TRANSVERSE AND LONGITUDINAL BEAM PROFILE MEASUREMENT USING OPTICAL TECHNIQUES IN TRISTAN ACCUMULATION RING

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Instantaneous beam profile of TRISTAN Accumulation Ring (AR) is measured both transversely and longitudinally using optical devices accepting the synchrotron radiation. They are used to study the bunch lengthening and the vertical instabililty.

Introduction

This paper reports electron beam profile measurement using the synchrotron radiation from the TRISTAN (Transposable Ring Intersecting STorage Accelerators in Nippon) Accumulation Ring (AR) [1].

The first part describes experimental setups. Four devices are available; a streak camera, a fiber array profile monitor enabling revolution-by-revolution observation, a high-speed camera with shutter speed shorter than the revolution time, and a usual TV camera for a quiet beam.

Their applications are then described; the bunch lengthening study and vertical beam instability study. In the former case, they give the correlation between the bunch lengthening and the energy widening as functions of beam current, energy and RF voltage. In the latter case, they are triggered synchronously with the instability to give the time history of the profile evolution.

Experimental Setup

Optical Parameters

Optical path of the synchrotron radiation is illustrated elsewhere[2]. 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 400-800nm range is 3.64μW/mA per mrad horizontal angle, which is attenuated down to 0.2μW/mA just behind the telescope. The instrumental angular apertures are 3mrad horizontally and 1.25mrad vertically. The resolution of the image is limited by three factors[2]; the curvature of the source orbit, the field-depth and the diffraction. They are estimated to be 265μm horizontally and 166μm vertically.

The betatron functions and the dispersion function at the radiation source are: β_x=5.74m, β_y=7.69m and η =0.86m, respectively.

Apparatus

The streak camera is Hamamatsu Photonics' C1370-01 temporal disperser with C1440 analyzer[5]. In the disperser, the incident synchrotron photons projected on the slit are converted into electrons: electrons are accelerated, swept in a direction perpendicular to the slit by the deflection field, multiplied in a microchannel plate, and finally converted to the optical image (called "streak image") at the phosphor screen. The analyzer consists of a silicon intensified target (SIT) vidicon camera, and a direct readout system.

We approximate that the streak images directly give the time structure of a bunch, because the beam and the synchrotron light travel with the same speed. Detailed discussion[2] gives the error due to the flight path difference to be 0.6psec, which is negligible compared with the resolution of the streak camera, 2psec.

The streak camera is triggered by the setup shown in Fig.1. We pick up the light pulse by a photomultiplier, delay it and feed it to the trigger input of the camera at the next revolution. In the instability study, the trigger pulse is gated by a signal of the bunch oscillation detector[3].

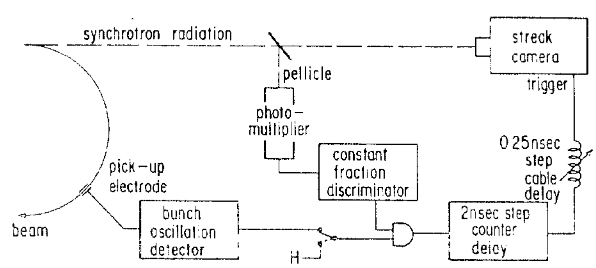

Fig. 1 Triggering of the streak camera.

The fiber array profile monitor[6] consists of ten pieces of fibers, whose lengths make an arithmetic series. One ends form a one-dimensional array to accept the incident light, and the other ends are bundled and connected to a photomultiplier tube, which receives time series of signals which are the spatial distribution at the input. Display of the spatial distribution on a CRT thus becomes possible. This profile monitor is also useful to observe the time history of radiation emitted from certain small area in the transverse plane.

The high-speed shutter camera is Hamamatsu Photonics' C1088-03. It has a gated-image tube. The minimum gate time is 1μsec, shorter than the revolution time of the AR(1.25μsec). The electrons of the image tube are multiplied by a microchannel plate, and hit a phospher plate to reconstruct the image. It is caught by a low-afterimage TV camera. The gating is applied during the blanking so that 30 or 60 frames/sec are available. A usual 2/3inch newvicon camera (National WV-1550) is also used for a quiet beam.

Data Calibration and Reduction

The source point of the radiation was examined by a bump field which generates gradient in the beam orbit; zero-crossing point was changed along the orbit and the point which gives no shift to the TV image was identified as the source. Next, to know the magnification, we focused an image of a section paper on the TV screen, ahead the telescope by the distance to the radiation source.

An image processing system, Nippon Firmware's Eyesis with NEC's PC-9801 personal computer, converts the TV images from the streak camera, the high-speed

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shutter camera and the newvicon camera into digital data to process them. The TRISTAN control computer directly connected to the readout system of the streak camera is also available for the data processing.

The calculation procedure of the bunch length, the bunch width and the bunch height are as follows. The background was first subtracted from the one-dimensional projection of a image. The above quantities are defined by the standard deviation of the resultant distribution. This definition is valid even if the distribution is far apart from the Gaussian. The estimated measurement error is 5%.

Bunch Lengthening

The three dimesional sizes of a single bunch (i.e., bunch length, width and height of a beam profile) are measured for various beam current, energies and RF voltages. The beam width and height are normalized to the width at a low current.

The results are shown in Fig. 2. The current dependence of bunch length indicates that the bunch lengthening occurs at 5mA and proceeds further at 20mA for 2.55GeV. It is strongly correlated to the beam

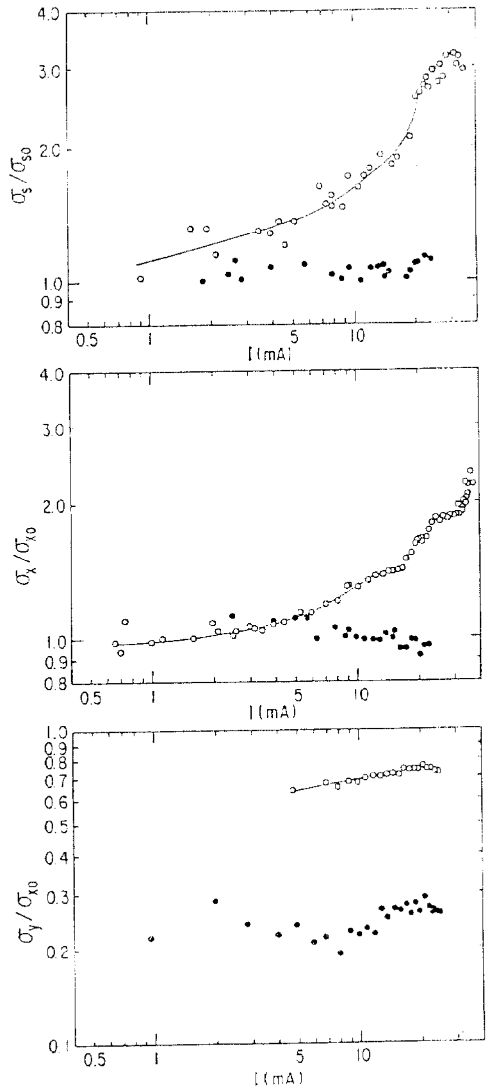
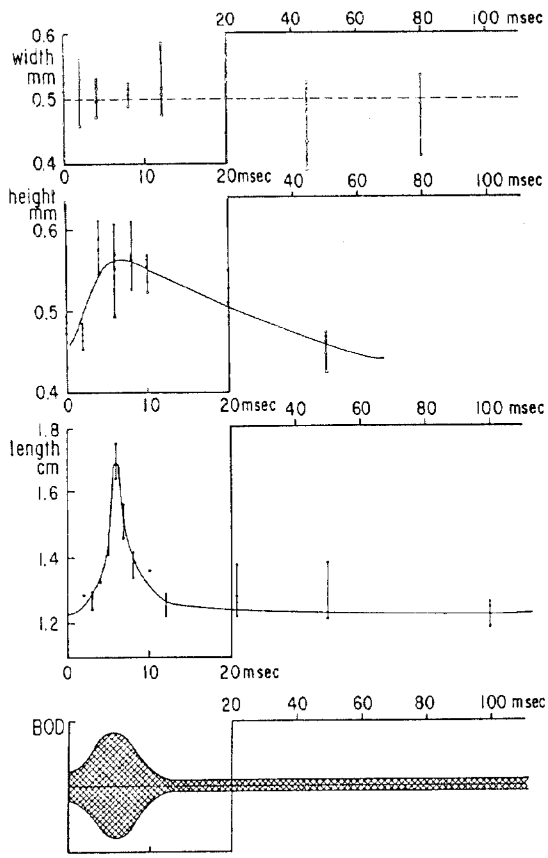


Fig.2 Beam current dependence of bunch length, width and height.
○ : E=2.55GeV, V=2MV, σ_{xc}=0.64mm, σ_{sc}=1.08cm.
● : E=4.8GeV, V=4.5MV, σ_{xc}=1.20mm, σ_{sc}=1.86cm.



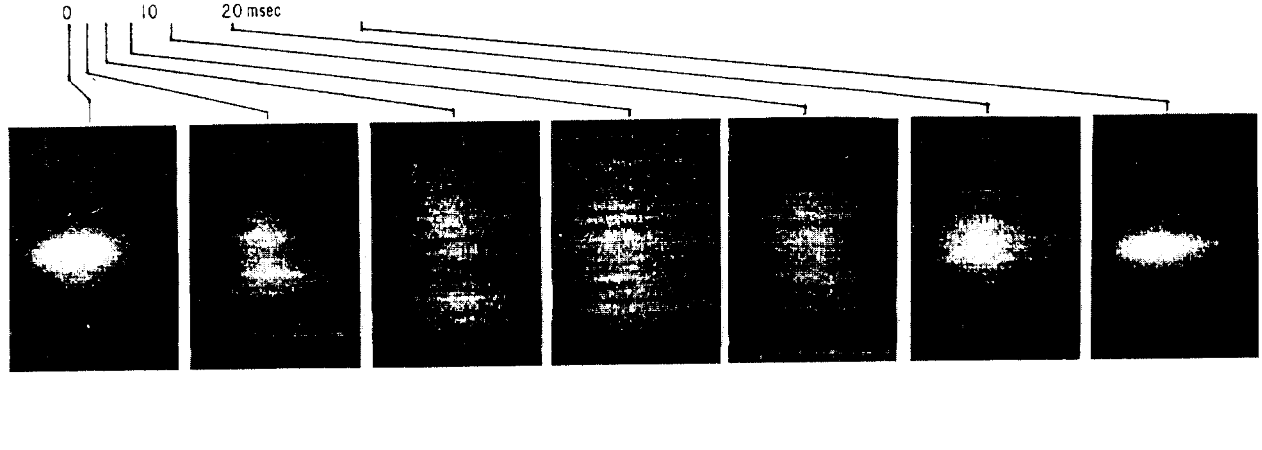


Fig.3 Time evolution of bunch width, height, length and bunch oscillation signal with transverse profiles caught by the high-speed shutter camera. RF voltage is 2.5MV. Beam current is 4mA. Repetition period of the istability is 120msec.

widening. Since the beam height does not change as the beam current increases, we conclude that the bunch lengthening is caused by energy widening due to a longitudinal beam instability.

The threshold current of this instability is strongly dependent on RF voltages. At lower currents the bunch length increases slowly whereas the beam width remains the same. This phenomenon at low currents could be explained by the potential well distortion[4]. For 4.8GeV, the bunch lengthening has not yet been observed up to 25mA.

The coupling of horizontal and vertical emittance is derived from the ratio of beam height to the beam width. The emittance coupling is 0.5 at 2.55GeV and 0.06 at 4.8GeV. The large coupling at 2.55GeV could be produced by some coupling resonances.

Vertical Instability

Current in AR had once been limited by a vertical blow up, though this phenomenon is not very serious recently. The transverse feedback has no effect on the instability. It is independent of the betatron tune and the chromaticity.

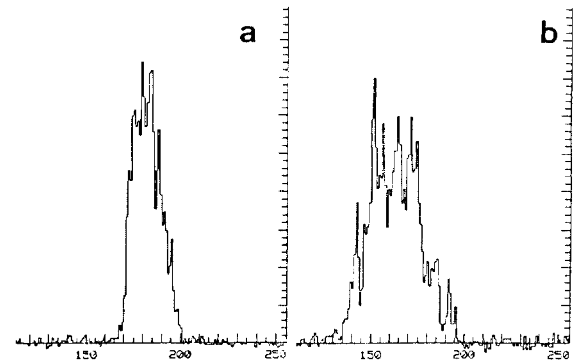


Fig. 4 Typical longitudinal profiles, 4psec/ch.:
(a) at the start of the instability,
(b) at its peak.

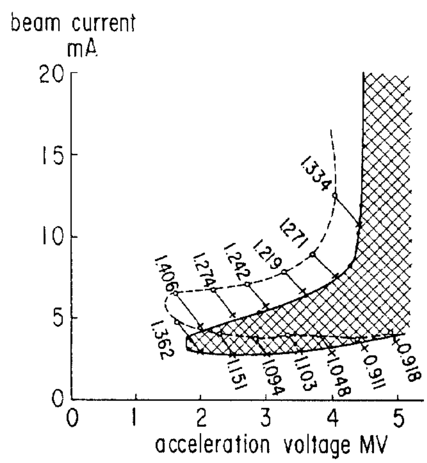


Fig. 5 Unstable region in the beam current-RF voltage plane with bunch length around it.

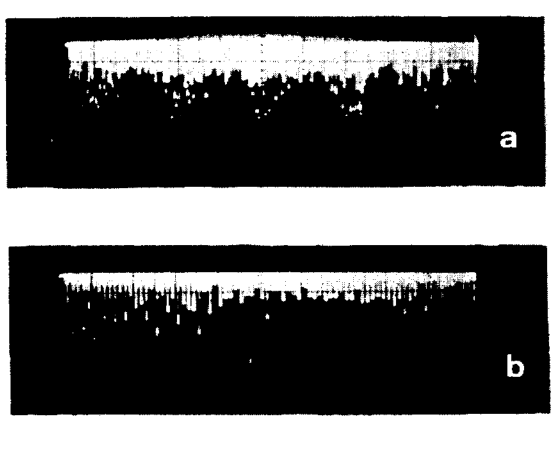


Fig. 6 Fine structure of the instability at its peak observed by waveforms of radiation intensity emitted from small central area of the transverse plane.
(a) 50μsec/div. (b) 10μsec/div.

The instability occurs intermittently. The rise and the decay times are a few msec while the repetition frequency is a few Hz. It increases with the beam current. Bunch sizes are measured as a function of time during whole cycle of instability. The result is given in Fig. 3 together with the output waveform of the bunch oscillation detector with 100-400kHz bandpass filter to mate with the betatron frequency, typically 200kHz. The bunch length and the height peak, but the width remains constant. The raw profile evolution in the transverse plane is also given.

Fig. 4(a) shows typical longitudinal profile at the start of the istability. We find that the time distribution is not symmetrical but leans forward. At the peak of the instability, it is disturbed as shown in Fig. 4(b).

The instability depends on the number of RF cavities and the RF voltage. Fig. 5 shows the region where the instability occurs in the plane of the beam current and the RF voltage: the bunch length around the region is also shown in the direction of third axis.

Fine structure of the instability at its peak, i.e., the waveform of radiation intensity emitted from a small central area in the transverse plane, is given in Fig. 6. There exists 10kHz oscillation in Fig. 6(a). Fig. 6(b) shows its enlargement in time. Incidentally, the betatron frequency is around 200kHz.

Further discussion on the mechanism of the instability is found in a separate paper[7].

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