



feedback system which monitors the intensities of gamma rays of the two beam lines.

First we consider the case that there is one target in the ring and the dispersion function at the target is so small that the energy spread does not affect the beam size. The electron beam stored in the ring has a natural emittance due to quantum excitations by synchrotron radiations.<sup>2</sup> Fig. 2 illustrates the emittance at the target position in the horizontal phase space  $(x, x')$ . The emittance is represented by an ellipse determined by the Twiss parameters.

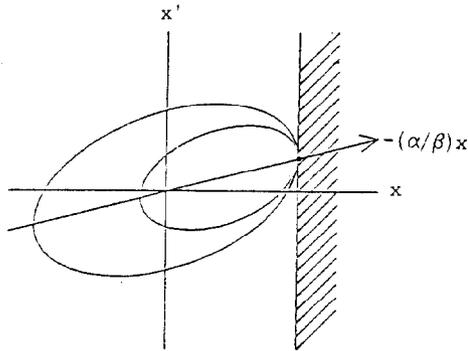


Fig. 2

The horizontal emittance of electron beam at a target. The hatched area means the target. As the beam current decays, the beam is made closer to the target in the direction of the arrow.

Every electron whose betatron amplitude is larger than the separation between the target and the center of the orbit collides with the target within several turns and converts its energy to gamma ray. The target has a sufficient thickness to drop an electron from the orbit by one collision, thus the edge of the emittance ellipse gets to contact with the target. The circulating electrons slightly diffuse from the inside to the outside of the ellipse to keep the natural emittance, so the collisions continue at the same point in the phase space, the edge of the ellipse. It means that we get a gamma ray which is radiated from a fixed position with a fixed angle. Although the electron is relativistic and emits a gamma ray in the direction of motion, the multiple scattering passing through the target causes a spread of the direction of the radiated gamma ray.

The generation rate of the gamma ray is proportional to the decay rate of the electron beam. The decay time  $\tau$  is estimated by the quantum life time

$$\tau = \tau_x (s_0^2/s^2) \exp(s^2/2s_0^2),$$

where  $s_0$ ,  $s$ , and  $\tau_x$  are the natural beam size, the separation of the beam center from the target, and the horizontal radiation damping time, respectively. We suppose  $s$  is much larger than  $s_0$ . (An expression for the case there is a dispersion is shown in Ref. [3]) The beam current and the intensity of gamma ray decay exponentially with the decay time  $\tau$ . To keep the intensity at a constant value we make the orbit closer to the target as the beam current decays and change  $\tau$  keeping a relation

$$-dI/dt = I/\tau = \text{const.} = I_0/T,$$

where  $I$ ,  $I_0$ , and  $T$  denote the beam current, the initial current, and the time needed for extracting all stored electrons, respectively. When we move the orbit, we have to keep the colliding point unchanged in the phase

space. This requires that the orbit must be moved along the line  $dx'/dx = -\alpha/\beta$ , which is shown by the arrow in Fig. 2.

We have two targets in the ring and operate them simultaneously. In this case each generation rate of gamma ray is no longer determined by its quantum life time written in the above equation; even if the orbit keeps the distance constant from one target, the generation rate is affected by the distance between the orbit and the other target. The ratio of the generation rates depends on their relative position in the phase space. For our purpose of operation it is not necessary to obtain an exact expression of the generation rates, because we use a feedback system which monitors the intensities of the two gamma rays and controls the orbit. The feedback is done independently for the two targets; it makes the orbit close to or apart from the target if each gamma-ray intensity is lower or higher than each desired value. This is a sufficient system although a change of the separation at one target may affect the intensity of the other target.

### Control System

We operate the target system automatically by the control computers of TRISTAN. We developed a program which controls whole process of a machine cycle, i.e., injection, acceleration, gamma ray extraction, and deceleration (standardization of magnets). During the cycle, the two targets are set at their pre-fixed places, almost 12 mm from the orbit center, and not changed. At injection we make a horizontal bump orbit near the targets to avoid the collision of the injected beam which has a large betatron oscillation amplitude. The amplitude of the bump orbit is -5 mm at both targets.

After acceleration we make horizontal and vertical bump orbits near the targets. The vertical orbit is used to cancel C.O.D. and not changed during the

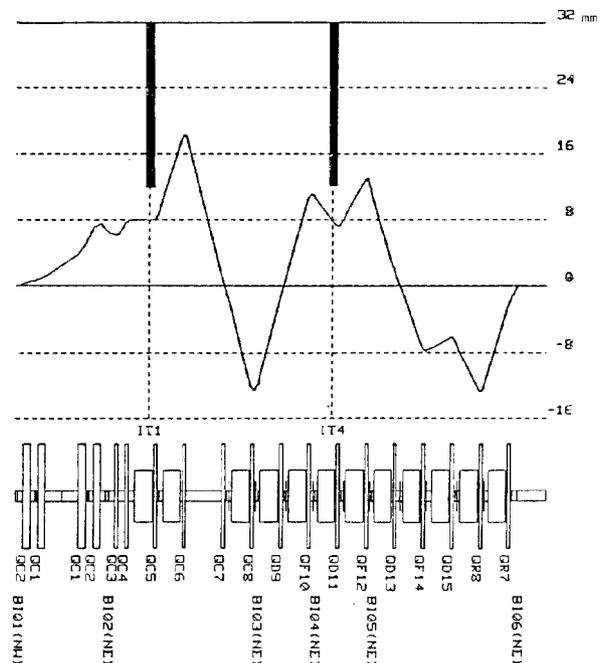


Fig. 3

The horizontal start orbit, made by six steering magnets from BI01(NW) to BI06(NE). The lattice of the AR is also shown. The targets are drawn by the vertical bars.

extraction. The control of intensities is done by moving the horizontal orbit. We installed six steering magnets to make the bump orbit as shown in Fig. 3. We can control the positions and the angles at both targets without affecting the orbit of the other places in the ring.

Fig. 3 also shows the horizontal start orbit, which is typically 4 mm apart from each target. After making the start orbit, the program starts the feedback. It monitors the gamma ray intensity of each target by the thick chamber and increases/decreases the horizontal orbit by its own amount in a feedback cycle if the intensity is lower/higher than the desired value. The orbit position is changed by typically 0.02 mm per feedback cycle, and its angle is so determined to keep the colliding angle constant in the direction of the arrow shown in Fig. 2. The feedback is repeated until the beam current becomes less than 0.1 mA.

The program also corrects the start orbit every time after a machine cycle to make the initial intensity close to the desired value and to decrease the settling time of the orbit. Each user of the beam line can open/close the beam gate independently at any time. When the gate is closed, the program makes the orbit 2 mm farther from the target to switch off the gamma ray and to save the stored electron beam.

The program is coded in KEK NODAL interpreter language<sup>4</sup>, which has a lot of facilities to write a multi-computer program. Although four computers are required to do the whole target operation, all processes are written in one target program unit using the facilities. The speed of the feedback cycle, typically 100 msec/cycle, is mainly determined by the response time of the network with the KEK NODAL interpreter. The orbit parameters and the excitations of the magnets are also calculated by a program written in KEK NODAL, and can be changed by the operator at any time.

### Results

In the run from May 1984 to February 1985 the typical extraction rate was 3.3 mA/min when two targets were operated. We injected and stored 20 mA electrons by a cycle, and it took 6 minutes to extract the gamma ray when the beam was used continuously. Actually the users often switched off the extraction to exchange the detectors, hence usually it took more than 30 minutes. It also took 2 minutes and 30 seconds in each cycle for injection, acceleration, and the others, so the duty factor was more than 90%. We accelerated electrons to 5 GeV. The change of orbits during an extraction from 20 mA to 0.1 mA was almost 0.9 mm at both targets.

TABLE I

beam energy	5.0	GeV	
$\tau_x$	5.4	msec	
damping time of			
synchrotron oscillation	2.6	msec	
relative energy spread	$8.8 \times 10^{-4}$		
	IT1	IT4	
$\beta_x$	3.79	3.79	m
$\alpha_x$	0.34	0.88	
dispersion function	0.14	0.74	m
derivative of			
dispersion function	0.10	-0.01	
horizontal beam size	0.82	1.03	mm

Table I lists some beam parameters at both targets. The dispersion is small at IT1 and the momentum spread does not affect the beam size. At IT4 the beam size is increased 20% by the momentum spread. This may cause a spread of collision angle at the target, and a deviation of the direction of the gamma ray even if the orbit is changed along the line  $dx'/dx = -\alpha/\beta$ . The spread of the radiation angle is  $9 \times 10^{-5}$  mrad and is much smaller than that caused by multiple scattering, which is 0.7 mrad. The amount of the deviation of the direction is almost equal to the spread, hence we did not take this effect into account in the run. Fig. 4 shows the spill of gamma rays under the feedback system. In this example two targets were operated simultaneously and continuously. The variations of the intensities were about 6%, and were sufficiently small for the users.

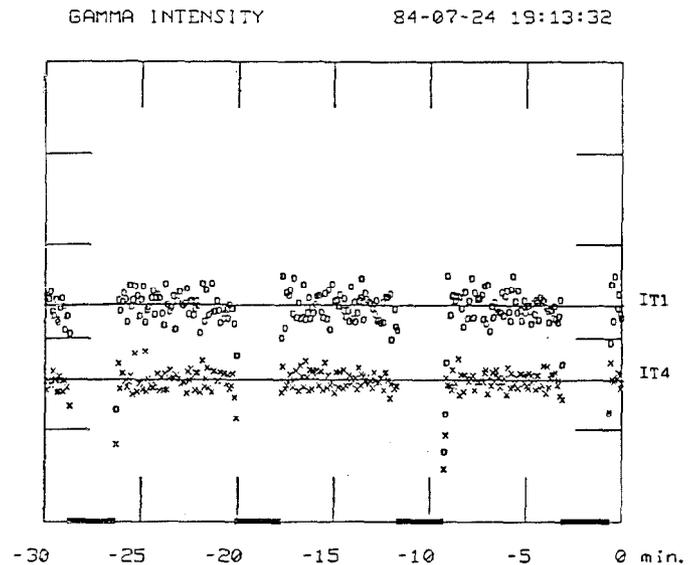


Fig. 4

The gamma ray intensities controlled by the feedback system. Two symbols o and x denote the intensity of IT1 and IT4, respectively. The desired value for each target is shown by the horizontal line.

### References

- [1] R. Sugahara *et al.*, "Automatic Calibration System for TOPAZ Barrel Lead Glass Calorimeter Modules", KEK preprint 84-23, March 1985
- [2] M. Sands, "The physics of electron storage rings an introduction", SLAC-121, 1970
- [3] A. W. Chao, "Electron Beam Lifetime Due to Horizontal Aperture Limitation", PEP-214, 1977
- [4] A. Akiyama *et al.*, "Computer Control System of TRISTAN", in Proceedings of the Europhysics Conference, Computing in Accelerator Design and Operation, 1983