SLOW EXTRACTION FROM THE KAON FACTORY EXTENDER RING

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Summary

The Extender ring for the proposed KAON factory at TRIUMF will employ 1/3-integer resonant extraction to spill out the protons slowly and provide experiments with a continuous beam. An array of sextupoles is provided to excite the $3\nu_x = 34$ stopband. A combination of electrostatic and magnetic septa will guide the extracted beam into the beamline. Chromatic extraction, using the natural chromaticity of the ring to shift the tune towards the resonance, or achromatic extraction from a chromaticity-corrected machine using tune-shift quadrupoles, can be used to drive the particles into instability. Results of tracking studies show that by achromatic extraction an extracted emittance of less than 1 πmm-mrad can be achieved.

Introduction

The Extender ring for the proposed TRIUMF KAON factory will employ 1/3-integral resonant extraction using the $3\nu_x = 34$ resonance. The resonance will be driven by four sextupoles equally spaced in a "+-+-" pattern around the ring. With this particular pattern chromaticity control is decoupled from extraction control and also excitation of the $2\nu_y-\nu_x = 15$ resonance is avoided. For a given emittance ε of the circulating beam, septum location x_s and stepsize Δx at that position, the strength of the sextupoles as well as the tune-distance from the resonance can be found as follows.[1]

In normalized coordinates,

$$X = x/\sqrt{\beta} ,$$

$$P = -\sqrt{\beta}(x' + x\alpha/\beta) ,$$

the position of one of the unstable fixed points is given by

$$X_o = \sqrt{\frac{\pi\varepsilon}{\sqrt{3}}} , \quad P_o = \frac{X_o}{\sqrt{3}}$$

and the sextupole strength is given by

$$B''\ell = 16\pi \; A \; B\rho \; \beta^{-3/2} ,$$

where

$$A = \frac{\Delta X}{18\pi(X_s-X_o)} .$$

The tune distance from 1/3 is given by

$$(\nu-1/3) = 2\sqrt{3}\; AX_o$$

for the phase-space area of the stability triangle to be the same as the area occupied by the circulating beam.

For the electrostatic extraction septum, a distance of 28 mm from the centre of the beam was chosen and a thickness of 100 μm was assumed. To achieve a hit rate of 1% or less, the stepsize at septum position has to be 10 mm or larger. Figure 1 shows the extraction elements in the Extender lattice. The septum has been placed in a region with negative dispersion to allow chromatic extraction by lowering the momentum of the beam. The strength of the sextupoles is 0.1 m^{-2}.

Extraction can be performed in either achromatic or chromatic mode. In the first case, the chromaticity of the ring is corrected and the tune independent of the momentum of the particle, extracting the full momentum bite of the ring at any given instant during the extraction cycle. For a circulating-beam emittance of 4.6 πmm-mrad, extraction will start at a tune difference of 0.017 from the resonance. In case of chromatic extraction, the natural chromaticity of the ring of -14 will be retained and the stable area for each particle depends on its momentum as shown in Fig. 2. The extracted momentum bite can potentially be made as small as ±0.03%, although synchrotron oscillations may increase this value.

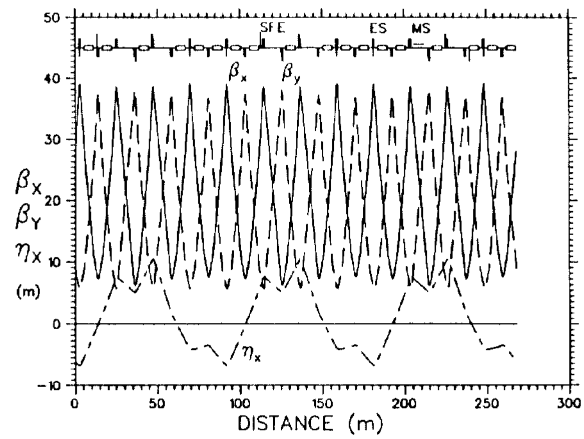

Fig. 1. Extraction elements in the Extender lattice. SFE is a sextupole, ES, MS are septa.

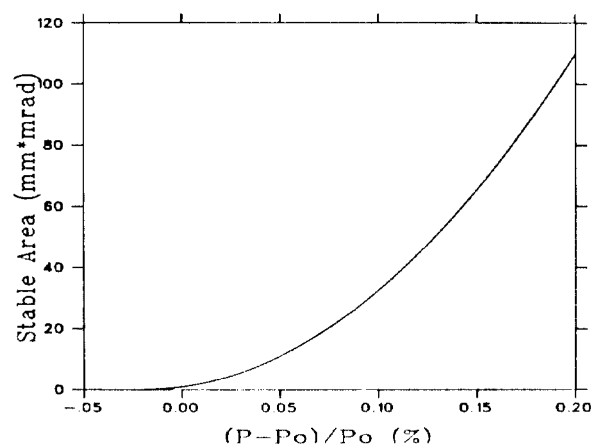

Fig. 2. Stable area as a fraction of beam momentum for natural chromaticity. Area of the circulating beam is 15 πmm-mrad.

Extraction Dynamics

Figure 3 shows the stability triangle at the onset of extraction, found by particle tracking using the program DIMAD.[2] A gap size of 17 mm is necessary to capture the extracted particles. The position of the extraction septum is indicated.

In order to determine the properties of the extracted beam and study the extraction dynamics, a program has been written that simulates the extraction process by integrating the equations of motion, taking into account synchrotron oscillation. Achromatic and chromatic extraction has been studied using this program with 2000 particles tracked over 2100 turns. Although the number of turns is about one-tenth of the

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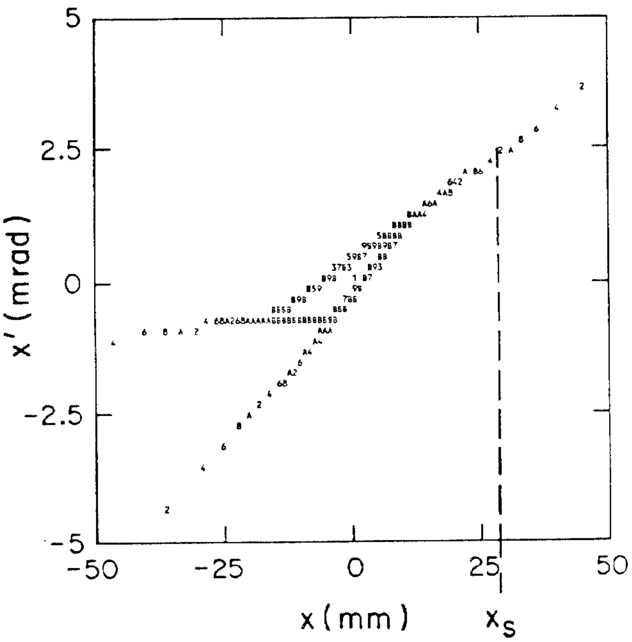

Fig. 3. Area of stability and separatrices in horizontal phase space. The septum is indicated by x_S.

actual number of turns in the ring, tests have shown this to be of little significance and the results presented here give a good description of the extraction process.

For achromatic extraction, Fig. 4 shows the macroscopic time structure of the beam using a tune-shift program that varies the tune according to a function of $(0.017-\Delta\nu)$ that takes partially into account the quadratic dependence of the stable area on the tune difference from the resonance. The duty factor is about 85%. The emittance of the extracted beam is about 1 πmm-mrad; this figure appears to be dominated by the chromaticity of the beta function at the extraction point. Momentum bite and microscopic time structure are the same as for the circulating beam, $\pm 0.16\%$ $\Delta p/p$ and 3 ns wide, since the machine is chromaticity corrected.

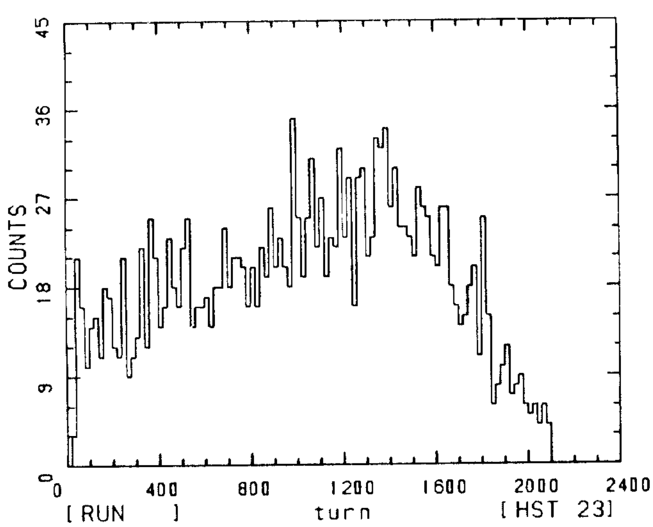

Fig. 4. Macroscopic time structure of the extracted beam for achromatic extraction.

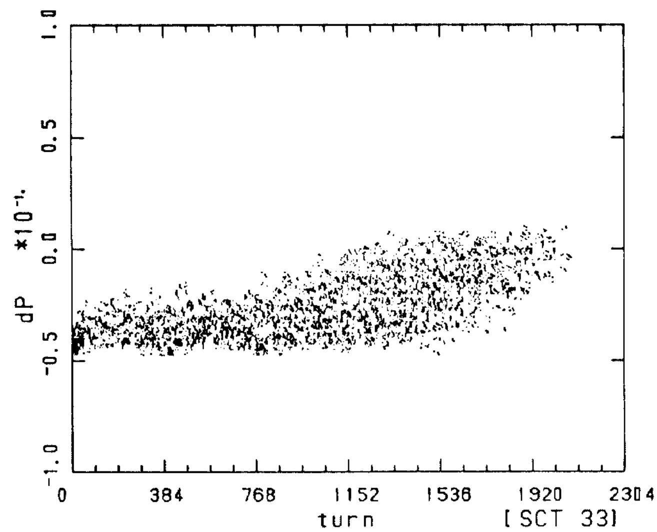

Fig. 5. Momentum deviation of the extracted beam from 30.9 GeV vs. turn number for chromatic extraction.

Extraction from a machine having natural chromaticity (about −14) has also been studied. Figure 5 shows the momentum of the extracted beam versus the turn number. As expected, the beam is extracted starting at low momentum. However, synchrotron oscillations disturb the process by allowing particles to re-enter the stable area, and the extracted momentum bite is broader than without synchrotron oscillations. Also, the emittance of the extracted beam is blown up to about 4 πmm-mrad. The duty factor is again about 85% with the time structure being similar to the previous case. Because particles at lower momenta have a smaller stable area than those at the reference momentum, extraction in this case starts already at a tune difference of about 0.03 from the resonance. It is planned to investigate chromatic extraction by reducing the momentum of the beam using the cavities provided in the ring. This avoids the change in momentum over extraction time that is apparent in Fig. 5. Figure 6 shows the longitudinal phase space occupied by the extracted beam. In addition to the reduced momentum bite there is also noticeable compression in the bunch length. In fact, the bunch length of the extracted beam is reduced by a factor of two to 1.5 ns.

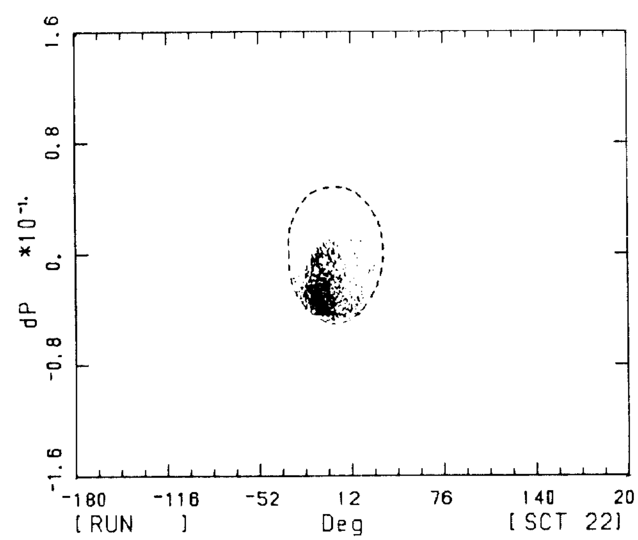

Fig. 6. Longitudinal phase space of extracted beam. Momentum deviation from 30.9 GeV/c is plotted vs. phase angle. The dashed oval is the area occupied by the circulating beam.

The electrostatic extraction septum will be about 5 m long in total, 2.5 m before and after the quadrupole, and have an electric field of 6.7 kV/cm. This gives the beam a total kick of 0.8 mrad, enough to achieve about 2 cm separation at the entrance of the first magnetic septum, located 90° apart of the extraction septum. This septum will be 3 m long with a field of 0.5 T. A second magnetic septum, 5 m long with a field of 1 T, will guide the beam into the beam line.

A well-known problem with 1/3-integral extraction is the fact that the stable area is zero only for a tune exactly on the resonance. Due to the finite time necessary for the unstable particles to get extracted, a small fraction of the beam will be recaptured after crossing the resonance and remain in the machine. Our simulations show this fraction, which has to be extracted using the fast abort system at the end of the cycle, to be of the order of 1-2% of the full intensity

Conclusion

A low-emittance beam with high duty factor will be available from the Extender ring using 1/3-integral slow extraction. The parameters necessary for the extraction system are given. Numerical simulations show that a duty factor of 75% or greater is achievable, while the emittance of the extracted beam in achromatic extraction is 1 πmm-mrad or less. The momentum distribution will be the same as that of the circulating beam, ±0.16% $\Delta p/p$. Chromatic extraction can improve the momentum bite, but more studies are necessary to determine the emittance of the extracted beam under this condition and find the smallest momentum bite possible.

Acknowledgement

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References

[1] K.R. Symon, Reports FN-130, FN-134, FN-140 and FN-144, Fermi National Laboratory (1968).

[2] R.V. Servranckx, K.L. Brown, L. Schachinger, and D. Douglas, "Users Guide to the Program DIMAD", Report 285 UC-28 (A), SLAC (1985).