Measured Emittance versus Store Time in the SLC Damping Ring*

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Abstract

Emittance studies at the SLC North Damping Ring led to precise measurements of the damping time using three independent methods. These measurements were done at three different locations: (1) in the ring using a fast gated video camera which allows the acquisition of the image of the synchrotron light from a single turn, (2) using the extracted beam and a single wire scanner in the ring-to-linac transport line, and (3) in the linac using four wire scanners. In addition the extracted beam emittance was studied as a function of various parameters. A significant dependence on the tune was observed.

Introduction

The Stanford Linear Collider uses two damping rings, the North Damping Ring (NDR) for the electrons and the South Damping Ring (SDR) for the positrons, to reduce the emittance of the beams before they are injected into the main part of the linear accelerator. The operating energy is 1.153 GeV. A small emittance of 12.1 nm rad is achieved by strong focussing with $\nu_x \approx 8.25$ and $\nu_y \approx 3.25$. The short circumference of 35.26 m and a small bending radius of about 2 m provide a short horizontal damping time of 3.8 ms. The nominal RF frequency is 714 MHz which corresponds to the 84^{th} harmonic of the revolution frequency.

The SLC damping rings were commissioned in 1984 and 1985. At that time the emittance measurements were done using a profile monitor in the ring-to-linac (RTL) transport line or a synchrotron light monitor. In 1984 the damping time in the SDR was also obtained indirectly, from the measured radiation loss per turn [1]. The 1984 results indicate that the damping times were roughly correct.

Recently a fast gated camera was installed which views synchrotron light from an NDR bending magnet. This allows the damping time to be measured directly, independent of the extraction process. Wire scanners were installed in the RTL and early in the linac to allow fast emittance measurements.

I. Measurement methods

Both damping rings are operated close to the coupling resonance $\nu_x - \nu_y = 5$. The closed orbit deviation is kept below 0.6 mm r.m.s. in both planes. The normalized emittance coming into the NDR may vary between 10 to $50 \cdot 10^{-5}$ m-rad.

Synchrotron light monitor

The synchrotron light monitor images the light produced in a bending magnet on a fast gated camera, which allows the acquisition from a single turn when triggered at 17 MHz [2]. The background subtracted digitized signal is projected onto horizontal and vertical axes from which the beam centroid position and the beam widths were extracted. The widths were obtained by fitting a Gaussian to the measured projection and the emittances were obtained using the model values of the beta function ($\beta_x, \beta_y = 0.66, 5.6$m) at the source point.

Wire scanner in the RTL

A wire scanner is located about 10 meters downstream of the damping ring in the ring-to-linac (RTL) transport line. The transverse beam size is measured with this wire scanner as a function of the strength of a quadrupole located upstream of the wire. The square of the beam size is fitted to a parabola from which the beam emittance and the beta functions are extracted. The beam size resolution of the SLC wire scanners is better than 10 μm.

Wire scanner in sector 2

A group of four wire scanners is located about 60 meters downstream of the damping ring in sector 2 of the linac. This group can be used to separate the twiss parameters and the emittance without adjusting any magnetic elements. The four measurements provide an additional degree of freedom and allows one to estimate the errors [3]. In 1991 the ring was operated mostly at the old working point at $\nu_x, \nu_y = .17$. At the end of that running cycle the tunes were changed and about 10 % smaller emittances:

$$\epsilon_x\gamma + \epsilon_y\gamma = 3.0 \pm 0.2\ 10^{-5}\ m - rad$$

were seen slightly above the $\nu_x, \nu_y = 1/4$ resonance (new working point in 1992). This is slightly higher than the expected $2.73 \cdot 10^{-5}$ m-rad predicted from the evaluation of synchrotron integrals. The difference between measurement and prediction may be due to misalignments of magnets which disturb the lattice functions and generate dispersion errors [4].

II. Damping time

The beam widths measured as a function of storage time were fitted to the relation:

$$\sigma^2(t) \propto \epsilon(t) = \epsilon_0 e^{-2t/\tau} + \epsilon_\infty(1 - e^{-2t/\tau})$$

where ϵ_∞ denotes the equilibrium emittance, ϵ_0 the initial emittance and τ the transverse damping time. In 1991 the only data available were from wire scanners in sector 2 of the linac. At that time the horizontal measurements seemed to indicate a flat top, e.g. apparently no damping, of the horizontal emittance in the first few milliseconds of storage time. In 1992 these measurements were repeated and the flat top region was not observed in the horizontal data beyond 1.5 msec when the normalized emittance coming into the damping ring was below $\gamma\epsilon_{x,t=0} < 20 \cdot 10^{-5}$. Scraping on the horizontal aperture in the extraction channel is a possible explanation for the flat top region of the horizontal data in the first milliseconds.

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Figure 1 shows a typical fit to the beam sizes as a function of storage time as measured by the synchrotron light monitor. Figure 2 shows the corresponding fit to the emittance measurements in the linac. A summary of the measured damping times obtained from the different measurement methods at the new working point near $\nu_x, \nu_y \approx .27$ is given in Table 1.

The horizontal damping times obtained by the different measurement methods agree fairly well with the prediction within the error bars. The vertical damping time appears slightly higher than the horizontal. The equilibrium value of the emittance extracted from the synchrotron light data is enlarged by the $70 \pm 10\, mum$ resolution, σ_{res}, of the system which is equal to the horizontal beam size at equilibrium. Thus

$$\sigma^2_{meas} = \sigma^2_{res} + \epsilon\beta \ ,$$

and the error on the horizontal equilibrium emittance is dominated by the uncertainty in the resolution. However

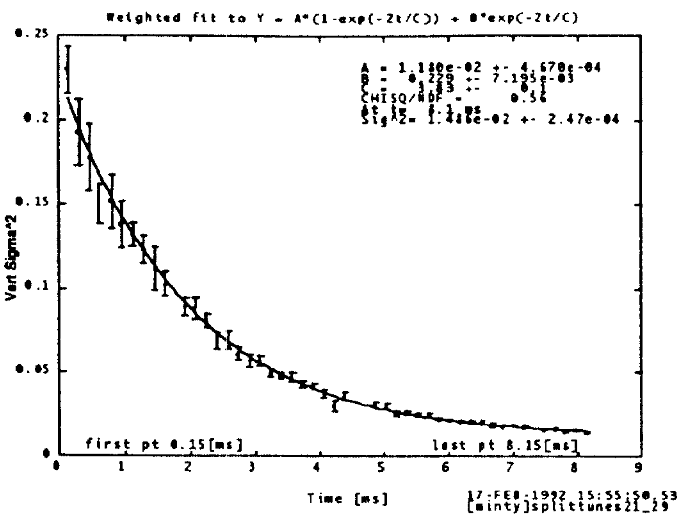

Figure 1. NDR Synchrotron light camera: beam size vs. time

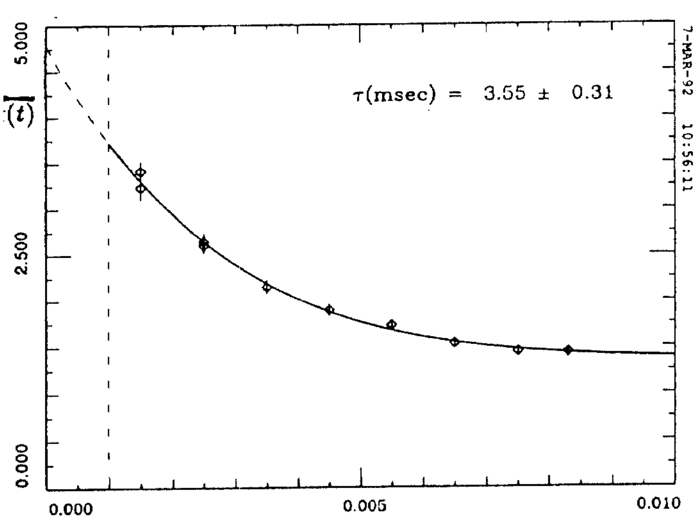

Figure 2. Linac wire scanners: extracted beam emittance vs. time (sec)

the given damping times are independent of the resolution which is substracted in quadrature from the beam width measurements.

Damping time vs. tune

The tune dependence of the horizontal damping time was studied with the fast gated synchrotron light camera. The measurements, which are summarized in Table 2, show a strongly increasing horizontal damping time with decreasing horizontal tune.

Measurements in 1991 of the extracted emittance in sector 2 showed a much weaker dependence of the horizontal damping time with the horizontal tune. At that time it was found to be important to steer the vertical orbit while decreasing the horizontal tune.

III. Emittance vs. tune and current

Changing the horizontal tune from $\nu_x = 8.17$ to $\nu_x = 8.29$ was observed to have a sensitive effect on the horizontal emittance. Figure 3 contains two data sets showing the horizontal emittance after storing the beam for 5.5 ms as a function of the horizontal tune. The beam was uncoupled, e.g. the fractional parts were separated by more than 0.05 and the current corresponded to $1.7 \cdot 10^{10}$ electrons.

In 1992 the tune dependence of the horizontal emittance was studied under coupled running conditions. Figure 4 shows a data set for $2.0 \cdot 10^{10}$ electrons. At each of the plotted data points the tune separation was adjusted in order to minimize the horizontal emittance. At the third and the fourth order resonance $\nu = 1/3, 1/4$ about one quarter of the electrons were lost, but the emittance remained small. Taking into account the coupling, these measurements have slopes which agree within a factor of two.

Table 1. Measured damping time for coupled tunes

method	τ_x [ms]	τ_y [ms]
Theoret.	3.84	3.88
Linac	3.8±0.2	4.2±0.2
RTL	3.95±0.3	3.95±0.25
Syn. light	4.03±0.19	4.25±0.16

Table 2. Synchrotron light camera
Damping time vs. tune

ν_x	ν_y	$\Delta\nu$	τ_x $[ms]$	τ_y $[ms]$
8.305	3.200	.105	4.81±0.17	3.86±0.08
8.289	3.260	.030	4.03±0.19	4.25±0.16
8.272	3.257	.015	3.74±0.09	4.40±0.17
8.229	3.279	.050	6.36±0.41	4.06±0.08
8.213	3.288	.075	6.11±0.42	3.99±0.05
8.213	3.288	.075	6.63±0.69	3.83±0.10
8.186	3.307	.121	9.31±0.84	4.12±0.09

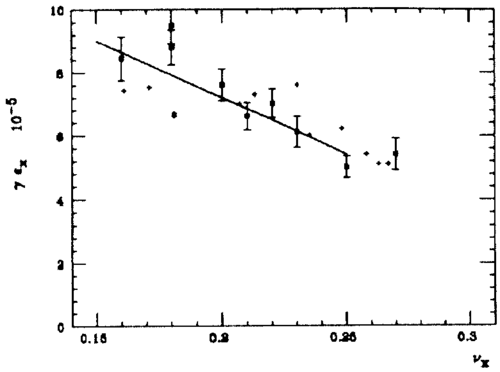

Fig. 3 ϵ_x at 5.5 ms vs. ν_x: uncoupled ring

The measured dependence of the emittance from the horizontal tune may be explained by dispersion generated by alignment errors which increases for a decreasing horizontal tune [4].

Emittance vs. current

Transverse wake fields in the damping ring itself or in the RTL might cause an emittance increase. Orbit bumps in the RF section of the ring did not enhance the emittance measured in sector 2. In a separate measurement the emittance was measured in sector 2 as a function of current. Figure 5 shows the measured data points. No increase of emittance with current was observed. These measurements were done with no bunch compression in the RTL.

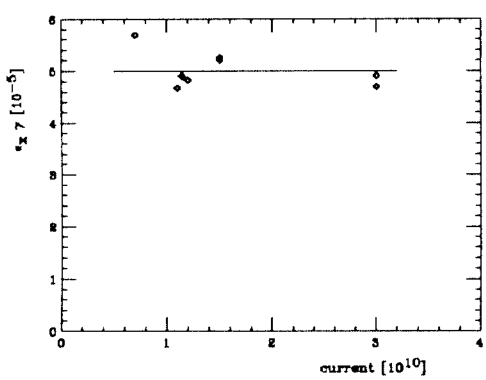

Fig. 5 emittance in sector 2 vs. current

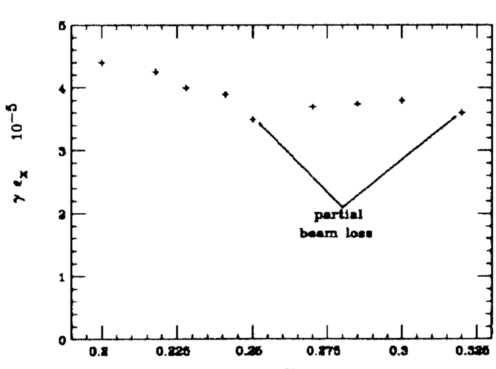

Fig. 4 ϵ_r at 5.5 ms vs. ν_x: coupled ring

Emittance vs. changes in circumference

In a storage ring the beam parameters vary with the RF frequency, which is a powerful tool to adjust the damping partition between the transverse and the longitudinal planes. However, the RF frequency of the SLC damping ring is locked to the frequency of the linac RF and damping time or emittance may not be optimized by off-momentum operation.

Unexpected tunnel temperature deviations between normal operation and the alignment period of the ring may have caused a change of about 5 mm in circumference which translates to a 1 % change of particle momentum: $\Delta R/R = -\alpha \Delta p/p$. A corresponding drift of about 1 mm in the horizontal orbit which has been observed between the running period 1991 and the first months of the 1992 run.

Emittance measurements using the wire scanners in sector 2 of the linac in 1991 and in 1992 show a change of 10 to 15 % which may be explained by a 10 to 15 % percent increase of the horizontal damping partition number J_x:

$$\epsilon_x(\delta) \propto \frac{E_0^2}{J_x(\delta)} .$$

A change of the horizontal damping partition number should increase the horizontal damping time by the same amount.

IV Conclusions

The transverse damping time and beam emittance were studied as a function of several ring parameters including tune, store time and bunch charge. Results from three different damping time measurement methods deviate less than 10 % from each other and from the theoretical prediction. The equilibrium emittances appear to be consistent with the prediction (perhaps 10 % high).

However, midway through the damping cycle (5.5 ms), the horizontal emittance is strongly tune dependent. The emittance depend mildly on the injected beam energy spread. Also, several transverse resonances are observed affecting the damping time and emittance in the horizontal tune range of 8.16 to 8.39. Changes in circumference translate into particle momentum deviations, which affect the damping partition of the ring and hence the equilibrium emittance. Additional studies are planned.

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