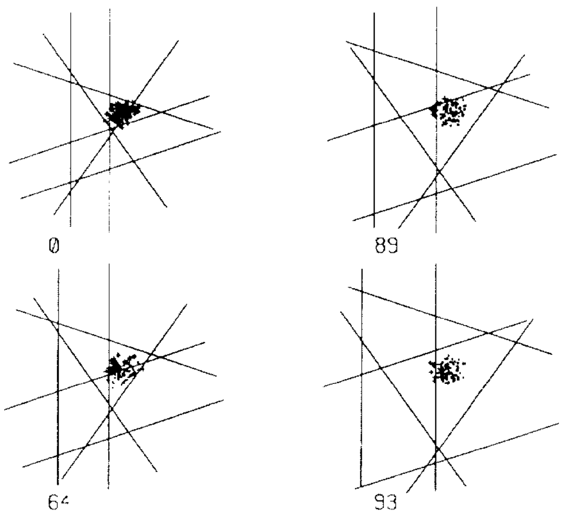
dp/p=0. First four turns. They are in the order $\begin{pmatrix}1 & 3\\ 2 & 4\end{pmatrix}$.

You need one plot series for every momentum, dp=-0.5%, dp=-0.4%....

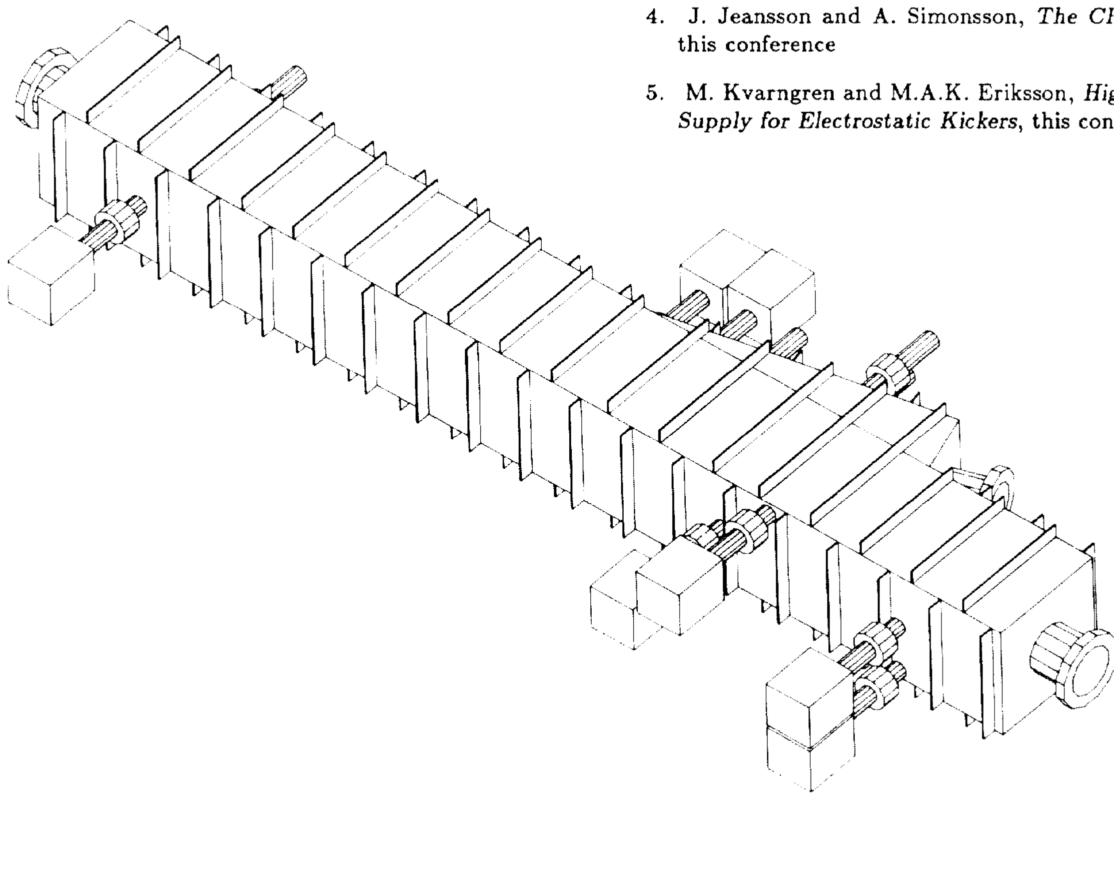
In every series the first plot shows the ions injected the first turn, the second those injected the second turn and so on.

The nuber in the lower left corner shows how many of the ions which will survive the injection.

Figure 4.



$dp/p=2\cdot 10^{-3}$.



Design Considerations

M. Nyberg has made drawings and most of the mechanical design.

The acceptance should not be smaller in the injection section than in the quadrupoles. The β-values are smaller in this section, so the real aperture can be smaller.

Length and gap for the kickers should be chosen so they can be fed by one power supply.

Stepping motors will be used to make final adjustments.

The ultra-high vacuum in the ring puts restrictions on the design. The unit should be bakeable to 300°C and preferably should all parts be made of stainless steel.

Voltages

During the injection the voltage should go from V_{max} to 0 in 50-100 μs (variable) to shift the central orbit back. V_{max} is negative and depends on q/A. The voltage need not be larger than 60 kV.

The power supply will be based on a standard pulse transformer. It is described in a separate contribution. [5]

To get a fast ramp down it is necessary to have as low capacitive load as possible.

References

1. G.H. Rees, *Injection*, CAS 84 CERN 85-9
2. K. Schindl and P. van der Stok, *Increase of Betatron Stacking Efficiency via Linear Coupling*, CERN 78-11
3. E. Wilson, *Transverse Beam Dynamics*, **74**, CAS 84
4. J. Jeansson and A. Simonsson, *The CRYRING Lattice*, this conference
5. M. Kvarngren and M.A.K. Eriksson, *High Voltage Power Supply for Electrostatic Kickers*, this conference