LONGITUDINAL INSTABILITY IN TRISTAN MAIN RING OBSERVED BY A STREAK CAMERA

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Variation of longitudinal profile is observed using a streak camera during an instability in TRISTAN Main Ring(MR). The streak camera has a horizontal sweep circuit to enable the revolution-by-revolution observation. The single bunch instability occurs at injection energy(7.5GeV) and at certain beam current region at given rf voltage, which shortens the beam lifetime below 1min, where the bunch often becomes several times longer than the quiet case. Two dimensional Fourier analysis is applied to study the structure of the profile.

1. Introduction

A certain region is found in the rf voltage-beam current plane where the TRISTAN MR accelerator can hardly hold the beam. This paper describes the variation of the longitudinal beam profile in this region observed by a streak camera. The camera has a horizontal sweep circuit in addition to a usual vertical sweep circuit which enables observation of the phenomena dependent on revolutions. The next section describes the instability in this region. Section 3 describes setups for observation. The results and the data reduction procedure, two dimensional Fourier transform, are given in section 4. To help understanding, two dimensional Fourier transforms of some simple oscillations are illustrated in an appendix.

2. Instability

Detailed structure of the region where the beam is not held depends on optics. An example of the region in the rf voltage-beam current plane is given in Fig. 1. We call the region an inhibit band or simply the band. At given rf voltage, we can inject high current across the band. The current decreases with its characteristic lifetime, usually more than an hour, until it reaches the upper boundary of the band. The decrease then becomes drastic, until the current reaches the lower boundary. Below the band, the current again has its own lifetime peacefully.

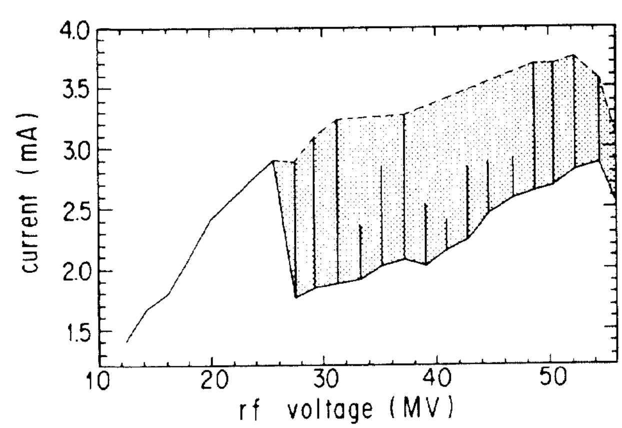

Fig. 1. An example of the inhibit band. $\nu_x = 36.605$, $\nu_y = 38.730$, $\xi_x = 0.95$, $\xi_y = 0.76$.

The observation is carried out at 7.5GeV beam energy and 27.3MV rf voltage with a single bunch. In this condition, the band appears when the beam current is between 2.8mA and 1.7mA. The beam blows up intermittently in the band. The blowup frequency is larger at the top than at the bottom. The lifetime in the band is less than 1 min. The observed bunch length is 55psec above the band, which is shortened down to 47psec below the band. In the band, the bunch length takes a value between these two in the interval between the blowups, but it becomes several times longer in the blowups. The bunch length in the absence of the instability is described elsewhere.[1]

A blowup is shown in Fig. 2, which is derived by difference of signals from two buttons horizontally separated. Because they are positioned where the dispersion function is large, the difference gives synchrotron oscillation. The streak camera is triggered by this signal.

Fig. 2. Beam blow up observed by button electrodes. Horizontal scale is 2msec/div.

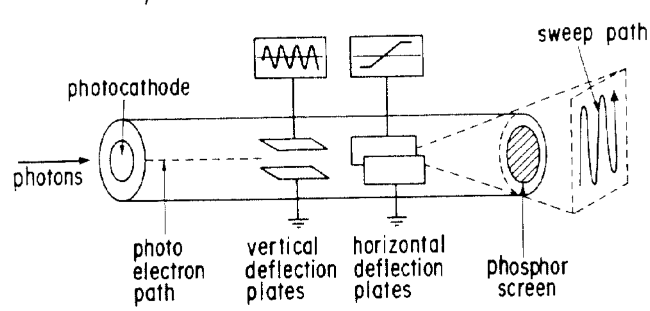

Fig. 3. Principle of the streak camera with dual time base.

3. Observation Setups

The streak camera is Hamamatsu C1587 with synchroscan unit M1955.[2] Its principle is given in Fig. 3. The synchroscan unit applys sinusoidal wave onto the vertical deflectors, whose frequency is 125MHz, 1/4 of the cavity frequency. The sinusoidal phase is adjusted so that the streak image appears at the middle of the screen. The horizontal image position is swept by a sawtooth wave. The sweep time can be changed from 10μsec to 10msec in 1-10 sequence. The camera can give $x - z$ beam profiles, where z is the longitudinal direction and x is one of the transverse directions. Information along the x axis is, however, hard to recover because of the convolution effect if the sweep time is larger than 1msec.

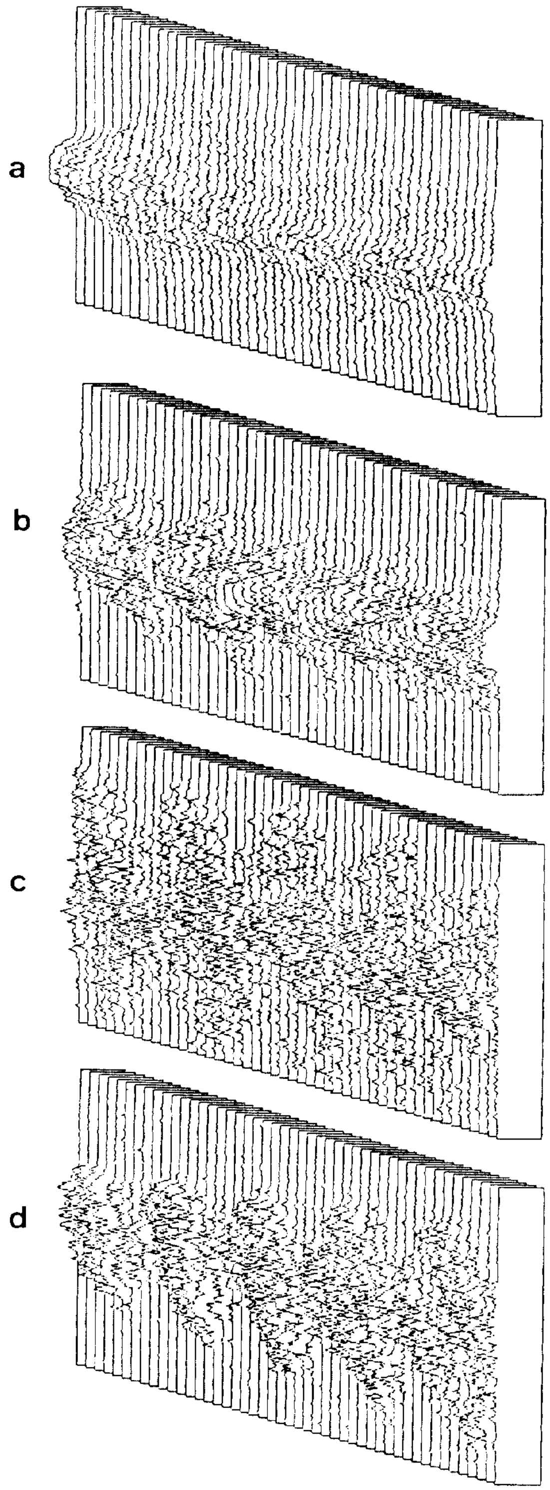

Fig. 4. Computer-processed streak pictures taken at the blowup. Vertical scale is 1.33nsec. Horizontal full scale is 9.6msec for (a) and 0.96msec for (b)-(d). Beam current is (a) 2.6mA, (b) 2.7mA, (c) 2.6mA, and (d) 2.0mA.

4. Results

A streak pictures is obtainable as TV video signal, which is converted into 256 × 256 8bit words. The A-D converter cannot cover whole area of the TV screen, so 4/100 of the horizontal information is lost during the conversion process. Fig. 4 gives computer-processed streak pictures taken at the blowups, where the longitudinal profiles are given in vertical direction, and their revolution-dependent variation are given in horizontal direction. Fig. 4(a) contains pictures of 960 revolutions, while (b)-(d) contains 96, so each trace in (a) gives sum of 20 revolutions while each in (b)-(d) gives sum of 2.

Fig. 4(a) shows almost the whole picture of the blow up, while (b)-(d) enlarge its part when it is growing. The values of beam current are 2.7mA, 2.6mA, and 2.0mA in (b), (c), (d), respectively. They are all in the band, but (b) is very close to the upper boundary, and (d) is close to the lower boundary. The instability is most active in (c). Fig. 4(a) is obtained when the current is 2.6mA.

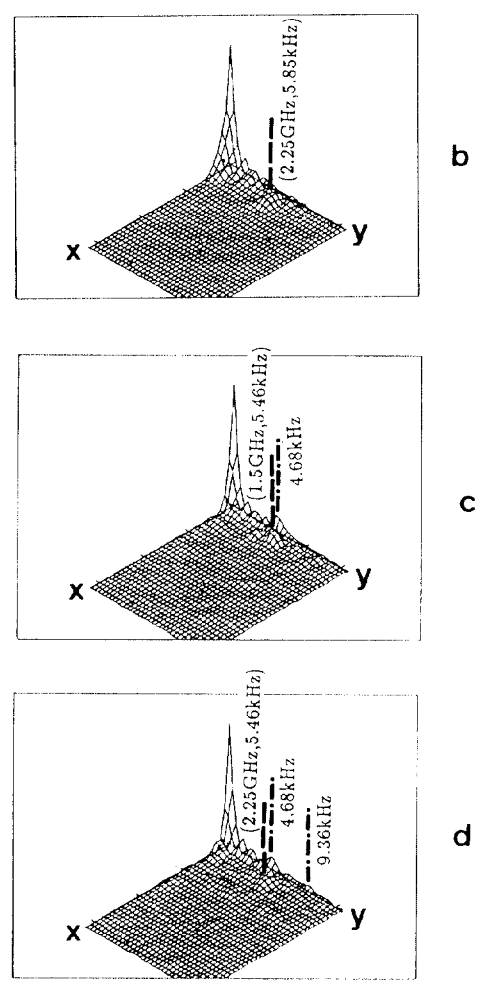

Fig. 5. Two dimensional FFT of data given in Fig. 4. (b)-(d) of this figure correspond to (b)-(d) of Fig. 4. Full scale in x direction is 24GHz and in y direction is 12.5kHz.

Because the digitizing interval of the TV signal does not synchronize with the revolution, a computer program is developed to obtain the longitudinal beam profile at each revolution from the data given in Fig. 4(b)-(d). One-dimensional and two dimensional Fast Fourier Transforms (FFT) are applied onto the results. The null data points are added to make the total data number 256 × 256 to apply the FFT.

Two dimensional power spectra obtained as results of the FFT are given in Fig. 5. Because a spectrum is symmetric, only a quarter is given in each figure. The x axis gives the transform of the variation within a bunch, and the y axis gives the variation dependent on revolutions. Though the FFT is applied on the whole data, just the low frequency region is enlarged and shown. So full scales are 24GHz in x direction and 12.5kHz in y direction.

Note that the Fourier transform of the Gaussian waveform $\exp(-x^2/\sigma^2)$ still gives the Gaussian, $\sqrt{2\pi}\sigma\exp(-(2\pi f_x\sigma)^2/2)$. We can then derive the average bunch length form the standard deviation of the x distribution at $y = 0$ of Fig. 5. They are 125psec, 302psec and 176psec for (b), (c) and (d), respectively.

We can regard that here the bunch is modulated by the synchrotron frequency. This kind of modulation is studied in the communication engineering.[8] The appendix shows two dimensional FFT results of typical modulations. The calculated synchrotron frequency is 6.5kHz. We find two peaks around this frequency, which are marked by dash lines and dot-dash lines in Fig. 5(b)-(d). The peak marked by dash lines, (2.25GHz,5.85kHz) in (b) (1.5GHz,5.46kHz) in (c) and (2.25GHz,5.46kHz) in (d), are separated from dc in the longitudinal direction, which is characteristic to the PWM. The peak marked by dot-dash lines in (d), 4.68kHz, has the remarkable secondary component in 9.36kHz, which is characteristic to the PPM. Only (c) has an isolated peak at 4.68kHz, probably due to the PAM. These modulation frequencies are not fully coincident. This results in the complication in Fig. 4. We cannot find any trace of the betatron oscillation in the figure.

We refrain from discussing the identification of the instability. It is out of the scope of this paper.

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REFERENCES

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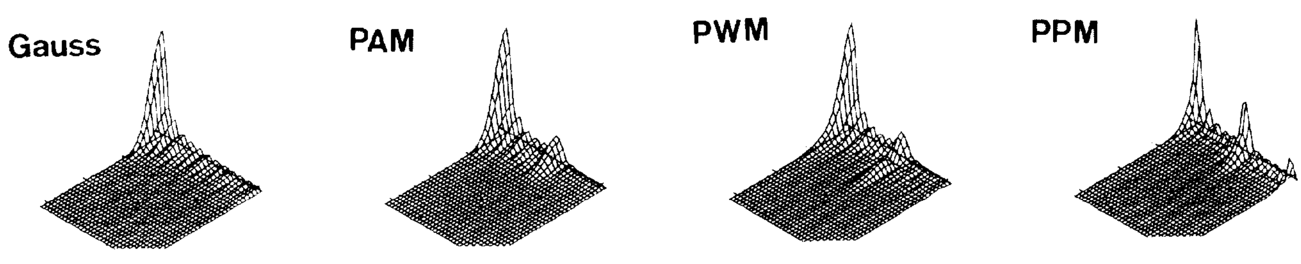
APPENDIX

To help understanding, here given are two dimensional FFT results of some simple examples. They are the Guassian bunch without oscillation and its modulations; pulse amplitude modulation (PAM), pulse width modulation (PWM) and pulse position modulation (PPM). The meanings of PAM, PWM and PPM are self-explanatory. The modulation frequency is equal to the synchrotron frequency. As same with those in the main text, the test data have value only for 96 revoultions, i.e.,

$$F(x,y) = \begin{cases} G(x,y), & \text{if } 0 \le y < 96; \\ 0, & \text{if } 96 \le y \le 255. \end{cases}$$

where x denotes the longitudinal scale and y denotes the revolution, and $x, y = 0, 1, 2, ..., 255$. The y directional spectrum of Gaussian of Fig. 6 is due to this window effect. $G(x,y)$ is explicitly given in each figure, where $\nu = 0.065 \times 2\pi, a = b = c = 0.5$ and $\sigma = 0.1$.

Only the PPM spectrum has second harmonics of the oscillation. The spectra of PAM and PWM resemble each other. However, careful observation tells that the synchrotron oscillation component of the PWM has a sideband in the longitudinal direction.



$\exp(-\frac{x^2}{2\sigma^2})$ $(1 - a\sin\nu y)\exp(-\frac{x^2}{2\sigma^2})$ $\exp(-\frac{x^2}{2(\sigma - b\sin\nu y)^2})$ $\exp(-\frac{(x - c\sin\nu y)^2}{2\sigma^2})$

Fig. A1. Two dimensional FFT results of some simple oscillations.