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γ_T- CHANGE IN THE KEK 12 GeV-PS

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Introduction

The beam intensity of the KEK 12 GeV-PS is presently $\sim 4 \times 10^{12}$ ppp and its deviation is ~ 7 % in short time. But the stability of the spill of the extracted beam is not so good. The origin of this problem is unstable acceleration due to transition crossing at $\gamma \simeq 6.5$.

For the intensity, the increase by ten times is investigated, but the space charge limit is estimated about 2×10^{13} ppp (500 MeV injection) and 6.5×10^{13} ppp (1 GeV injection) where the horizontal and vertical emittances are 80 and 20 πmm-mrad., the tune spread is 0.25 and the bunching factor is 0.3. The Keil-Schnell criteria give the limits as, for the transversal stability with zero-chromaticity:

$$N_\perp < 1.4 \times 10^{15}\ \beta\gamma|\eta|\ \Delta p/p \quad ,$$

for the longitudinal stability:

$$N_\parallel < 8.8 \times 10^{19}\ \beta^2\gamma|\eta|\ (\Delta p/p)^2 \quad ,$$

where β and γ are the Lorentz kinematical factors, $\eta = \gamma_T^{-2} - \gamma^{-2}$, and $\Delta p/p$ is the FWHM of the momentum spread of the beam. In the above the impedances are roughly estimated from the transversal head-tail instability at 500 MeV,

$$Z_\perp(\omega) \simeq 2 \times 10^5\ (\Omega/m) \quad , \quad Z_\parallel(\omega)/n \simeq 30\ (\Omega) \quad .$$

At present, the injection energy is 500 MeV and typically $\Delta p/p = 0.15$ %, then $N_\perp < 10^{11}$. To overcome this limit, the non-zero chromaticity scheme and the Landau damping by the octupole magnets are adopted. Figure 1 shows the stable area of $|\eta|$ where $N_\parallel \max \geq 2.6 \times 10^{13}$ with $\Delta p/p = 0.1$ %. The present value of $|\eta|$ is also plotted in the same figure. From this it is easily understood why the transition crossing is so harmful in stable acceleration even with the γ_T-jump, which is shown in Fig. 2.

To avoid these problems, the 1-GeV injection scheme is now discussed, but the most important key is to remove the transition crossing by changing γ_T.

How to change γ_T

The lattice structure of the KEK 12 GeV-PS is given in Table 1. Changing the phase advance per cell, γ_T is limitted as

$$1.5\ (20°\ \text{cell}) \leq \gamma_T \leq 9.5\ (180°\ \text{cell}) \quad .$$

Because the configuration of the ring should not be changed, the quadrupole perturbation must be introduced to wiggle the momentum dispersion function D (which is noted as η by Courant and Snyder.) This results in a shorter circumference for the particle with high momentum than the one in the unperturbed ring, that is, the value of γ_T becomes large or pure imaginary.

An simple perturbation is the quadrupole doublets[1] in each superperiod which is shown in Fig. 3 for $\gamma_T \simeq 200$. The locations of the doublets are also shown in it. The doublet consists of a pair of quadrupoles which are located at the points mutually 180° away in the betatron phase, where the beta function are the same, $\beta_1 (\simeq 15$ m), and the momentum dispersion function are D_1 and D_2, in order to localize the perturbation of β. Then the perturbed γ_T is given

$$\gamma_T^{-2} = \gamma_{To}^{-2}\left[1 + \frac{\gamma_{To}^2}{2\pi R}\frac{N}{\rho}\left(\frac{R}{\nu}\right)^{3/2}\sqrt{\beta_1}\,K \times \{-(D_1 - D_2) + \beta_1 K(D_1 + D_2)\cot\frac{\pi\nu}{N}\}\right] \quad ,$$

and

$$\beta_{max} = \beta_{0max}\ (1 + \beta_1 K)$$

where K is the strength of each quadrupole, that is, $K = (B'\ell/B\rho)_1 = -(B'\ell/B\rho)_2$, N is the superperiodicity, R is the averaged radius of the ring, ρ is the bending radius and ν is the tune. In this scheme, the vertical tune will be chosen to be near the horizontal one to minimize the perturbation in its plane. The typical value of K to obtain a very high γ_T (or an imaginary γ_T) is,

$$K(T/m) \simeq 0.08\ (\nu \simeq 7.2)\ \text{or}\ 0.06\ (\nu \simeq 7.4)$$

This method is limitted by the aperture at 5F and 6F which is easily seen from Fig. 3.

The other method is controlling J_p[2] defined by Courant and Snyder. Using the smooth approximation, γ_T is given by

$$\gamma_T^{-2} = \gamma_{To}^{-2}\left[1 + 9\nu^4/(2\pi^2)\sum_{p>0}|J_p|^2(4\nu^2-p^2)^{-2}(\nu^2-p^2)^{-1}\right] ,$$

$$J_p = \int_0^{2\pi R}(\beta B'/B\rho)\exp(-ip\phi)ds \quad .$$

From Table 1, one can easily see that this ring has the periodicity of 28 in quadrupoles, so that the Fourier components with $p = 2m$ ($1 \leq m \leq 7$) or $p = 7n$ ($n = 1, 2$) are easily controlled. The lattice is suitably designed for $\nu \simeq 7$, that is, the phase advance per cell is almost 90°, therefore the excitation of J_7 is most effective by 14 quadrupoles and in such a case J_{14} is not excited automatically, and the perturbation of β will be small because of $2\nu \simeq 14$. Then from the above expression, it is seen that

$$\begin{pmatrix} \nu > 7 \\ \nu < 7 \end{pmatrix} \text{ to make } \gamma_T \begin{pmatrix} \text{smaller} \\ \text{larger} \end{pmatrix} \text{ than } \gamma_{To} \quad ,$$

and

$$K(T/m) \geq 0.15\ \{\text{or}\ 0.11\}\ \text{for}\ \gamma_T < 1.53\ (500\ \text{MeV})$$
$$\{\text{or}\ \gamma_T < 2.07\ (1\ \text{GeV})\}\ \text{with}\ \nu \simeq 7.2 \quad ,$$

also

$$K(T/m) > 0.03 \quad \text{for} \quad \gamma_T \gtrsim 200 \quad \text{with} \quad \nu \simeq 6.87 \quad .$$

Figure 4 shows the latter case. This scheme is limitted by the large D at the perturbation quadrupoles and the maximum D is almost linear to the magnitude of K.

The comparison of the two methods, "doublet" and "harmonic", is given in Table 2.

Scheme in progress

The doublet scheme is adopted because of the smaller number of magnets and the consistency with the half-integer slow extraction system. The injected beam would have the emittances ($\pi\varepsilon_x$ and $\pi\varepsilon_y$) of $\varepsilon_x \simeq$ 80 and $\varepsilon_y \simeq$ 30 mm-mrad., and the momentum spread of $\Delta p/p$(FWHM) $\simeq$ 1 % to reach the space charge limit, so that the change of γ_T should be done after enough adiabatic damping by acceleration to keep the beam size less than the aperture, ± 50 mm horizontally and ± 25 mm vertically. The excitation curve of the perturbation quadrupoles and the resultant γ_T are shown in Fig. 5, then also η stays in the stable area of Fig. 1. The beam size at 12 GeV is expected as $|x| \lesssim 38$ (mm) and $|y| < 10$ (mm) with the RF acceleration voltage of 80 kV. The momentum dispersion function at the extraction septum is rather large, i.e., D $\simeq$ 4.5 (m), but this will be no problem because the stable acceleration will be certainly realized. The most serious problem is the beam loading. The increase of the RF voltage to about 115 kV seems rather easy and the more essential improvement is also been discussed.

The two pairs of the doublet is installed in this June and the experiment with beam will be done. The full pairs, i.e., four pairs, will be completed before the end of this fiscal year and the success would be hoped in the next year.

References

1) W. Hardt, CERN/MPS/DL/70-16 (1970), CERN/MPS/DL/71-7 (1971), CERN/MPS/DL/74-3 (1974).
2) L.C. Teng, FN-207 (1970). S. Ohnuma, Fermilab P-Note 105 (1980).

Table 1

Superperiodicity		4
One period		L L N N N N N
L-cell		(F)01(D)02(B)03
N-cell		(F)02(B)03(D)02(B)03
Drift Space	01:	5.445 m
	02:	1.809 m
	03:	0.369 m
Magnets	(F):	Focussing Quad., 0.615 m
	(D):	Defocussing Quad., 0.615 m
	(B):	Bending Dipole, 3.273 m

Table 2

	Doublet	Harmonic
Magnet No. at $\gamma_T \simeq 200$,	8	14
β_x max (m)	50	23
β_y max (m)	28	21
D max (m)	6	15

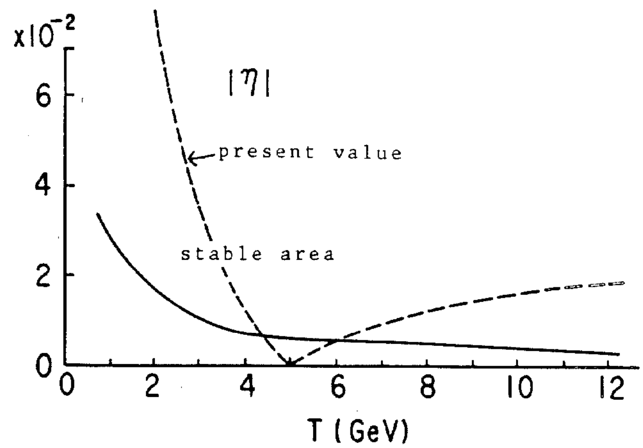

Fig. 1 η vs. acceleration energy.

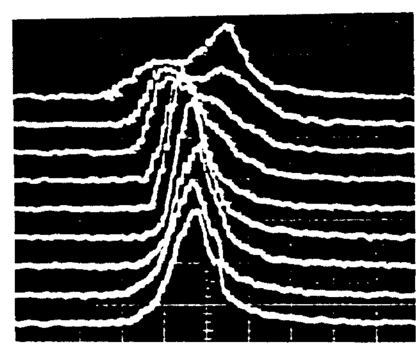

Fig. 2 Bunch shape near the transition crossing (The horizontal display is 20 nsec/div.)

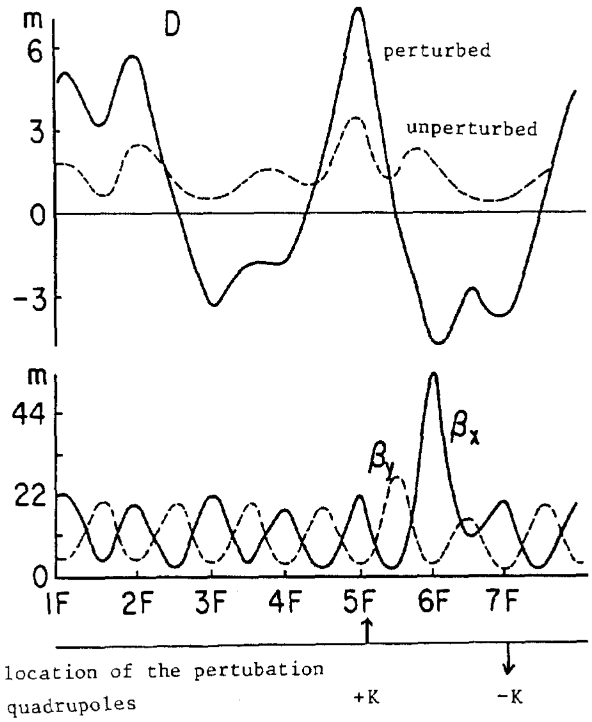

Fig. 3 Betatron oscillation parameters in one superperiod when γ_T is about 200 in the doublet scheme.

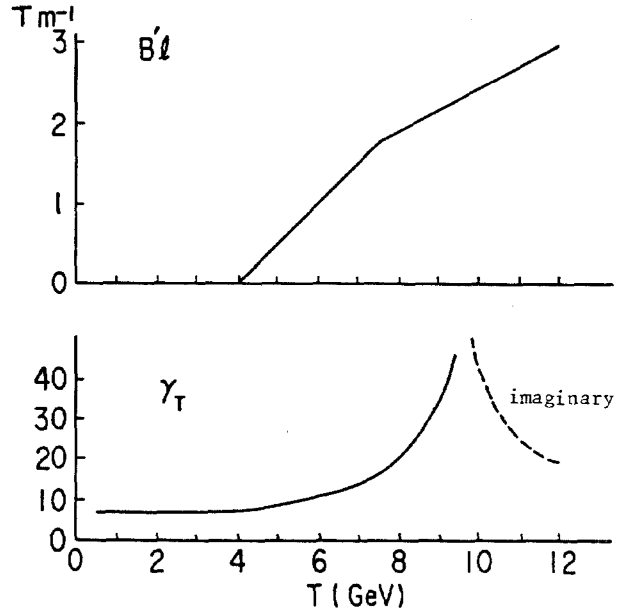

Fig. 5 Excitation curve of the doublet and the resultant γ_T.

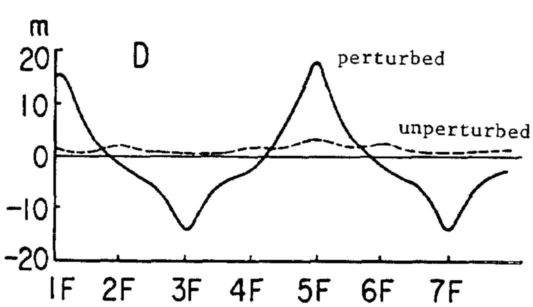

Fig. 4 Dispersion function in one superperiod when $\gamma_T \simeq 200$ in the harmonic scheme.