OPTICAL BEAM DIAGNOSTICS IN TRISTAN ACCUMULATION RING

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Visible radiation component of synchrotron radiation from the TRISTAN accumulation ring is used in four ways to diagnose the accelerator beam: cross-sectional profile observation by a TV system, time structure measurement by a streak camera, beam current measurement by a photodiode, and quantitative one-dimensional profile measurement by an optical fiber delay system. Details of the diagnostics are described with technical problems encountered at their operation.

1. INTRODUCTION

This paper reports beam diagnostics using the synchrotron radiation from the TRISTAN (Transposable Ring Intersecting STorage Accelerators in Nippon) Accumulation Ring (AR)[1]. Principal parameters of the AR electron beam are 100mA maximum current, 795kHz revolution frequency, 6.5GeV maximum beam energy and 30psec typical bunch length. Its synchrotron radiation at 6GeV beam energy has spectrum ranging continuously up to x-ray region with 20keV critical energy. This paper reports the beam diagnostics using only the visible component.

Section 2 of this paper describes the optical path and section 3 describes optical parameters. The visible radiation is presently used in four ways; cross-sectional profile observation by a TV system, time structure measurement by a streak camera, beam current measurement by a photodiode, and quantitative one-dimensional profile measurement by optical fiber delays. Section 4 describes them in detail. Technical problems encountered at the operation are discussed in section 5.

The optical method has following advantages over the conventional electromagnetic method. First, it can differentiate the positron beam and the electron beam. Second, it affords intuitive information. Third, it enables diagnostics in the picosecond region. Fourth, it is free from electromagnetic noise.
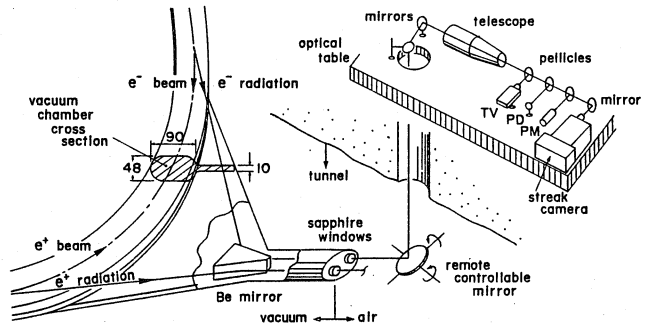

Fig.1 Schematic of optical apparatus.

2. OPTICAL PATH

Figure 1 shows the sketch of the optical apparatus. The synchrotron radiation separated from the particle beam passes through the branch of the main vacuum duct, 10mm high and 2050mm long. Two faces of a mirror block of pure Be shown in Fig. 2 reflect two optical beams, one each for e+ and e-, outside the vacuum duct. The mirror is clamped between two Al plates on the upper and the lower sides. Each plate has a cooling water path inside to which two Al tubes are welded. The Al cooling tube assembly clamped to the vacuum chamber supports the mirror as well.
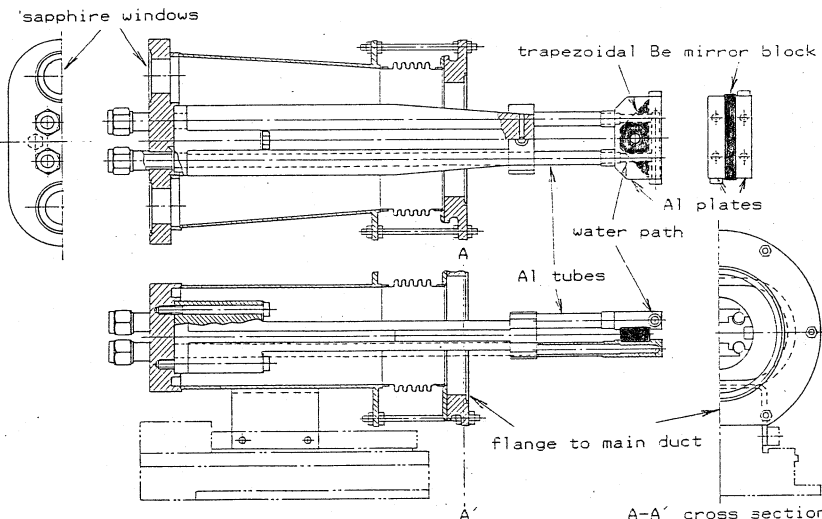

Fig.2 Be mirror and its chamber.

The exit windows are made of sapphire, 3mm thick and 30mm diameter. These windows limit the horizontal aperture of the diagnostics. Each beam is then reflected upward by a 100mm diameter mirror on a 2-axis remote-controllable mount to come out from the tunnel. A 1m x 2m optical table with a 500mm hole to let the beam in is settled upstairs, 9m apart from the light source. An SMC Pentax f=1000mm telescope focuses the image and pellicle beam splitters distribute it to various devices on the table.

3. OPTICAL PARAMETERS

Typical optical parameters are as follows. The vertical opening angle of the 600nm radiation at 6GeV beam energy is 1.83mrad. The total radiation power in the spectral range of 400-800nm at 6GeV beam energy is 3.64μW/mA per mrad horizontal angle. It is attenuated by the optical elements so that the measured total light power just behind the telescope is only 0.2μW/mA. The instrumental angular apertures (half of the opening angles) are horizontally θ_h=3mrad and vertically θ_v=1.25mrad.

As for the resolution of the image, we have to take account of three causes horizontally and two vertically which limit it. The first is the error due to the curvature of the source. It affects only the horizontal resolution. The equation to estimate the error is given in ref[2], which can be approximated in our case as $\epsilon_1 = R * \theta_h^2$, where R is the bending radius. Inserting the parameters already mentioned, we have ϵ_1=209μm. The second is the field-depth limit which is given in ref[3] as $\epsilon_2 = R * \theta_v^2$. We substitute the natural divergence of ref[3] by the instrumental aperture in this case, because the latter is smaller. The resultant resolution is 36μm. The last is the diffraction limit which is also given in ref[3] as $\epsilon_3 = (\pi R/6)^{1/3} \lambda^{2/3}$ or about 163μm for λ=600nm. The resultant resolution, root of their squared sum, are about 265μm horizontally and 166μm vertically.

4. DIAGNOSTICS

4.1 Profile Observation

A commercially available 2/3inch newvicon camera (National WV-1550) is used. The image formed by the telescope is magnified by f=16mm lens of the TV camera, which is positioned so that the resultant visual field on the TV screen is vertically 12mm and horizontally 16mm.
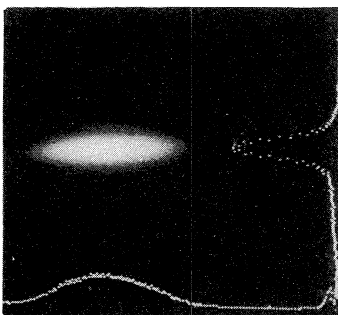

Fig.3 Gray-scaled TV images with two-dimensional histograms.

The video signal is sent to the center control building by optical fiber cable. Figure 3 shows examples of the off-line computer-processed beam image, where the profiles are emphasized by the gray scale (color coding is also possible) and the vertical and horizontal histograms are also displayed. Note that the TV camera cannot catch the cross-section of a single revolution, because its scan frequency is 60Hz.

The TV image is always monitored at the control desk, because it is a intuitive measure of beam strength (beam current), beam insta-bility and beam orbit.

4.2 Time Structure Measurement

We can conclude that the streak pictures directly give the time structure of a bunch, because the beam and the synchrotron light travel with the same speed. Detailed discus-sion[4] gives the error due to the flight path difference to be .6psec,which is negligible compared with the time resolution, 2psec, of our streak camera, Hamamatsu Systems' C1370-01 temporal disperser with C1440 analyzer.

It is triggered by the setup shown in Fig. 4. We pick up the light pulse by a photomulti-plier tube, shape it by a discriminater, delay it by a counter driven by the radio-frequency of the cavity, and finally feed it to the camera to trigger it at the next revolution. Rotation of a Dove prism enables both horizon-tal and vertical time structure observations.
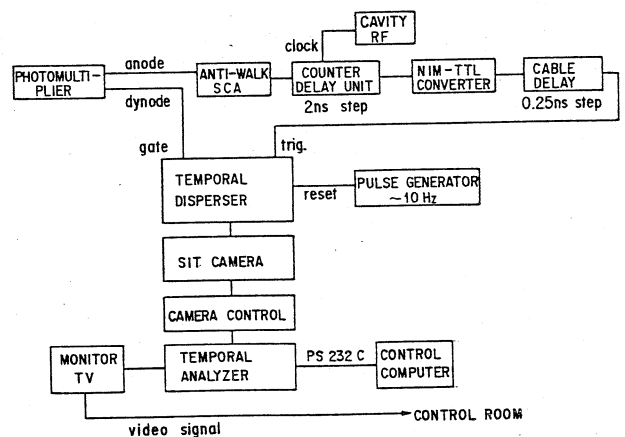

Fig.4 Setup of streak camera triggering.

The streak camera has been used to measure the bunch length[5]. It can be also useful to study oscillations; Figure 5 gives a series of pictures showing motion of two sub-bunches in the same bucket.

4.3 Beam Current Measurement

We can approximate that the visible light power is proportional to the beam current, independently of the beam energy at the AR[6]. A TO5-packaged photodiode with an FET opera-tional amplifier (Hamamatsu S1406-06) is used to measure it. The computer occasionally calibrates the output with the absolute current monitor, DCCT.
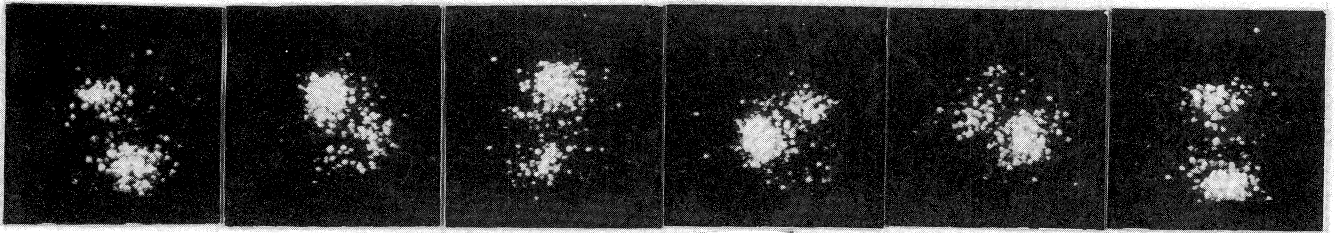
Fig.5 Streak pictures showing motion of two sub-bunches in a single bucket. 500psec/vertical full scale and 15mm/horizontal full scale.

Optical beam current measurement has two features. First, it is free from electromagnetic noise. Contrarily, the DCCT signal is contaminated by the magnet current when the beam is rapidly accelerated. Second, it can differenciate the positron current and the electron current by their directions, while the DCCT measures their total.

4.4 Quantitative Profile Measurement

Figure 6 shows the principle of this method. A one-dimensional array of optical fibers accepts the light, where the lengths of fibers make an arithmetic series. The other ends of the fibers are bundled and connected to a photomultiplier tube. The photomultiplier receives time series of signals that is the spatial distribution at the fiber input. It becomes thus possible to display the spatial distribution on a CRT, and to store it in a waveform memory.

The present system uses ten graded-indexed GeO_2-SiO_2 fibers with 400μm core radius, whose lengths range from 2m to 20m with 2m steps, equivalent to delays from 10nsec to 100nsec with 10nsec steps. Hamamatsu's R1828 photomultiplier picks up the optical output.

Figure 7 is the TEKTRONIX R7912 trace of the optical delay output which shows the momentary horizontal beam profile of the AR. One notable advantage is the fact that this method enables observation of each bunch, if only the time intervals of the bunches are longer than 100nsec. Observation of revolution-by-revolution change is also possible.
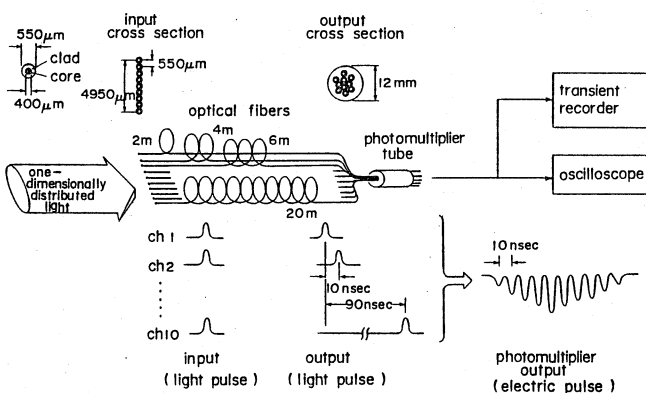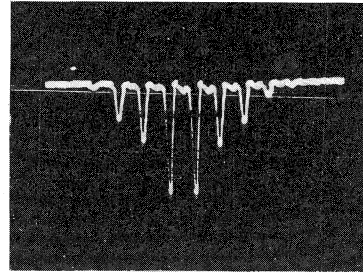

Fig.7 An example of momentary horizontal profile of AR beam. Timewise 10nsec between two peaks, which is equivalent to 550μm in space.

5. TECHNICAL PROBLEMS

After several months of operation, we found some problems in the Be mirror, the TV system and the current measuremet by the photodiode. On the Be mirror carbon atoms had been deposited by the photo-chemical dissociation of CO gas, which attenuates the light intensity into the diagnostics. This effect has now become weak as the baking of the duct wall improves the vacuum.

A false image has been often found on the TV screen due to the reflection inside the flat vacuum duct branch. Even after the careful alignment of the light path, it is difficult to eliminate the vertical asymmetry of the image. Fluctuation of the image used to be another problem, which was due to the air convection in the hole connecting the tunnel and the optical table. The air-seal of the hole has solved the problem.

The output of the photodiode measuring the beam current becomes unstable as the beam vertically oscillates, because the narrow vertical aperture slices the radiation. We will pay soft-ware effort to deal with this problem.

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Fig.6 Principle of space-to-time conversion of optical signal using fiber delay.