SLAC – PUB – 3690
May 1985
(A)

ACCELERATOR PHYSICS MEASUREMENTS AT THE DAMPING RING*

L. RIVKIN (CALTECH), J.P. DELAHAYE (CERN), K. WILLE (DESY), M. ALLEN, K. BANE, T. FIEGUTH, A. HOFMANN, A. HUTTON, M. LEE, W. LINEBARGER, P. MORTON, M. ROSS, R. RUTH, H. SCHWARZ, J. SEEMAN, J. SHEPPARD, R. STIENING, P. WILSON, M. WOODLEY

SLAC, Stanford University, Stanford, CA 94305

Abstract

Besides the optics measurements described elsewhere, machine experiments were done at the SLC damping ring to determine some of its parameters. The synchrotron radiation energy loss which gives the damping rates was measured by observing the RF-voltage dependence of the synchronous phase angle. The emittance was obtained from the synchrotron light monitor, scraper measurements and by extracting the beam through a doublet and measuring its size for different quadrupole settings. Current dependent effects such as parasitic mode losses, head tail instabilities, synchrotron and betatron frequency shifts were measured to estimate the impedance. RF-cavity beam loading and its compensation were also studied and ion collection was investigated. All results agree reasonably well with expectations and indicate no limitations to the design performance.

Introduction

The damping ring is part of the Stanford Linear Collider (SLC) and has the purpose to reduce the emittance of the beam before it is injected into the main part of the linear accelerator[1]. To achieve a short damping time this ring has a small circumference of 35.27 m and a small bending radius of 2.037 m. The small emittance is achieved by strong focussing with $\nu_x \sim 7.25$ and $\nu_y \sim 3.25$ and with momentum compaction $\alpha = 0.018$. The RF frequency is 714 MHz and the bunch length is a few mm. The operating energy is 1.21 GeV but some experiments have been carried out at 0.95 GeV. The design operating intensity is 68 mA ($5 \cdot 10^{10}$) particles per bunch. The vacuum chamber is small with inside dimensions between 15 and 25 mm. Besides optics measurements[2], described elsewhere, a series of machine experiments have been carried out at the damping ring to determine some of its parameters.

Emittance measurements

The emittance of the damping ring was measured in three different ways: on the synchrotron light monitor, using scrapers and with the extracted beam on the profile monitor in the beginning of the ring–to–linac transport line.

SLM:

The synchrotron light monitor images the light from a bending magnet onto a TV camera using a single achromatic lens. The video signal is processed using a Colorado Video device that allows to select and measure the amplitude of a single horizontal scan or a set of vertical samples. Using the transverse beam sizes obtained and the model values for the beta functions we measured at $E = 0.95$ Gev

$$\epsilon_{x0} = \epsilon_x + \epsilon_y = (1.0 \cdot 10^{-8} + 2.7 \cdot 10^{-9})\pi m\,rad = 1.27 \cdot 10^{-8}\pi m\,rad$$

to be compared with the theoretical[3] emittance at this energy of $\epsilon_{x0} = 1.2 \cdot 10^{-8}\pi$m rad.

Scrapers:

The device consists of four jaws independently driven by stepping motors. By moving one of the jaws into the beam tails and measuring the lifetime as a function of scraper position we can deduce the transverse beam size. The procedure assumes the case of a Gaussian distribution of particles in the beam. Usually the tails of the distribution are different due to other processes like multiple Coulomb scattering on the residual gas and one has to measure very short lifetimes in order to determine the σ of the core. Similarly to the SLM case above the dispersion at the scraper azimuth is zero and the values for the β functions were taken from the model. At $E = 0.95$ Gev the result was

$$\epsilon_{x0} = \epsilon_x + \epsilon_y = (1.2 \cdot 10^{-8} + 5 \cdot 10^{-9})\pi m\,rad = 1.7 \cdot 10^{-8}\pi m\,rad$$

Quad and screen method:

The transverse beam size is measured on the screen as a function of the strength of a quadrupole some distance upstream of the screen. The square of the beam size is a quadratic function of the strength and, fitting a parabola to the results, one obtains three parameters that are sufficient to determine the beam emittance. The results at $E = 0.95$ Gev were

$$\epsilon_{x0} = \epsilon_x + \epsilon_y = (2.4 \cdot 10^{-8} + 1.6 \cdot 10^{-8})\pi m\,rad = 4 \cdot 10^{-8}\pi m\,rad$$

This method overestimates the emittance of the coupled beam, which was the case with the damping ring[4].

Damping times

The sum of all three damping rates was determined by measuring the synchrotron radiation loss per turn. The change in the synchronous phase of the bunch as a function of RF voltage was measured in a setup similar to the one used for measurements of the parasitic mode losses. Using the relationship

$$U_0 = V_{RF} \sin \phi_s \approx V_{RF}\, \phi_s$$

the loss per turn was measured for two different currents and the extrapolation to zero current at $E = 1.21$ Gev gives

$$U_0 = 84.0\,\text{Kev} \qquad \Sigma\frac{1}{\tau_i} = 1180.2\,\text{sec}^{-1}$$

so for the vertical damping time, which should be very close to one quarter of that, $\tau_y = 3.4$ msec. These are to be compared to the theoretical $U_0 = 84.4$ Kev and $\tau_y = 3.45$ msec. The damping times were also obtained from the measurements of the extracted beam size as a function of storage time in the ring at $E = 0.95$ Gev. The values $\tau_x = 6.7$ msec and $\tau_y = 4.6$ msec were lower then predictions for that energy of $\tau_x = 6.4$ msec and $\tau_y = 7.1$ msec but the measured loss per turn again gave results in good agreement with the theory.

Dynamic aperture

The horizontal dynamic aperture was measured by exciting the stored beam with the kicker to a short lifetime and driving the scraper in until the lifetime changed. The resulting acceptance was $A_x = 3.7 \cdot 10^{-6}\pi$ mrad, comparable to the design incoming positron emittance.

Intensity dependent effects

Different current dependent effects have been measured in the damping ring with the aim to check some predictions, to get an idea of the chamber impedance and to estimate the stability at higher intensities.

* Work supported by the Department of Energy, contracts DE – AC03 – 76SF00515 and DE – AC03 – 81ER40050.

Poster paper presented at the 1985 Particle Accelerator Conference
Vancouver, B.C., Canada, May 13-16, 1985

Parasitic mode loss

The wall current induced by the circulating bunch leads to an energy loss per turn due to the resistive longitudinal impedance of the beam surroundings. It is usually quantified by the so-called parasitic mode loss factor[5] k. To make up for this loss the synchronous phase angle ϕ_s of the bunch has to increase with increasing current, Fig.1. This parasitic mode loss has been measured in the damping ring by filtering the RF-component of the bunch signal from an intensity monitor and comparing it with the RF-cavity voltage for different beam intensities by means of a vector voltmeter[6]. The relative phase and amplitude of the signal is displayed on an x-y recorder while the beam intensity is reduced with a scraper, Fig.1. From the slope of this curve the parasitic mode loss factor has been determined. Such measurements have been carried out for different bunch lengths σ, however the accuracy was not good enough to determine the dependence of k on σ. All the results have therefore been scaled with the expected dependence to a bunch length of $\sigma = 7\,mm$ and compared with calculations

experiment: $k = 4.8\,V/pC$, expectation: $k = 3.2\,V/pC$.

This agreement is quite good considering the errors of the measurement and the complicated structure of the vacuum chamber.

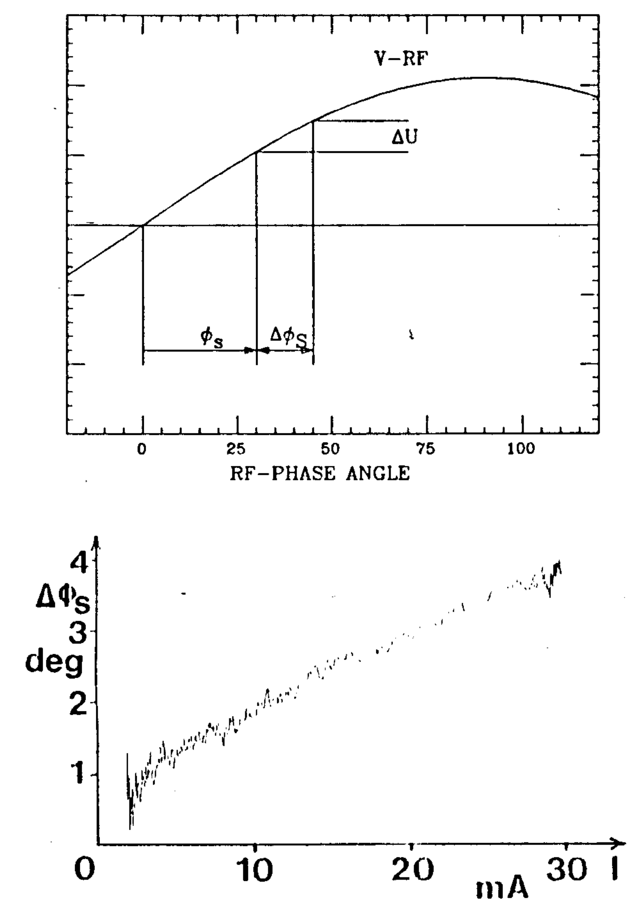


Fig.1: Measurement of the parasitic mode loss by observing ϕ_s vs. current.

Synchrotron frequency shift

The reactive part of the longitudinal wall impedance can lead to a shift of the synchrotron frequency with increasing current. This effect is usually weak for the dipole mode but stronger for the quadrupole mode. A measurement of these shifts is shown in Fig.2 for two different bunch lengths. The dipole mode has been excited by phase modulating the RF-voltage at the synchrotron frequency and the quadrupole mode by amplitude modulation at twice this frequency. From many such measurements the average shift of the quadrupole mode frequency with bunch current is about

$$\frac{df_2}{dI} = -0.3\,MHz/A$$

at 1.2 GeV, while the dipole mode has a small, slightly positive shift.

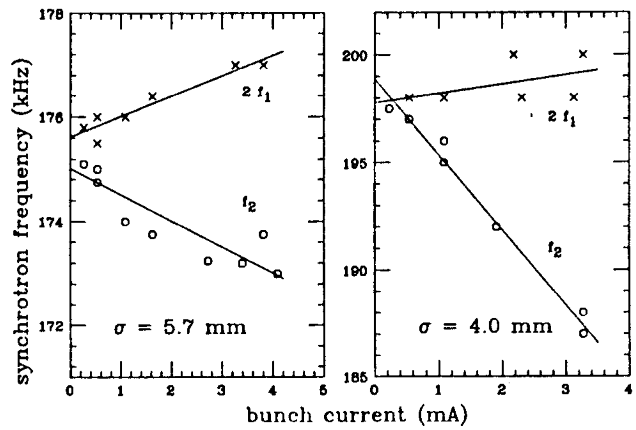


Fig.2. Current dependence of the dipole f_1 and quadrupole f_2 synchrotron frequency.

Head-tail growth rate

By making the chromaticity negative the head tail instability can be provoked in the damping ring. Its growth rate depends on the resistive part of the transverse impedance. To measure it a bunch has been injected into the damping ring operating with a negative vertical chromaticity. The amplitude of the developing head-tail instability has been measured by sending the signal of a position monitor to the spectrum analyzer used as a filter for the betatron frequency with a logarithmic display. The exponentially growing instability shows up as a straight line with a slope being proportional to the growth rate up to the point where the beam gets lost, Fig.3. This growth rate has been measured as a function of current and a straight line has been fit through the measurements. It extrapolates to a value at vanishing current equal to the radiation damping rate. For a chromaticity of $d\nu/(dp/p) \sim -4$ the observed growth rate was of the order of

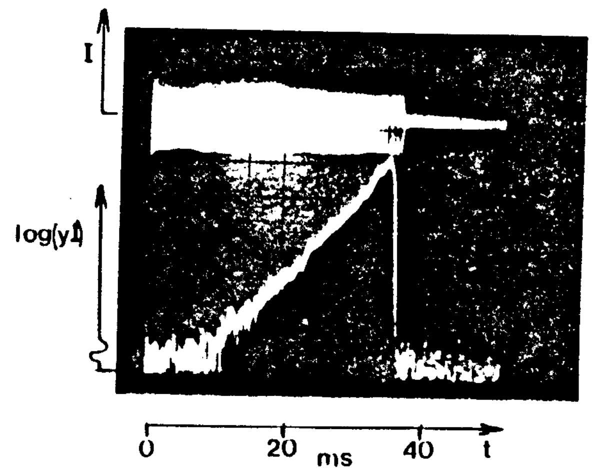
$$\frac{d(1/\tau)}{dI} \sim 4 \cdot 10^6\,A^{-1}s^{-1}$$

Betatron frequency shift

The transverse reactive impedance can lead to a shift of the betatron frequency with increasing current. This has been observed in the damping ring for the vertical tune. At an energy of 0.95 GeV and for a bunch length of 4.5 mm this shift was

$$\frac{d\nu_y}{dI} \sim -0.104\,A^{-1}.$$

Extrapolating this to the design current of 68 mA this tune shift becomes just about half of the synchrotron tune and the fast head tail instability might occur. However at the design energy of 1.21 GeV the situation should be stable.



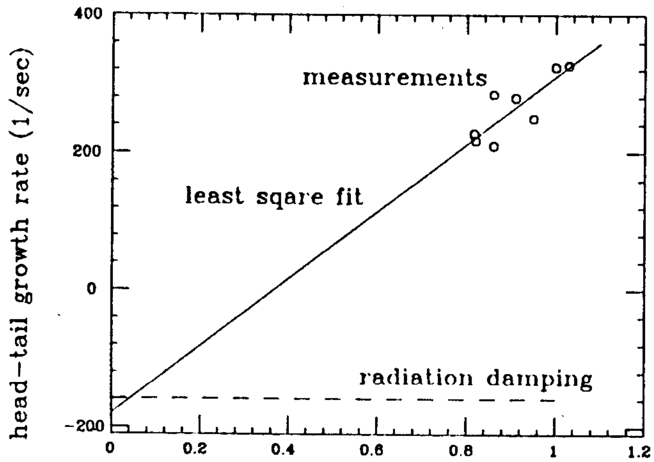


Fig 3: Growth rate of the head-tail instability. Top: exponential growth of the amplitude, bottom: growth rate vs. current.

Impedance estimate

As a simple model for the impedance of the damping ring we used a broad band resonator with resonance frequency f_r, shunt impedance R_s and quality factor $Q = 1$ and tried to fit the measured data which all represent integrals over the impedance times the spectra of the bunch modes. For the longitudinal data we get a reasonable fit with $f_r = 5\,GHz$ and $R_s = 2.8\,k\Omega$. The relatively high resonance frequency is consistent with the small dimension of the vacuum chamber of the damping ring. For the impedance divided by the mode number (n = freq./rev. freq.) at low frequency we get $Z/n \sim 4.5\,\Omega$. Taking an effective chamber radius of ~12 mm we get a reasonable fit through the tune shift measurements but too large a value for the head-tail growth rates.

In summary, the measured intensity dependent effect are not far from reasonable expectations and indicate no problems for the design intensity operation. Recently a current of 55 mA ($4 \cdot 10^{10}$*particles*) has been successfully stored in the ring.

Beam loading compensation for the RF-system

The single turn injection of electron bunches with $5 \cdot 10^{10}$ particles causes large transients in the RF-system which makes it necessary to provide a phase jump at the injection time[7]. The damping ring RF-system provides a fast phase shifter, which can produce the required phase jumps of about 50° in 100 ns at the drive to the cavities. The system is operational and has been tested with $\sim 10^{10}$ injected particles. The results are shown in Fig.4 which demonstrates that the correct phase jump significantly reduces the excitation of phase oscillations at injection.

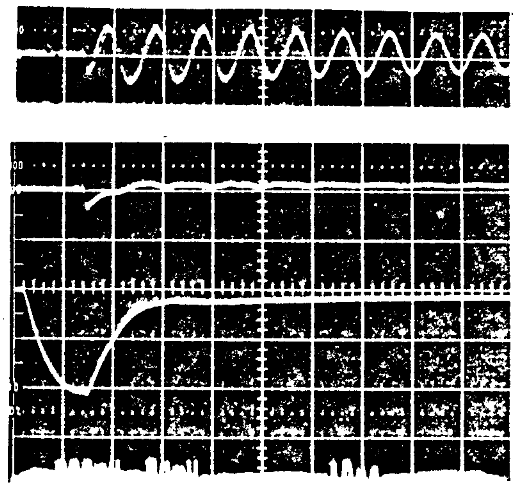


Fig.4: Beam loading compensation. Top trace: synchroton oscillation performed by the beam starting at injection, middle trace: beam phase oscillation after phase jump is applied, bottom trace: actual phase of the RF-field in the cavity which presets RF for better injection (phase jump 28°).

Ions

We have seen no ion effects in the vacuum chamber well cleaned by the synchrotron radiation as corroborated by the measurements of the betatron tune shift with intensity presented above as well as by exciting the beam with the kicker and observing no tune change. By artificially worsening the vacuum in the ring we were able to observe positive tune shift with intensity. Up to the intensity of $4 \cdot 10^{10} e^-$ per bunch we have observed no deleterious effects that we would feel compelled to attribute to ions.

References:

[1] G. Fischer *et al.*, Proc. 12th Int. Conf. on High Energy Accel., FNAL (1983) p. 37.

[2] J. Jaeger, M. Lee, M. Woodley, SLAC-PUB-3408 (1984).

[3] J.P. Delahaye, L. Rivkin, contribution to this conference.

[4] L. Rivkin, PhD Thesis, Caltech.

[5] P. Wilson, J. Styles, K. Bane, IEEE Trans. on Nucl. Sci. NS 30-4 2400 (1983).

[6] M. Allen *et al.*, IEEE Trans. on Nucl. Sci. NS 22-3 1838 (1975).

[7] M. Allen, H. Schwarz, P. Wilson, IEEE Trans. on Nucl. Sci. NS 30-4 3447 (1983).