# MEASUREMENTS OF BUNCH LENGTHENING USING A BUNCH LENGTH MONITOR IN THE TRISTAN AR

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## Abstract

A bunch length monitor using beam spectrum has been developed in the TRISTAN Accumulation Ring (AR). Calibration of the monitor is done with a calculated natural bunch length. Measurements of the bunch length are done together with a measurement using a streak camera at the injection energy of 2.5 GeV. A jump of the bunch length accompanied with coherent synchrotron oscillations is observed during a bunch lengthening process, which has hysteresis characteristics.

## Introduction

Bunch lengthening is one of the most important issues in electron/positron rings from the aspect of beam dynamics. Bunch lengthening actually occurs in the AR [1]. The bunch length is usually measured by a streak camera. This measurement has an advantage of detecting a charge distribution, however, has a disadvantage of following dynamical changes of the bunch length.

## A bunch length monitor

In order to measure the bunch length more easily in real time, a new type of a bunch length monitor has been developed in the TRISTAN AR using the method of detecting the beam spectrum. Since a design and detector electronics of this monitor are described in references [2] and [3], this note describes only an outline of the monitor. A simplified block diagram of the detector is shown in Fig.1. A beam pulse is picked up by a stripline mounted at the bottom of a vacuum chamber. The stripline is 30 cm long. A beam pulse passing through a coaxial cable (Hitachi-HF20D, 35 m) is divided into two paths. One goes through the Band Pass Filter (BPF) of 250 MHz and the other of 1.62 GHz. The ACU calculates a square root of log-ratio of amplitudes of the two frequency components in order to get a signal proportional to a bunch length. The ACU has two outputs with different bandwidth. One has 1 kHz bandwidth much slower than the synchrotron frequency ($f_s$) of 15 - 40 kHz. This signal goes to an ADC to display an average bunch length on a screen. The other has 150 kHz bandwidth faster than the $f_s$ and is used for detecting coherent oscillations.

## Calibration of the monitor

The monitor system is composed of three components i.e., a stripline electrode, a coaxial cable and heterodyne receivers with two channels. Since the 250 MHz channel has higher gain (or lower loss), a gain difference between the 250 MHz and the 1.62 GHz channels of the monitor will produce an offset error at the output. Estimated and measured gain differences are shown below.

| components | gain difference (dB) |
|---|---|
| Stripline | 3.29 |
| Coaxial Cable | 3.46 |
| Heterodyne Receiver | 1.30 |
| total | 8.05 dB |

This difference must be compensated. The ATT-2 at the 250 MHz line in Fig.1 is used for compensating these differences with 0.25 dB step.

A calibration of the monitor has been done using a beam bunch. When beam current is as small as possible, a longitudinal distribution of a bunch will be Gaussian and its rms bunch length will be equal to the natural bunch length ($\sigma_{lo}$) because an effect of the wake fields is very small. The natural bunch length is controlled by a total accelerating cavity voltage ($V_c$). The $V_c$ is calculated from a measured synchrotron frequency. A bunch length was measured around beam current of 1 mA or $7.8*10^9$ particles/bunch when the $V_c$ was 0.68 MV, where $\sigma_{lo}$=1.83 cm and $f_s$=14.8 kHz. The measured natural bunch length can be obtained from a crossing point between an extrapolated line from measured values and the zero current line. A measured bunch length is adjusted by using the ATT-2 so as to be equal to the calculated natural bunch length of 1.83 cm. It is confirmed that an optimum value of ATT-2 is 7.5 dB, which is consistent with the expected value of 8.05 dB. The natural bunch length is measured and compared with calculated values as a parameter of the $V_c$. The results are shown in Table 1. Measured and calculated bunch lengths agree with about 10%.

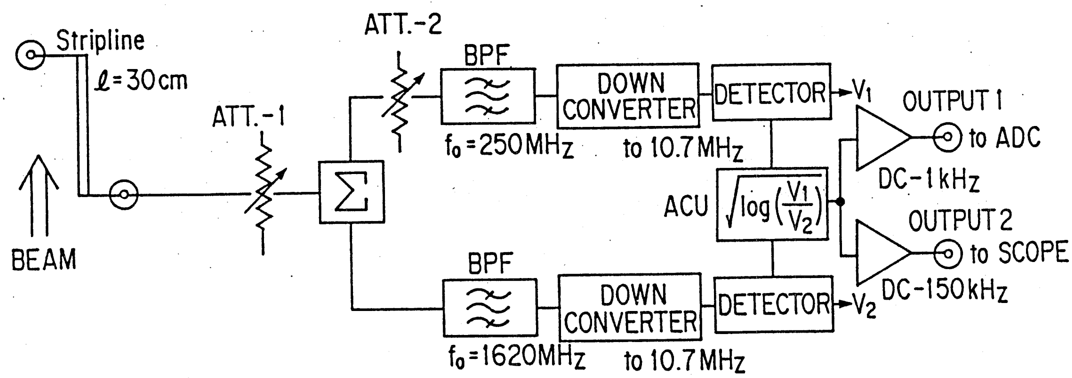



*Figure 1 Simplified block diagram of bunch length monitor.*

Table 1 Measured and calculated natural bunch length

| $V_c$ (MV) | $\sigma_{1o}$(cm) | $\sigma_{1m}$(cm) | error(%) |
|---|---|---|---|
| 0.68(0.5) | 1.83 | 1.81-1.84 | 0.3 |
| 0.94(0.7) | 1.54 | 1.59-1.64 | 4.8 |
| 1.18(1.0) | 1.37 | 1.38-1.43 | 2.5 |
| 1.58(1.5) | 1.18 | 1.31-1.34 | 12.2 |
| 1.85(1.8) | 1.09 | 1.11-1.18 | 5.0 |

## Measurements of the bunch length

One bunch is stored in the AR. The bunch length vs. the beam current was measured by the bunch length monitor (BLM) as a parameter of the $V_c$ at the injection energy of 2.5 GeV. The bunch length was also measured by a streak camera (ST). A ST stores a longitudinal bunch shape of the synchrotron light then measures a FWHM (Full Width Half Maximum) of a stored pulse in time domain. A relation between FWHM and the rms bunch length($\sigma$) is FWHM=2.35*$\sigma$ for a Gaussian bunch. On the other hand, the BLM estimates an rms bunch length from a measurement in frequency domain. In both cases, the rms bunch length should be equal under a Gaussian distribution.

Fig.2 shows bunch lengths as a function of the beam current measured by the two methods. The bunch lengthening is observed in both measurements without clear threshold current. No coherent oscillations is observed below 3 mA. As the beam current is increased, a difference between the BLM and the ST is remarkable. When beam current is 3 - 4 mA, coherent bunch oscillations with quadrupole synchrotron frequency ($2f_s$) are observed at the wideband output of the BLM. Then, a jump of the bunch length occurs and strong coherent oscillations are excited with synchrotron frequencies up to the fourth order mode. This jump is also confirmed by the ST. The threshold current of this jump depends on the $V_c$ or the bunch length. After the jump, the measured values by the ST are scattered, which may be due to coherent bunch oscillations. Excited coherent oscillations modes are not coupled each other up to the beam current of 30 mA.

When the beam current is decreased after the $\sigma_1$-jump, the jump does not occur at the same beam current where the jump occurs when the beam current is increased. Coherent oscillations are still excited. As the beam current is further decreased, a jump occurs at a lower current. Fig.3 shows the hysteresis of the $\sigma_1$-jump. After the jump down, no coherent oscillation is observed. One may understand that this jump is a nonlinear phenomenon. Two bunch lengths are possible during the two jumps. A mode of the coherent oscillations, however, is clearly different between higher and lower bunch lengths as seen in Fig.4. Only quadrupole oscillations ($2f_s \simeq$ 40 kHz) are excited at the lower or shorter bunch length.

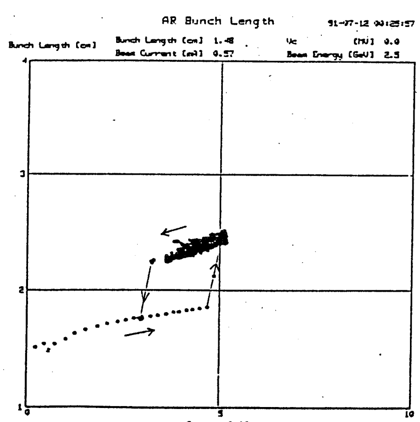
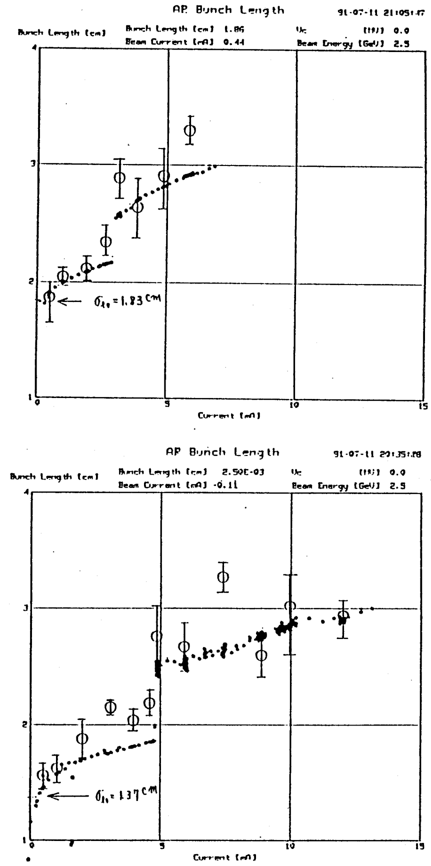


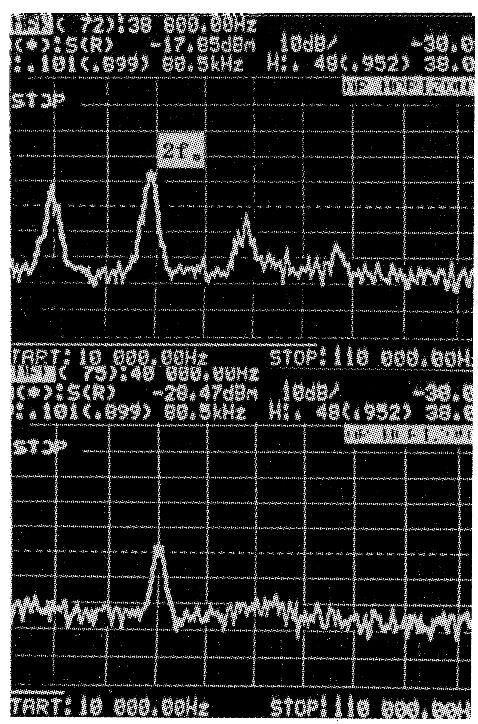

*Figure 3 A hysteresis of the $\sigma_l$-jump at $V_c$=1.18 MV.*




a)

b)

*Figure 2 Measured bunch length as a function of beam current at a) $V_c$=0.68 MV and b) $V_c$=1.18 MV.*
Φ :values measured by a streak camera.




a)

b)

*Figure 4 Coherent oscillations at higher(a) and lower(b) bunch lengths between the jumps at beam current of 4mA and $V_c$=1.18 MV.*

## Discussion and Conclusion

The bunch length was measured by the two methods in frequency and in time domains. When a bunch is Gaussian, the two methods are consistent. When a bunch shape is shifted from a Gaussian, however, they will bring different outputs. A real bunch shape is not a Gaussian, especially when a bunch is distorted by the longitudinal wake (the potential well distortion) and a bunch is tumbling in the phase space. In order to see an effect of a bunch shape, three type of the bunch shape such as a Gaussian, a parabolic and a triangular shapes are compared. They have same intensity and same full width at base line (FWBL) of bunch, where four times of the rms value is defined as FWBL for a Gaussian bunch. Their Fourier amplitudes are calculated and seen in Fig. 5. One can see from Fig. 5 that the amplitude of the Gaussian falls down fast as frequency goes up. The triangular shape is 0.6 dB larger than that of the Gaussian at 1.6 GHz when the rms bunch length is 2 cm. This suggests that the BLM indicates about 15% shorter length for a triangular bunch shape. On the other hand, the relation between FWHM and the rms value in time domain is changed. Though a triangular shape is not a real bunch shape, this analysis qualitatively explains the difference between the BLM and the ST.

Even though the energy spread of a bunch is not measured, an onset of coherent oscillations with higher modes will cause an increase of the energy spread. Therefore, the $\sigma_1$-jump is considered to be an onset of the turbulent bunch lengthening [4]. The threshold current of the instability has two values due to the hysteresis. The hysteresis will explain the mysterious result measured in SPEAR[4] why the threshold of the turbulent instability is not settled in one value around 2 cm bunch length. Further study is needed to resolve a mechanism of an onset of the turbulent bunch lengthening.

In conclusion, following items are summarized.
(1) The BLM can measure a bunch length of more than 1 cm with an accuracy of 10%.
(2) The BLM is also useful for detecting bunch oscillations.
(3) The $\sigma_1$-jump accompanied with coherent oscillations is observed and the jump has hysteresis, which should be an onset of the turbulent bunch lengthening.


## Acknowledgements

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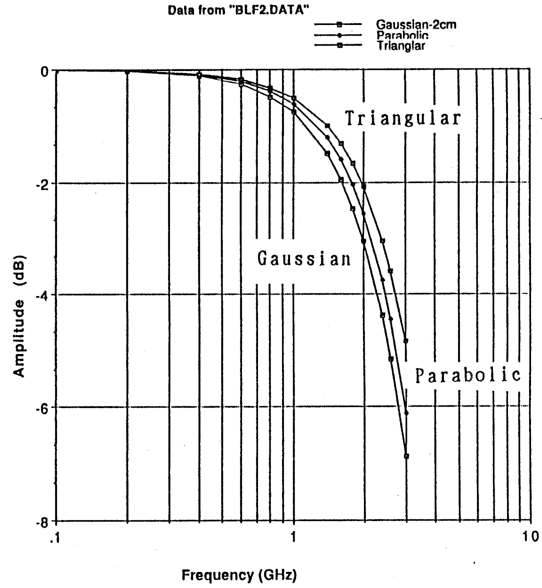


*Figure 5 Beam spectra with different bunch shapes at FWBL = 8 cm.*

## References


[1] K. Nakajima et al., "Bunch Lengthening in TRISTAN AR", Proc. of 5th Symp. on Accelerator Science and Technology, KEK, (1984) p.297.
[2] T. Ieiri, "A Real Time Bunch Length Monitor in the TRISTAN AR", AIP Conference Proceedings No.229 p.280.
[3] T. Ieiri, "A Real Time Bunch Length Monitor using Beam Spectrum for the TRISTAN AR", KEK Proceedings 91-2, p.246.
[4] P.B. Wilson et al., IEEE Trans. Nucl. Sci. NS-24 (1977) p1211.