**PB30**

# Basic Design of an Asymmetric Double Slow Extraction System for the KEK-PS

Yoshihiko SHOJI, Katsumi MARUTSUKA, Takeshi TOYAMA and Hikaru SATO

National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

Simultaneous extraction to two beam lines of the KEK 12GeV Proton Synchrotron (KEK-PS) has been theoretically calculated. Unlike double extractions at other facilities, the two extraction lines are not equal in resonant phase. The test operation is also reported.

## INTRODUCTION

Resonant slow extraction is widely used in almost all existing synchrotrons. Some of them have two extraction lines, and extract beam to both that of lines simultaneously in order to save on the operation time. ZGS at ANL, reported by E. A. Crosbie and Y. Cho et al.[1], was initially designed for double extraction. Its two extraction lines were set just at opposite sides of the ring, and other elements were also symmetrically positioned. SPS at CERN, reported by M. Gyr et al.[2], had two lines which were not diametrically symmetric. In order to realize equality of the two lines in resonant phase, they divided the set of F-quadrupoles into 2 halves and excited them with slightly different currents. At the KEK-PS the new slow extraction line (EP1)[3] for the newly built North Counter Hall was constructed in 1991, besides the EP2 for the East Counter Hall. The present lay-out of the KEK-PS is shown in Figure 1. Each extraction line has its own independent extraction system designed for single extraction; they are not symmetrically positioned. However, strong request for a longer machine time makes double extraction an urgent theme. We report on the possibility of double extraction with minimum change to the present system.

## BASIC DESIGN OF DOUBLE EXTRACTION

The extraction system of the KEK-PS was designed based on theoretical studies by K. Endo and C. Steinbach [4], utilizing the half-integer resonance ($2\nu_h=15$). One perturbing quadrupole magnet (EQ) is inserted into the lattice in order to produce a half-integer stop-band. One octupole magnet (OCT) is excited in order to separate phase space into stable and unstable regions. The tune is then approached slowly to the half-integer, the stable region becomes ever smaller, and particles are ejected from the machine. The shaved beam at the first septum, ESS (electro-static septum), is deflected by 5 magnetic septa (named SeptumA, B, C, D and E)(Figure 2) and guided to the extraction channel.

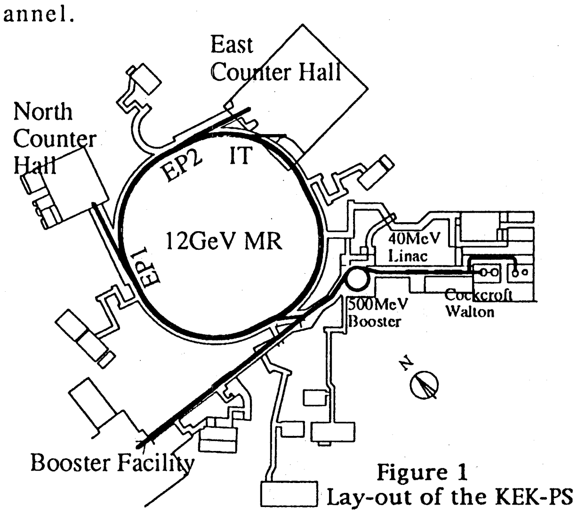



Figure 1
Lay-out of the KEK-PS

A resonant phase at the ESS is $2\mu j$, where $\mu j$ is the betatron phase advance from the ESS to EQ. It determines the perturbation to the twiss parameters ($\alpha$, $\beta$ and $\gamma$) and the angle of the outgoing separatrix. In normalized phase space,

$$\Delta Y/\Delta X|_{X=0} = \tan\mu j = \sin(2\mu j)/[1+\cos(2\mu j)] \quad (1)$$

Here, X and Y are coordinates defined by the following well-known equations:

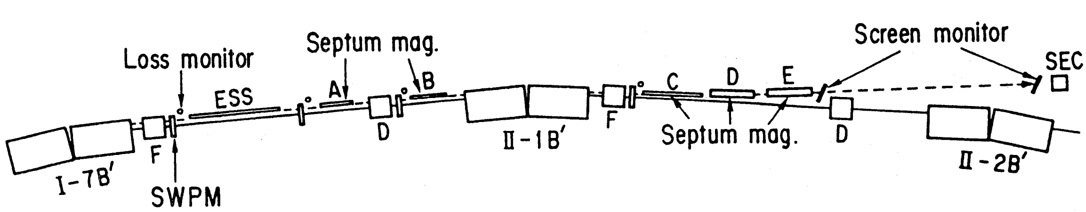



Figure 2 Septum array of a slow extraction line (EP1).

$$X \equiv x/\sqrt{\beta}$$
$$Y \equiv \sqrt{\beta}\ [\,x' + (\beta/\alpha)x\,]\,, \qquad (2)$$

where $\alpha$ and $\beta$ are the unperturbed twiss parameters. An unperturbed lattice means that EQ is zero, and thus has no half-integer stop-band. The $2\mu j$ is $(3/8)\pi$ at single extraction, as shown in Figure 3. In order to guide the extracted beam through the septum array $2\mu j$ must satisfy

$$0 < 2\mu j < \pi\ . \qquad (3)$$

When $2\mu j = \pi$ (the perturbed beta function is smallest) the outgoing separatrix arm would hardly reach to the ESS. On the other hand, when $2\mu j$ is less than 0 (the perturbed beta function is maximum at $2\mu$ i=0) the circulating and the extracted beam would not have a sufficient turn separation at the down stream septum. For double extraction, both EP1 and EP2 should satisfy equation (3). A solution could exist because the resonant-phase differnce between EP1 and EP2 is $\Delta(2\mu j) = -\pi/2$.

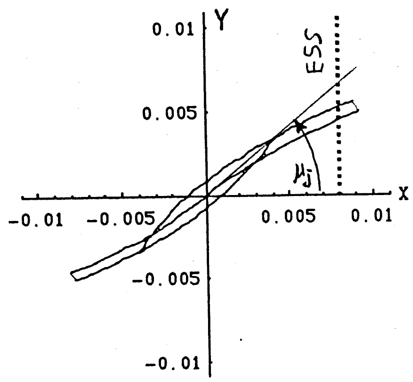



Figure 3 Separatrix in normalized phase space.

The next step was to perform a single-particle tracking simulation. The main lattice magnets (56 quadrupoles and 48 dipooles) wereused in the calculation as thick lens matrices. Their higher order components were approximated with two thin multipoles set at both ends of each magnet. Sextupole magnets for chromaticity control and perturbations (EQ and OCT) were approximated as thin-lens components. The strengths of EQ, OCT and the sextupoles were set at the values used for a single extraction (their strengths were 0.03 $m^{-1}$ and 4.0 $m^{-3}$, respectively [5] and the horizontal chromaticity was -6). We calculated the outgoing separatrix lines in the x-x' plane of two particles. One has a Courant-Snyder invariant of zero and a momentum displacement of -0.08%; the other has a Courant-Snyder invariant of $3\pi$ mm mrad and a +0.08% momentum displacement. Figure 4 (b) shows the separatrices of single extraction. Here, ESS was set so that the step-size was about 10mm. Figure 4 (a) shows the separatrices at EP1 when EQ and OCT of EP2 were used. Figure 4 (c) shows separatrices at the EP2 when EQ and OCT of EP1 were used. The resonant phase ($2\mu j$) is $-\pi/8$, $(3/8)\pi$ and $(7/8)\pi$ for (a), (b) and (c), respectively. Table I shows the performance of extraction in three cases. Case (b) was the best. Although case (c) was acceptable, case (a) was not. Therefore, the setting of EQ and OCT for EP1 is one possible solution.

For double extraction it would be important to enlarge the step-size because the same step-size would be shared with two extraction channels. We calculated two ways to enlarge the step-size. One way is to also excite OCT for EP2 besides OCT for EP1. Another is to set the ESS far from the equilibrium orbit (identical to reducing the bump height). As listed in Table II, the first way is better because the step-sizes at EP1 and EP2 were well balanced.

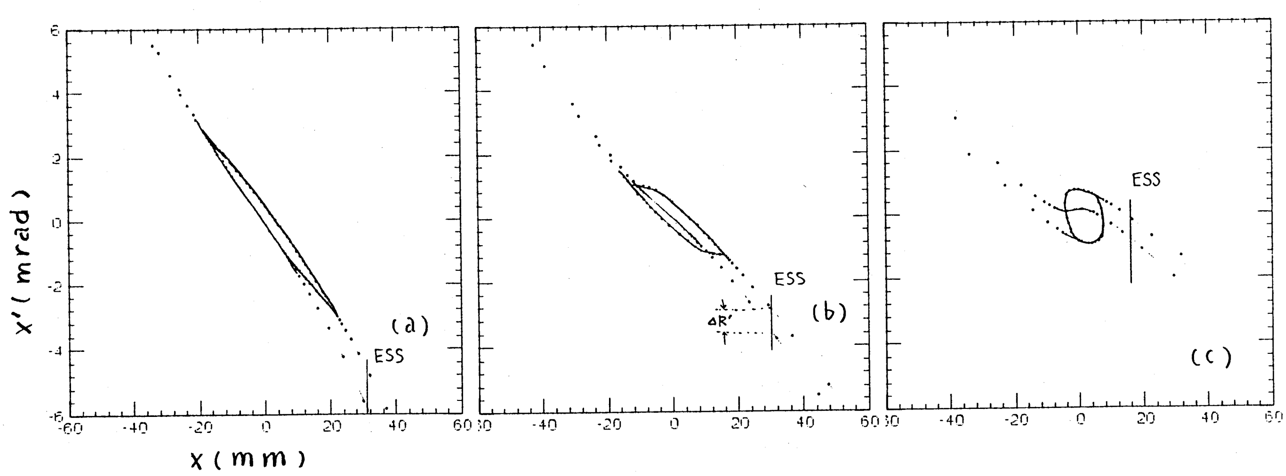



Figure 4 Separatrix at the ESS edge
(a) Separatrix at EP1 when EQ and OCT for EP2 are excited.
(b) Separatrix at EP2 when EQ and OCT for EP2 are excited or at EP1 when EQ and OCT for EP1 is excited.
(c) Separatrix at EP2 when EQ and OCT for EP1 are excited.

Table I Extraction parameters at the entrance of the ESSs of EP1 and EP2.

| | | | |
|---|---|---|---|
| perturbation for EP2 | EP1 | EP2 | |
| perturbation for EP1 | | EP2 | EP1 |
| Picture in Figure 3 | (a) | (b) | (c) |
| resonant phase $2\mu j$ (rad) | $-\pi/8$ | $(3/8)\pi$ | $(7/8)\pi$ |
| Extraction Bump (mm) | 13 | 15 | 29 |
| (mrad) | 1.1 | -1.2 | -3.9 |
| step-size (mm) | 7.5 | 9 | 6 |
| angle divergence (mrad) | 1.23 | 0.65 | 0.63 |
| Expected beam loss (%) | 22% | 4% | 5% |
| emittance (mm mrad) | $4.6\pi$ | $2.9\pi$ | $1.9\pi$ |

Table II Extension of the step-size by (1) exciting OCT of EP2 or by (2) lowering the extraction bump.

| method | (1) | | (2) | |
|---|---|---|---|---|
| extraction line | EP1 | EP2 | EP1 | EP2 |
| Bump height (mm) | 15 | 28 | 10 | 25 |
| step-size (mm) | 9.5 | 8.5 | 11 | 8 |

## EXPERIMENTAL RESULTS

For double extraction we started from single extraction for EP1, and then gradually raised the local bump orbit for EP2 to share the step-size of the extracted beam. Here, the servo-spill control system [6] for EP1 was used. The extracted beam intensity for EP1 and for EP2 changed with the bump height at EP2, as shown in Figure 5. The required bump height of EP2 was higher by 16mm and steeper by 4mrad than that of EP1, as had been predicted. However, the step-size at EP2 appeared to have a long tail, which was not expected.

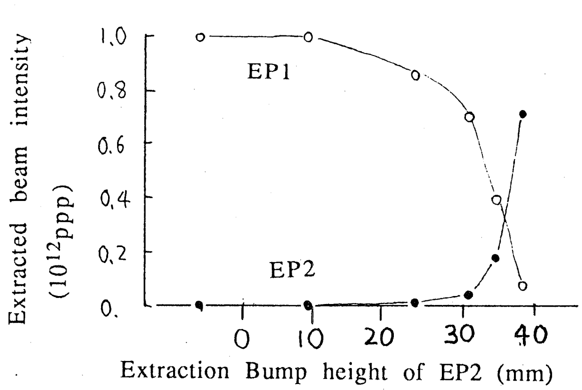
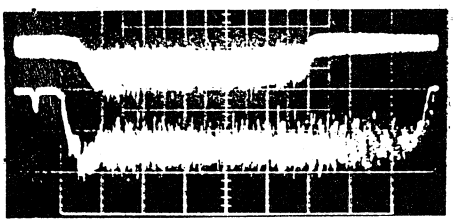



Figure 5 Bump height of EP2 and the extracted beam ratio while the bump of EP1 is kept constant.

After a delicate adjustment of the extraction elements the beam losses at each of the extraction channels were about 1.5-times those of single extraction (totally 3 times). The losses were less depended on the extraction ratio. Figure 6 shows the spill structure of a doubly extracted beam to EP1 and to EP2 with an intensity ratio of 1 to 4. The parasitic use of an internal target (triple extraction) was also successful.

Under long-term operation, double extraction was less stable to same external disturbance than single extraction. External disturbances, such as drifting of the magnetic field or emittance change due to the condition of the injectors, easily change the intensity ratio of EP1 to EP2, because they are asymmetric. To stabilize double extraction for daily operation, we need another kind of feed-back system.



EP1 ($2.2\times10^{11}$ppp)
EP2 ($1.3\times10^{12}$ppp)
MR ($1.6\times10^{12}$ppp)

Figure 6 Spill structures of doubly extracted beam. The spill was controlled only for EP1. Their lengths were different because the heat tolerances were different at EP1 and at EP2 [1].

When a very small amount of the beam was extracted to EP2 (less than a twentieth of EP1), double extraction was stable because of the long tail of the step-size at EP2. However this was though to be scattered protons mainly at the magnetic septa of EP1, which therefore would when the beam loss at EP1 is improved.

## CONCLUSION

We succeeded to extract beams to two lines within a short period (less than a day). For its daily use, an improvement of the servo control system or of more stabilization of the entire machine is desired.

Although this solution is not the best, it is possibly a solution involving a minimum change of the present system. If we can afford other resonances, $\nu h=20/3$ or $\nu h=16/3$ there might be better solutions, where the resonant phases ($3\mu j$) of EP1 and EP2 are identical. However, we should redesign most of the system for the third-integer resonant extraction.

## REFERENCES

[1] E.A.Crosbie et al.,Proc. of 1973 IEEE PAC, p434
Y. Cho et al., Proc. of HEACC 1974, p.451,
[2] M. Gyr et al., Proc. of 1985 IEEE PAC, p2997.
[3] Y. Shoji et al, Proc. of the 8-th Symp. on Acc. Sci. & Tech., 1991, p.281.
[4] K. Endo and C. Steinbach, KEK-77-13. 1973.
[5] Y. Shoji et al., KEK-Report 93-10, 1993.
[6] H. Sato et al, Prpc. of 1992 HEACC, p.495.