SLOW BEAM EXTRACTION OF THE JAPANESE HADRON PROJECT

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Abstract

A beam stretcher scheme which is operated at 50 Hz for the extraction of high-intensity proton beam (100μA) of the Japanese Hadron Project is studied. The third-order resonance extraction is adopted, to overlap the outgoing separatrices of various emittances and reduce effective septum thickness. Having a finite chromaticity of ~ -0.05, tuning of the operating point to resonance is accomplished by the method of RF acceleration. Beam tracking studies have shown that the extraction of beams with emittances up to 30π mm · mrad is possible with this method, although the effect of space charge forces has not yet been taken into account in the simulation.

Introduction

The Japanese Hadron Project(JHP) aims at providing high-intensity proton beam, both bunched and stretched, at a kinetic energy of 1 GeV. The proton beam is delivered from a 1 GeV linac and is shaped as required in a compressor/stretcher ring. The proton beam from the linac is injected into two rf buckets of the ring. In the stretcher mode of operation, one bunch is extracted to the spallation neutron facility by fast extraction, and after that, another bunch is stretched and extracted slowly to the meson science facility. The time avaraged intensity is 200μA, which is shared between two facilities. The repetition rate of the system is supposed to be 50 Hz.[1]

A feature which should be reminded of in designing the present extraction system is that, because of high intensity, an emittance as high as 30π mm · mrad is required to relax the space charge effect on the stored beam. Another feature is a rather short extraction time (less than 20 ms), which is limited by high repetition.[2] The usual technique of shifting the operating point to resonance by changing the field strength of quadrupole magnets is too slow to be adopted in the present case. Therefore we propose a scheme of shifting the operating point through momentum change, which is fast enough to accomplish within the limited duration. Non-zero chromaticity should be needed in this scheme.

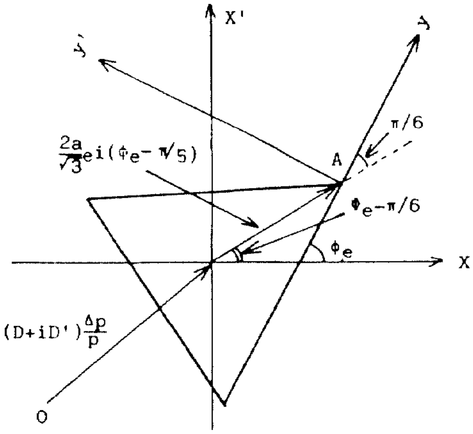

Fig. 1 Direction of outgoing separatrix in a normalized phase space at the azimuthal position of the first septum.

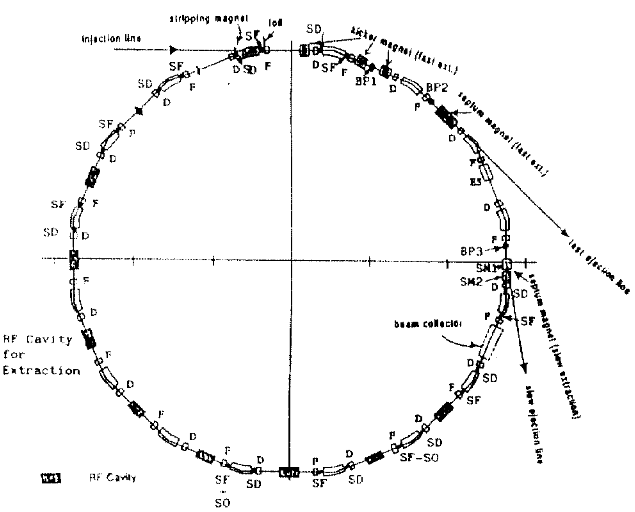

Fig. 2 Layout of the compressor/stretcher ring of the JHP and its equipments for slow beam extraction.

In order to reduce beam loss during the extraction process, it is required to attain a reasonably large turn separation, compared with the 'effective' thickness, seen by the beam, of the first thin septum. In this context, the direction of the outgoing beam should be kept constant as far as possible, during extraction. For this reason, a scheme to overlap outgoing separatrices at every instant by making use of the third order resonance extraction has been pursued in the JHP.

In the present paper, the basic concept of the scheme to overlap outgoing beams at the position of the first septum is described briefly at first. Then the slow beam extraction system adopted in the JHP is presented. Finally, typical results of beam tracking for this extraction system are given.

Condition of Overlapping Outgoing Separatrices

The condition of overlapping outgoing separatrices with various emittances, at the position of the first septum, is given by W. Hardt as follows;

$$\xi_H = -S/(D'\cos\phi_e - D\sin\phi_e)/4\pi Q, \qquad (1)$$

where ξ_H is the horizontal chromaticity defined by $(\Delta Q/Q)/(\Delta p/p)$, S the strength of the resonance exciting sextupole, ϕ_e the angle which the outgoing separatrix makes with the X coordinate of the normalized phase space(Fig. 1), D and D' the normalized dispersion function and its derivative. Q is the number of betatron oscillations per revolution. This condition is derived to get rid of amplitude dependence of the y' coordinate (Fig.1) of the unstable fixed point A on the outgoing separatrix.[3]

The angle ϕ_e is related to the betatron phases of the sextupole and the first septum (ψ_s and ψ_e, respectively) by the relation

$$\phi_e = \pi/6 + \psi_s - \psi_e . \qquad (2)$$

Since ϕ_e varies in principle with changes in betatron tune, the direction of y' axis itself rotates when observed in the laboratory frame to which the septum is fixed. In order to suppress the deviation of the direction of the outgoing beams originated by this rotation, it is necessary to locate the sextupole as close as possible to the septum and reduce the amount of rotation angle of the outgoing separatrix.

Slow Extraction System of the JHP

In Fig. 2, the layout of the compressor/stretcher ring of the JHP is shown together with the equipments for the slow extraction. The orbit bump to make the aperture minimum at the first septum(ES) is produced with three DC-excited bump magnets, BP1, BP2 and BP3, which are arranged to make no orbit distortion outside the region of these magnets. The chromaticity correction is made by sextupole magnets located between the dipole and quadrupole magnets. Cells in the bump orbit and their opposite ones do not include sextupoles in order that the production of the bump orbit does not interfere with the adjustment of chromaticities. Twofold symmetry is kept to compensate the contribution to the resonance of these sextupoles for chromaticity adjustment.

As shown in Fig. 2, two sextupole magnets(S_0 and $-S_0$) as the resonance exciter are located at the same position of superperiodicity of the main lattice with the same strength and opposite polarity in order to eliminate their contribution to chromaticities. In this case their effects as the resonance exciter can be replaced with a single effective sextupole magnet whose strength S and betatron phase ψ_s are related to the strength S_i and phase ψ_i of individual magnet by the relation[3]

$$S \cdot \exp(3i\psi_s) = \Sigma S_i \cdot \exp(3i\psi_i). \qquad (3)$$

In the present case, the effective sextupole locates almost 30° upstream of ES in betatron phase as illustrated in Fig. 3. The present configuration satisfies the above mentioned condition that the phase advance from the effective sextupole to the first septum should not be too large for alignment of the direction of the outgoing beam at the septum throughout the whole extraction process.

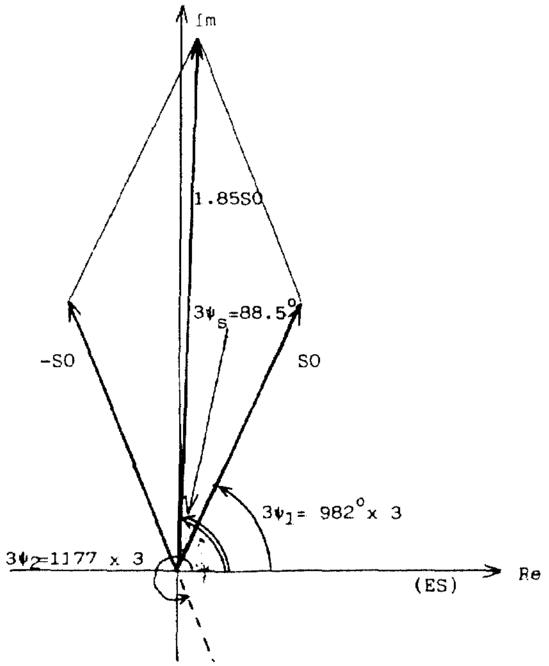

Fig. 3 Location of the effective sextupole relative to the first septum. The real axis is chosen to be the azimuth of ES.

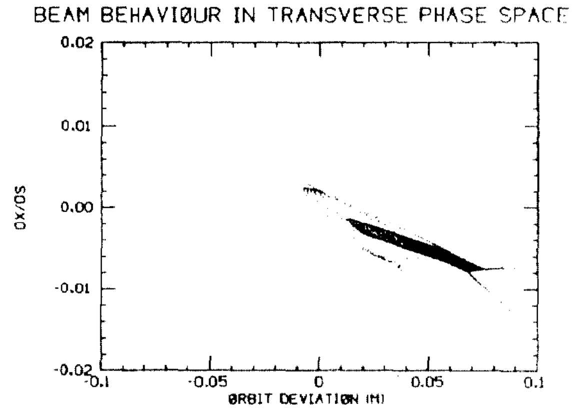

Fig. 4(a) Example of overlapping of outgoing separatrices between beams with different emittances. Horizontal chromaticity is corrected to be -0.052.

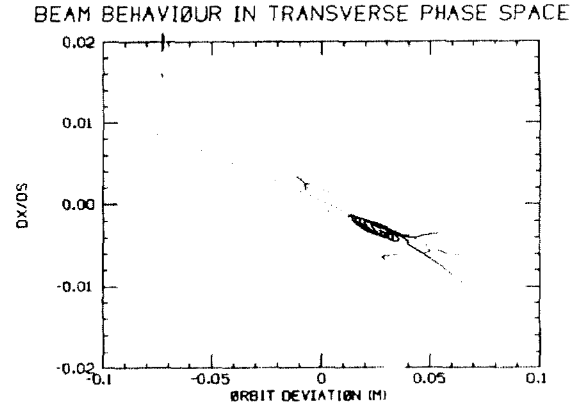

Fig. 4(b) Example of the case where the overlapping condition is not satisfied. Horizontal chromaticity is corrected to be -0.098 and all the other parameters are the same as Fig. 4(a).

Table 1

Equipments for JHP Slow Extraction

Bump Magnets	BP1	Deflection Angle -0.548 mrad
	BP2	〃 1.51 mrad
	BP3	〃 1.51 mrad
Sextupole Magnets		
Resonance Exciter		S_0 and $-S_0$ (S_0= 0.185 1/m^2)
Chromaticity Corrector		10 S_F (S_F= 0.216 1/m^2)
		10 S_D (S_D=-0.349 1/m^2)
Electrostatic Septum		E = 60 kV/cm, L = 2.5 m, Deflection Angle = 10 mrad Septum Thickness = 0.1 mm
Septum Magnets	SM1	B = 5 kG, L = 1.0 m, Deflection Angle=88.6 mrad Septum Thickness = 15 mm
	SM2	B = 10 kG, L = 1.0 m, Deflection Angle=177.8mrad Septum Thickness = 50 mm

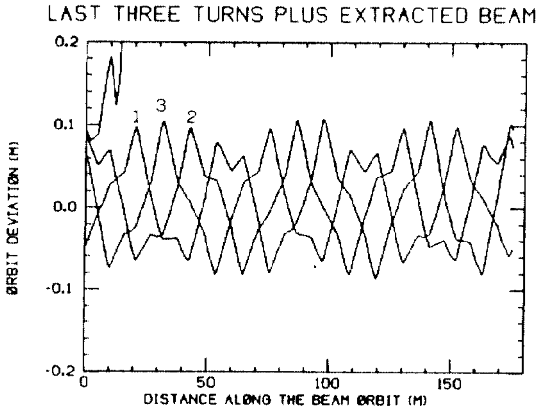

Fig. 5 Beam locations over the whole circumference in three turns just before the extraction and the locations of the extracted beam. The calculation corresponds to the case of Fig. 4(a). Numbers in the figure show the sequence in three turns before extraction.

The first septum is necessarily of an electrostatic type which utilize thin wires to reduce septum thickness.[4] For the present case of high intensity of 100 μA, the thickness of the septum should be reduced to an order of ten microns, which might require technical developments including additional use of separate preseptum[5] with shorter length and lower voltage. However it is not the scope of the present paper to discuss technical details and here we have assumed 60 kV/cm and 0.1 mm as electric field strength of ES and septum thickness, respectively. The length of the septum is assumed to be 2.5 m. As for septum magnets, we assumed 5 kG and 10 kG for SM1 and SM2 with septum thickness of 15 mm and 50 mm, respectively. In table 1, basic parameters of equipments for the slow extraction of the JHP are listed.

Another condition to determine the arrangement of the resonance exciter is the direction of the outgoing beam in the real space. In order to keep necessary space for the septum of the second septum of a magnet type, the direction of the outgoing beam at the first septum is required to be almost pararell to x axis. The arrangement shown in Fig. 2 satisfies also this condition as will be shown in the next section.

Beam Tracking

For the extraction system above mentioned, beam tracking has been performed. The calculation is based on the matrix formalism and the effect of the sextupole field is taken into account by the thin-lens approximation. In the calculation of the effect of RF acceleration, phase change due to momentum dependence on revolution period is taken into account.

The operating point of betatron tunes, at which the injection is performed, is chosen to be close to the resonance, so long as the beam stability is kept during injection. In the present case, the injection time of 400μs, which corresponds to about 600 turns around the ring, is needed to accumulate the designed intensity. In order to allow the beam circulate stably during this period, the distance of the operating point from the resonance should be greater than the critical value calculated from the following relation:

$$\Delta Q = |S|/8\pi \cdot 2/\sqrt{3} \cdot \sqrt{\pi \varepsilon /\sqrt{3}} \,. \qquad (4)$$

Here ε is the emittance of the circulating beam, and S is the strength of the resonance exciting sextupole. For the beam with an emittance of 30π mm · mrad, the operating point at injection should be apart from the resonance by at least 0.0031. In the case of Fig. 4, the operating point at injection is chosen to be (4.3380,3.25).

The chromaticity is corrected according to Eq.(1), to realize the overlapping condition of outgoing separatrices. An example shown in Fig. 4(a) is a result calculated with a chromaticity of -0.052. As is shown in the figure, beams with different emittances are overlapped, if the chromaticity is appropriately corrected. The corresponding chromaticity calculated with Eq.(1) is -0.058 which agrees fairly well with the one obtained in the simulation. If the chromaticity is different from the optimized value, the overlapping condition is destroyed, as shown in Fig. 4(b) where the chromaticity is -0.098.

Figure 5 shows the trajectories of the circulating beam at the last three turns before extraction and the extracted beam. Orbit parameters are the same as those in the case of Fig. 4(a) and the emittance of the circulating beam is 30π mm · mrad.

The turn separation at the first septum is calculated to be 9.6 mm and 4.7 mm for cases of circulating beam emittances of 30π mm · mrad and 0.5π mm · mrad, respectively, which causes a beam loss of a few percent if the thickness of the first septum is 0.1 mm as we have assumed. Further research and development is needed to make the effective septum thickness to be almost one order smaller as already mentioned in order to keep beam loss as low as 0.1%.

References

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