Gamma ray source using internal targets in the TRISTAN accumulation ring

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INTRODUCTION

Two detectors for high energy physics experiments called TOPAZ and VENUS are to be installed in the TRISTAN main ring. They have several thousands of lead glass counters as calorimeters. Each counter needs calibration using electron beams of several GeV before the installation. Such high energy electron beams were obtained in the KEK 12 GeV proton synchrotron, which is, however, at present not operational due to the construction of the TRISTAN project.

As an alternative electron source the TRISTAN accumulation ring (AR) is now operational, and is able to accelerate and store electron beams of more than 5 GeV. We planned to extract high energy gamma rays by inserting a internal target into the AR, because a direct beam extraction is not easy. Two gamma ray lines are prepared by the two detector groups. Each detector group has its own target and gamma ray line. It is also required that the gamma rays should be simultaneously produced at the two targets with the least interference between them. The circulating electron beams gradually collide with the target and produce gamma rays, which are extracted from the AR through a Be-foil window. By a converter the gamma ray is changed into high energy electrons and positrons, which are finally used for the calibration of the lead glass counter. The momentum of the electron beam is defined by an analyzer magnet.

At present two gamma ray lines, IT1 and IT4, are available as shown in Fig. 1, and are able to produce the electron beams for the two detector groups simultaneously.

TARGET SYSTEM

Each internal target is located in the beam duct at a bending magnet gap and inserted horizontally from the outside of the beam orbit. The target is suffered from enormous synchrotron radiation and hence is made of molybdenum which is heat-resistive and easy to

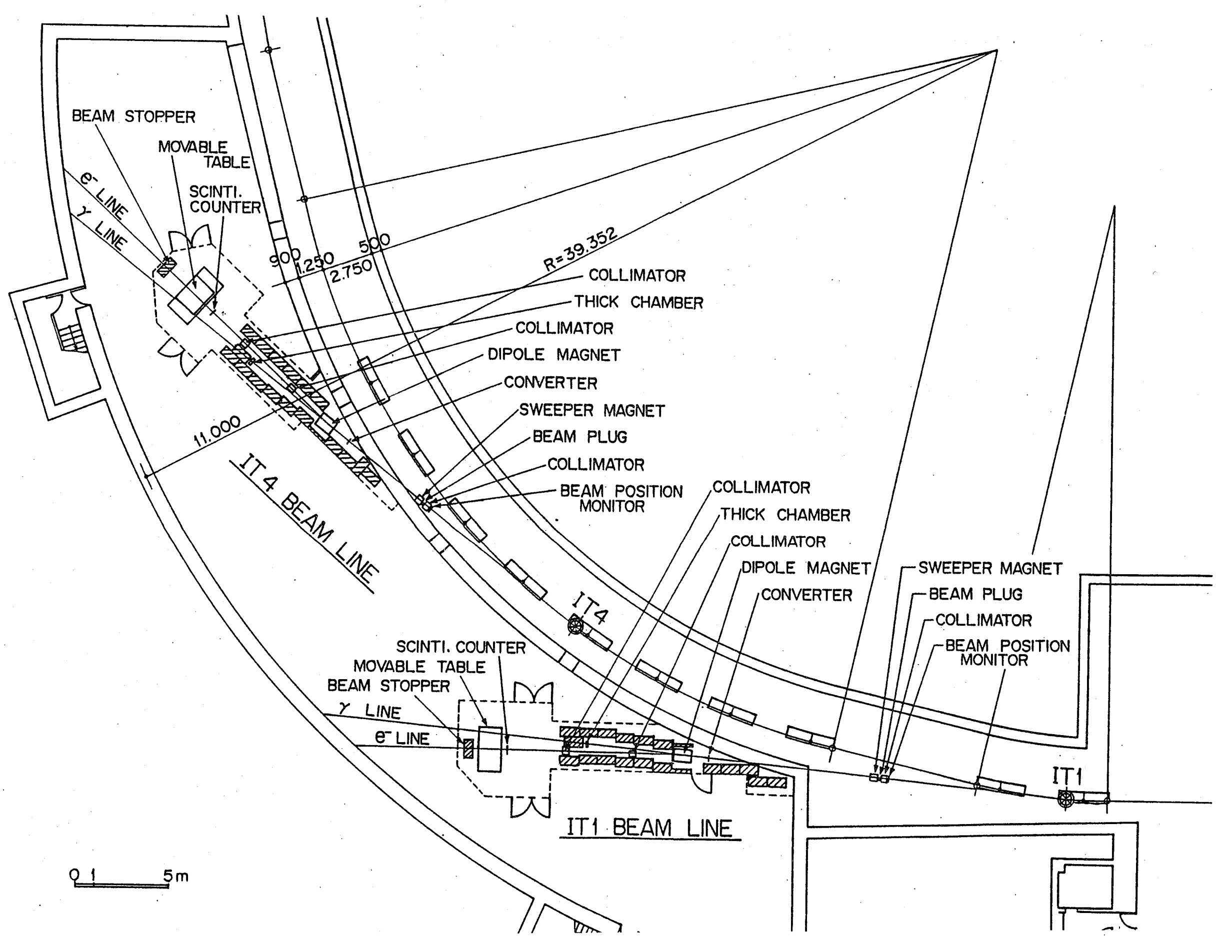

Fig. 1
The layout of internal targets and gamma ray beam lines in the TRISTAN accumulation ring. The targets are named IT1 and IT4.

fabricate. The target head is 3 mm thick and 6 mm high, and is cooled by water flowing through a hole inside the target holder. The target position is monitored by a potentiometer and can be precisely adjusted within 0.05 mm by a remote control.

PRINCIPLE

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. 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. Every electron whose amplitude is larger than the separation between the target and the orbit center 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 a collision. Then the edge of the emittance ellipse just contacts to the target position. The circulating electrons slightly diffuse from the inside to the outside of the ellipse to keep the emittance constant, 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 emits gamma ray in the same direction as its movement, the multiple scattering of the electron passing through the target makes the spread 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 is estimated by the quantum life time

$$\tau = \tau_x (s_0^2/s^2) \exp(s^2/2s_0^2), \qquad (1)$$

where s_0, s, and τ_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. The beam current and the intensity of gamma ray decay exponentially with the decay time τ. To keep the intensity

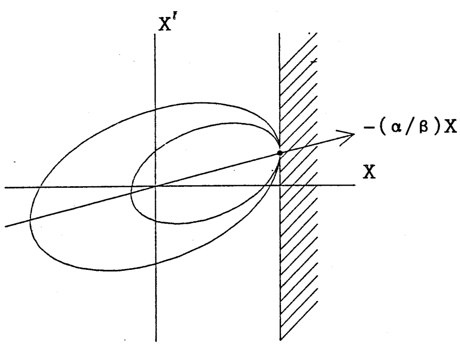

Fig. 2
The horizontal emittance of electron beam at a target. The hatched area means the target. As the beam current decays, the beam is made closer to the target in the direction of the arrow.

at a constant value we make the orbit closer to the target as the beam current decays. We change keeping a relation

$$-dI/dt = I/\tau = \text{const.} = I_0/T, \qquad (2)$$

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 keep the colliding point unchanged in the phase space to produce the gamma ray in the same direction. This is done by moving the orbit along the line $dx'/dx=-\alpha/\beta$, which is drawn by the arrow in Fig. 2.

Actually, we have two targets in the ring and we operate them simultaneously. Each generation rate of gamma ray is no longer determined by its quantum life time written by eq. (1); even if one target keeps the separation constant from the orbit, the generation rate may be affected by the position of the other target. The ratio of the generation rates is determined by their relative position in the phase space. It is not necessary to obtain an exact expression of the generation rates, because we use a feedback system which monitors the real-time intensity of the gamma ray and controls the orbit. The feedback is done independently for the two targets; at each channel it makes the orbit close to or apart from the target if the gamma ray intensity is lower or higher than the desired value. This is sufficient for our 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 around the targets to avoid the collision of the injected beam with a large betatron oscillation. The amplitude of the bump orbit is -5 mm at both targets.

After acceleration we make horizontal and vertical bump orbits around the targets. The latter is used to cancel C.O.D. and not changed during the extraction. The control of intensities are 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 at 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 derivative is so determined to keep the colliding angle constant as shown in Fig. 2. The feedback is done about 10 times a second. The feedback is repeated until the beam current becomes less than 0.1 mA.

The program also corrects the start orbit 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 1 mm farther from the target to save the stored electron beam.

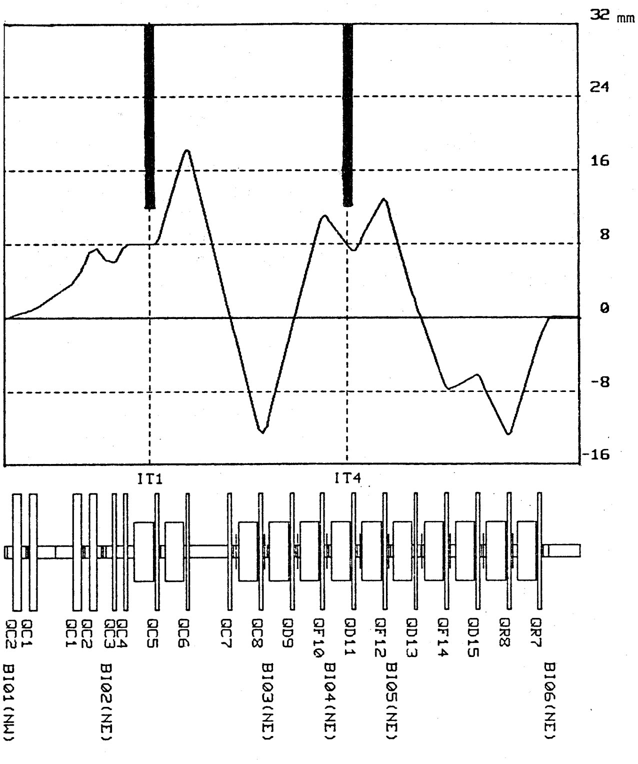

Fig. 3
The horizontal start orbit, made by six steering magnets from BI01(NW) to BI06(NE). The lattice of the ring is also shown. The targets are drawn by the vertical bars.

RESULTS

In the run from May to July in 1984 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 for the gamma ray extraction. It also took 2 minutes and 30 seconds for injection, acceleration, and the others, so we had a 70% duty factor. 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 for both targets.

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 9×10^{-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 and hence we did not take this effect into account in the run. Fig. 4 shows the spill of gamma rays under the feedback system. The variations of the intensities are about 6%, and are sufficiently small for the users.

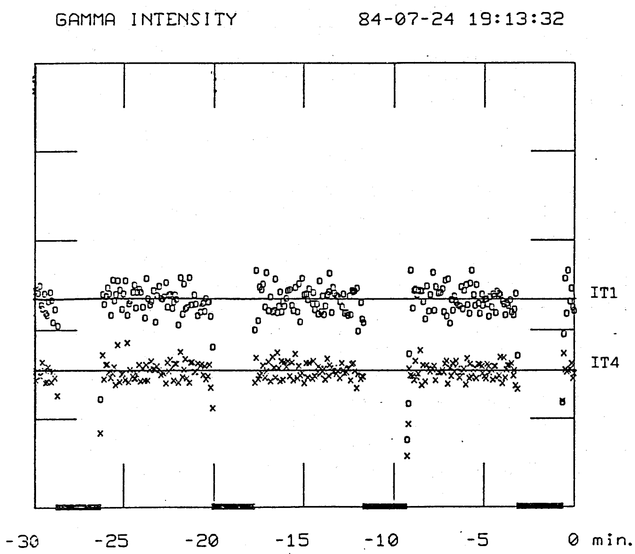

Fig. 4
The gamma ray intensities controlled by the feedback system. Two symbols o and x denote the intensity of IT1 and IT4, respectively. The desired value for each target is shown by the horizontal line.

TABLE I

beam energy	5.0		GeV
τ_x	5.4		msec
damping time of synchrotron oscillation	2.6		msec
relative energy spread	8.8×10^{-4}		
	IT1	IT4	
β_x	3.79	3.79	m
α_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

REFERENCE

1) M. Sands, The physics of electron storage rings an introduction, SLAC-121 (1970)