

BUNCH LENGTH MEASUREMENTS AT ADONE

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Abstract

The Adone vacuum chamber has been recently replaced aiming at the reduction of the longitudinal coupling impedance. Measurements in this new condition show that the bunch length is now of the same order of magnitude of the vacuum pipe. We present the results and compare them with the previous measurements.

Introduction

The Adone vacuum chamber has been recently substituted with a new one, mainly to improve the performance of the vacuum system, and to install 24 beam position monitors. With respect to the previous one, care has been taken to provide a smoother surface to the beam environment. Namely, most bellows (46 out of 50) have been provided with RF shields and the vacuum pump ports masked by oblong holes to increase the associated waveguide cutoff beyond the characteristic frequencies of the bunches.

In these new conditions the bunch length in Adone has been measured for different values of energy and RF voltage, and with bunch current ranging from 1 to 40 mA. Measured data are presented, compared with the previous ones, and used to get information about the behaviour of the longitudinal impedance.

Table I shows the machine parameters relevant to the measurements presented in this paper.

TABLE I

Maximum beam energy (MeV)	1500
Average radius (m)	16.71
RF frequency (MHz)	51.4
RF voltage (kV)	50+200
Harmonic number	18
Momentum compaction	0.063
Horizontal betatron wavenumber	3.15
Vertical betatron wavenumber	3.15
Vacuum chamber aperture (cm)	horizontal 19. vertical 7.2

Beam Instrumentation

The accelerating voltage in Adone is given by a single cavity tuned to the 18th harmonic of the revolution frequency. The injection system allows for operation in either multi-bunch or single-bunch mode.

A fast feedback system acting in the transverse plane is used to counteract the head-tail instability.

The rigid-bunch longitudinal motion is stabilized by Robinson damping, as usual, by slightly detuning the resonant frequency of the accelerating cavity. However, under some operating conditions, the amount of detuning is maintained below the optimum in order not to present too large a mismatched load to the power transmitter, which is the case when the cavity is detuned.

A resistive feedback system provides additional damping if needed. In this system the phase error of the beam center-of-mass with respect to the cavity voltage is detected and, after time

differentiation and amplification, fed back to modulate the phase of the RF driver.

The relevant parameters we want to measure are:

- **Bunch current / single bunch purity.** The beam current is measured with a DC current transformer (DCCT) sensitive to the total average current. During the measurements Adone was operated in single-bunch mode. The single bunch purity is checked and corrected for by examining the response of a longitudinal pickup at an oscilloscope or by means of a spectrum analyzer.

- **RF Voltage.** The accelerating voltage is measured by detecting the voltage induced in a sampling loop inside the RF cavity. A similar device is used to stabilize the cavity voltage versus a reference value. However, in spite of the fact that the sample RF voltage still holds a constant value, the effective voltage seen by the beam may be slightly modified by the parasitic reactive term (the in-phase component of the beam-cavity longitudinal oscillation) introduced by the RF phase feedback and, to a lesser extent, by the fast feedback, according to the system gain and the beam current.

- **Synchrotron and betatron tunes.** A low-noise error signal from an intermediate stage of the RF feedback is detected with an HP 3582A FFT dual channel spectrum analyzer. The analyzer sensitivity is good enough to resolve very small residual oscillations. Alternatively, the output frequency of a PLL locked to the above signal is measured with a counter. The frequency measured with either of these methods is that of the coherent dipole oscillations. The above measurement is used to evaluate the effective voltage seen by the beam and has been used to calibrate the RF sensing loop. The horizontal betatron tune is measured by the method described in [1] to keep track of possible variation of the momentum compaction factor.

- **Bunch length.** The longitudinal current distribution in the bunch is measured by looking at the time-modulation of the synchrotron radiation. Figure 1 is a block diagram of the measuring setup. All the instrumentation is controlled by a personal computer with GPIB control capability.

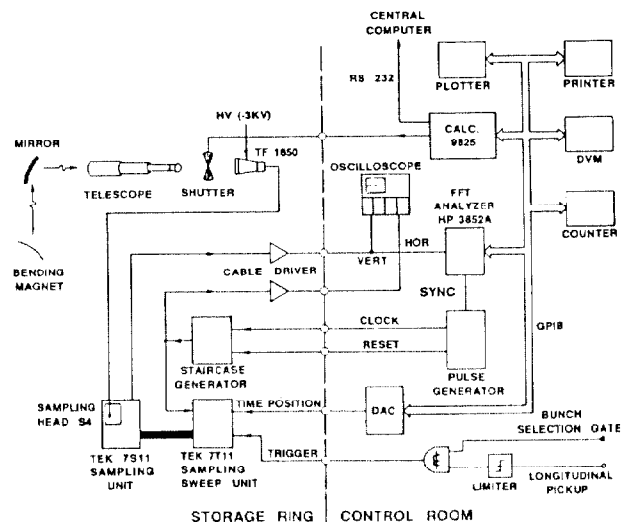


Fig.1 - Block diagram of the measuring setup

The visible light from a bending magnet is extracted from the vacuum chamber, after reflection on a stainless-steel mirror, through a transparent window and looked at with a fast photodiode. A vacuum photodiode with coaxial structure matched to 50 Ω (TF 1850 by ITL) is used. The rise-time claimed by the manufacturer is 100 ps.

The sensitivity of this device is such to yield voltage levels of a fraction of millivolt or a few tens mV at most, according to the bunch current. The poor sensitivity calls for averaging to reduce noise; however the achievable bandwidth is larger than that of other beam monitors.

A two-lenses telescope is used to illuminate uniformly the photo-cathode surface. A beam shutter is inserted to subtract the signal base-line and to protect the photodiode.

The photodiode output is brought with ≈ 1 m. of RG-223 cable to a sampling head TEK S2 (25 ps rise-time), housed in a self-powered bin containing a 7S11 Sampling Unit and a 7T11 Sampling Sweep Unit (Tektronix), placed near the vacuum chamber. The time sweep and the time-position are controlled by external DAC's driven by the computer. The trigger is derived from a longitudinal pickup gated with a bunch selection signal and it is thus synchronous with the selected bunch.

The vertical output from the sampling unit is low-pass filtered and buffered to drive a long 50 Ω cable to the control room, where it is routed to the FFT analyzer, which is synchronized with the sweep driver and used in an unusual way as a time averager rather than as a spectrum analyzer.

The result are plotted and transferred to our central computing facility for further analysis.

Experimental results

Fig.2 shows a set of bunch length measurements, at a constant RF voltage of 137 kV, as a function of the current stored in a single bunch, at three different beam energies (600, 800 and 1000 MeV).

The rms bunch length has been estimated, assuming gaussian shape, from the distance between 20% and 80% of the maximum on the leading edge of the pulse. The values have been corrected for the photodiode risetime. The measured pulses exhibit both an asymmetry between rise and fall time and an oscillation on the trailing edge, probably due to a reflection. Obviously, the effect is worse for short bunches. An example of a measured pulse is shown in Fig.3.

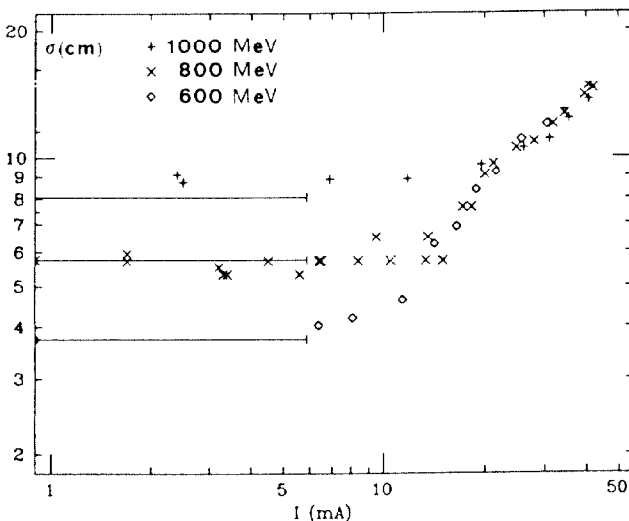


Fig.2 - Bunch length measurements at 137 kV as a function of stored bunch current

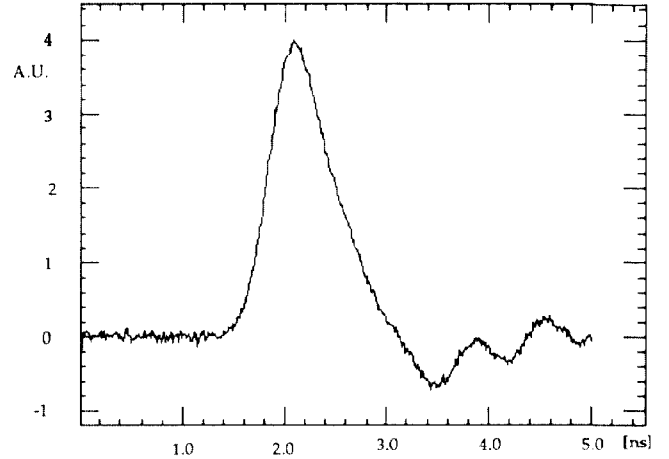


Fig.3 - Example of measured beam pulse

Fig.2 clearly shows that a current threshold exists, beyond which the bunch length is dominated by longitudinal instabilities. The so-called "turbulent regime" can be analyzed by comparing it to the model developed at SPEAR [2], which uses the scaling parameter

$$\xi = (\alpha_c I) / (E v_s^2) \quad (1)$$

where I is the average bunch current, α_c the momentum compaction factor, v_s the synchrotron frequency and E the beam energy. According to this model, the bunch length σ_l depends on parameter ξ as

$$\sigma_l \propto (\xi Z_0 R^3)^{1/(2+a)} \quad (2)$$

where R is the average machine radius. Z_0 and a are parameters characterizing the longitudinal impedance responsible for the instability

$$Z(\omega) = 2\pi R Z_0 \omega^a \quad (3)$$

where ω is the angular frequency.

Fig.4 shows on a logarithmic scale the bunch length in the lengthening regime, measured at different beam energies (600, 800 1000 and 1100 MeV) and RF peak voltages, as a function of parameter ξ . It can be observed that the points tend to cluster around a curve showing a clear slope change near a bunch length $\sigma^* \approx 10$ cm. We have therefore interpolated this curve with two straight lines connecting the points respectively above and below σ^* . These two lines are shown in Fig.5, together with the fit to the measurements performed before the replacement of the vacuum chamber.

From the comparison between the old [3] and the new data above σ^* , an impedance reduction of the order of a factor 3 can be inferred. Since the bunch is shorter than before, its length becomes of the same order of the pipe cutoff, which has been estimated to be ≈ 13 cm. In this new range our measurement system is affected by instrumental errors. Namely, for signals shorter than ≈ 0.3 ns the trailing edge seems to be influenced by the photodiode response. For this reason we have measured the bunch length on the leading edge of the pulse. The fit through the experimental points obtained in this way shows a transition from a regime of long bunches to one where the bunches are shorter than the cutoff and the impedance decreases with the bunch length.

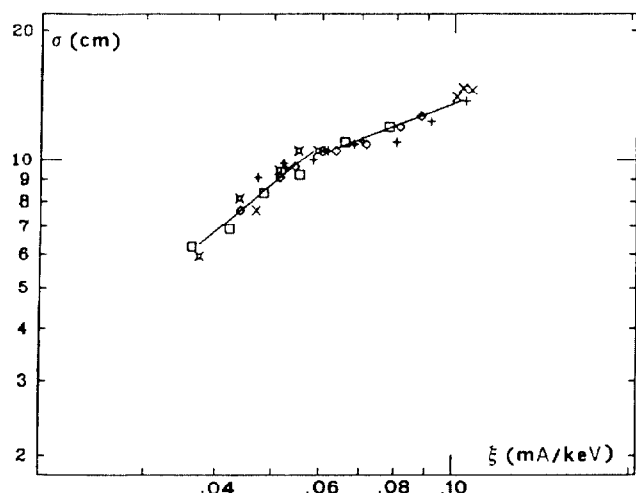


Fig.4 - Bunch length as a function of parameter ξ in the bunch lengthening regime

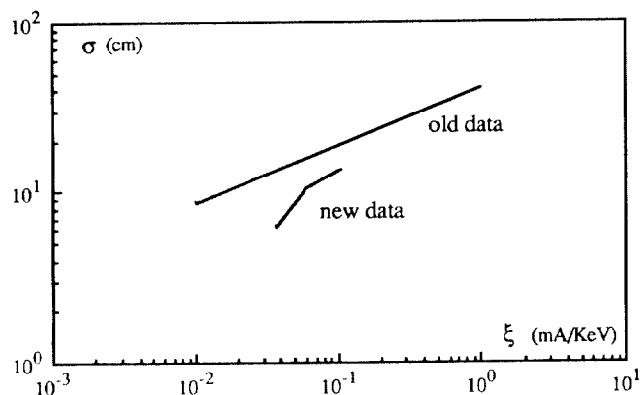


Fig.5 - Comparison between old and new measurements

The ξ range covered by the measurement is much smaller than the previous one. because, on the low ξ side, we were limited by the time resolution of our instrumentation and on the high ξ side the attainable bunch current is limited by instabilities (in the old set of measurements, the lower value of the RF frequency, 8.56 MHz, allowed us to reach larger values of ξ). For this reason, the slope of the curve may be affected by a large error. We find

$$\begin{aligned} a &= -1.1 \pm 0.2 \quad \text{in the short bunch regime} \\ a &= 0.0 \pm 0.4 \quad \text{in the long bunch regime} \end{aligned}$$

Due to the tight schedule imposed us by the scarce availability of machine-physics time, we decided to postpone the measurement of the current-dependent energy loss and frequency shift of the coherent quadrupole and higher modes of oscillation. We decided, as well, to postpone measurements of beam longitudinal and transverse dimensions with positrons awaiting the availability, in the near future, of a new injection system. These and other measurements are part of the refinement program of the present work.

References

- [1] A. Aragona, C. Biscari, S. DeSimone, E. Gianfelice, S. Guiducci, V. Lollo, S. Pella, M.A. Preger, M. Serio - "Measurement and steering of beam position in Adone" - Nota Interna LNF 87/16 (P) (1987)
- [2] A.W. Chao, J. Gareyte - "Scaling law for bunch lengthening in SPEAR II" - SPEAR-197/PEP-224 Stanford Linear Accelerator Center (1976) (unpublished)
- [3] S. Tazzari - "Scaling dell'allungamento anomalo secondo il modello di Chao-Gareyte" - Memorandum Interno Adone T-93 (1978) (unpublished)