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FAST DAMPING OF TRANSVERSE COHERENT DIPOLE OSCILLATIONS IN SPEAR*

The SPEAR Group**
Stanford Linear Accelerator Center
Stanford, California

Summary

The fast damping phenomenon observed in SPEAR is discussed in this paper. Some of the effects of various beam parameters such as chromaticity, rf voltage, octupole lens strength and beam current upon the fast damping are presented.

Introduction

Fast damping of coherent transverse oscillations of the center of charge of a single bunch beam has been observed in VEPP-2[1] and SPEAR. This damping for horizontal oscillations has been studied in SPEAR and the results seem to be consistent with those predicted by the "Head-Tail" theory for wake fields that vary rapidly over the length of the bunch.[2,3,4,5] This phenomenon was investigated experimentally by shock-exciting the beam horizontally and then observing the decay of the amplitude of the coherent signal. In order to establish that the decay of the coherent signal corresponds to a decay in particle amplitude and not to a randomization of phases of the coherent motion, the transverse particle density was also observed as a function of time. This damping rate has been measured for various parameters of the beam. It has proven possible to eliminate this fast damping of particle amplitude by means of octupole fields which produce a spread in the particle betatron frequencies, leading to Landau damping of the coherent motion.[6]

Experimental Observations

The two kickers which produce the required beam bump during injection were used to produce an initial amplitude of the horizontal oscillation for the center of charge of a stored beam.[7] By varying the relative strength of the kicker pulses, it was possible to excite horizontal amplitudes that were large enough to be detected and studied.

The response of the beam after the kick is observed by two types of detectors.[8] The first of these is a strip-line monitor that gives a signal proportional to the position of the center of charge of the beam. The second is a profile monitor that scans the synchrotron light emitted by the beam; the maximum output signal from this monitor is proportional to the maximum density of the beam averaged over times longer than the transverse betatron oscillation period. Thus the maximum signal from the profile monitor is inversely proportional to the beam width. The beam width derived from the profile monitor includes the contribution from the incoherent particle motion and coherent motion at the betatron frequency. An example of the fast damping as observed by the two detectors is shown in Figs. 1 and 2. The two figures are for identical beam parameters but different sweep speeds. The top traces are the envelope of the coherent beam motion while the bottom traces are the evolution of the peak particle density.

If the peak particle density increases while the coherent signal decays, then this would be evidence that the amplitude of the oscillation decays, while if the peak particle density does not increase, this would be evidence that the decay of the coherent signal is due to a randomization of the phases of the coherent motion. Figures 1 and 2 are thus evidence that the amplitude of the oscillation decays. Since the active feedback system was off during these experiments and the radiation damping time is long (~60 msec for beam parameters in Figs. 1 and 2) compared to the fast damping times measured in SPEAR, there must be a feedback field produced by the beam in its passive surroundings.

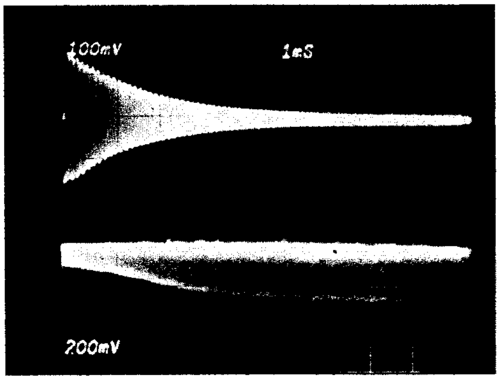

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Fig. 1. Fast Damping

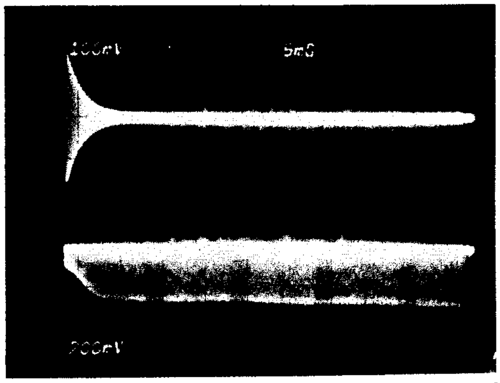

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Fig. 2. Fast Damping

Low Current Phenomena

In this section, the fast damping phenomenon discussed will be for currents in a single bunch <40 mA. The fast damping rate of horizontal coherent oscillations as a function of horizontal chromaticity ξ_x is shown in Fig. 3 for three values of the rf voltage.

In this figure, the energy was 1.5 GeV, the average current 20 mA and the chromaticity ξ_x is defined by $\Delta\nu_x = \xi_x(\Delta p/p)$. One can see from Fig. 3 that the fast damping rate is a linear function of the chromaticity.

The bunch length in SPEAR shortens with increasing rf voltage; hence the results in Fig. 3 show that the variation of the damping rate with chromaticity, $d\alpha/d\xi_x$, decreases with increasing bunch length. This last fact is consistent with the "Head-Tail" instability with fast varying wake fields.

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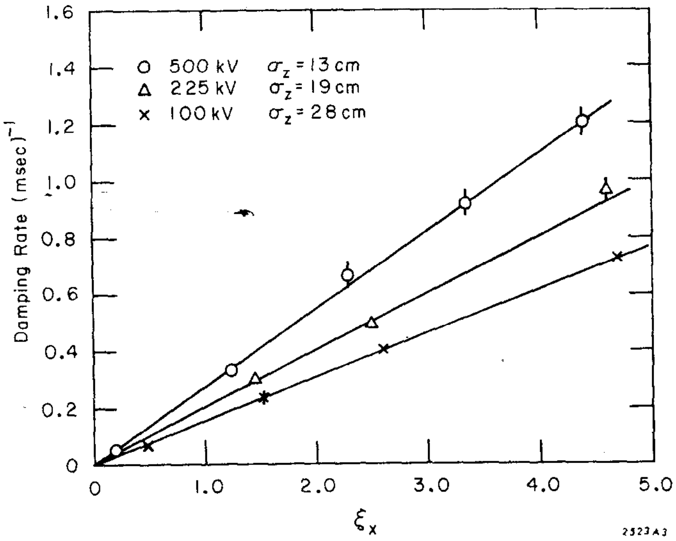

Fig. 3. Fast Damping rate versus chromaticity. E = 1.5 GeV; I = 20 mA

Below currents of 40 mA, the decay of the coherent oscillation signal observed is similar to the decay presented in Figs. 1 and 2. The damping rate versus the average current is shown in Fig. 4 for various values of the rf voltage with an energy of 1.5 GeV and chromaticity ξ_x = 2.4. Due to the bunch lengthening phenomenon in SPEAR, the length of the bunch increases with current and is probably the explanation of why the fast damping rate varies more slowly than linearly with current.

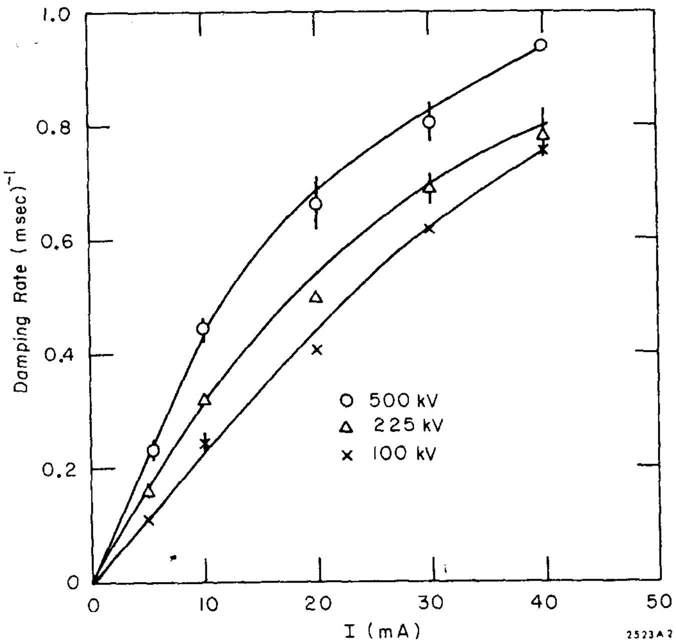

Fig. 4. Fast damping rate versus average current.
E = 1.5 GeV; ξ_x = 2.4

The fast damping rate, α, is normally expected to be inversely proportional to the energy so that the decay rate is plotted as a function of (1/E) in Fig. 5. Because the bunch length decreases as (1/E) increases (i.e., as the energy decreases), we see from Fig. 5 that α increases faster than (1/E).

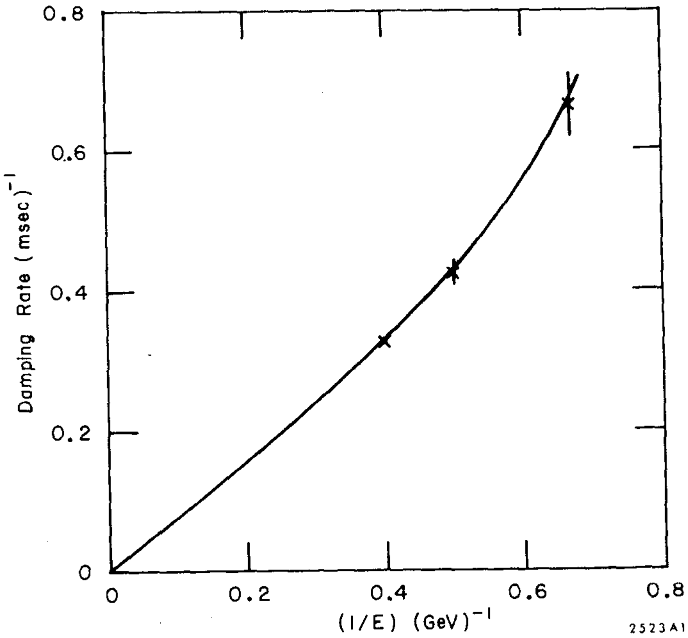

Fig. 5. Fast damping rate versus (Energy)$^{-1}$
I = 20 mA; V = 200 kV; ξ_x = 2.4

High Current Phenomena

When the current in a single bunch circulating in SPEAR exceeds 40 mA, the fast damping phenomenon is not as simple to interpret as it was for the lower current. The response of a 100-mA beam is shown in Figs. 6, 7 and 8. Again, the top traces are the envelope of the coherent horizontal motion for the center of charge in the beam while the bottom traces are the peak particle density averaged over the transverse betatron period. In all three figures, the beam parameters were identical except for the chromaticity and the rf voltage. The horizontal chromaticity ξ_x = 2.1 in both Figs. 6 and 7, but the rf voltage was 100 kV in Fig. 6 and 225 kV in Fig. 7. The rf voltage was 100 kV in Figs. 6 and 8, but ξ_x was 2.1 in Fig. 6 and 4.2 in Fig. 8. The motion displayed in Figs. 6, 7 and 8 seems to indicate that the center of charge is oscillating horizontally at more than one coherent frequency, and that the difference between these frequencies produces a beating that depends upon the bunch length and the chromaticity.

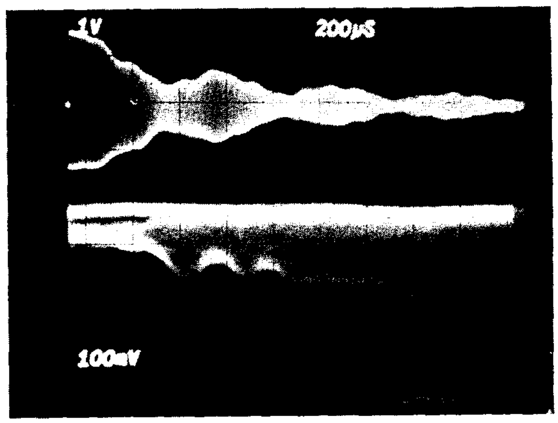

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Fig. 6. I = 100 mA; ξ_x = 2.4; V = 100 kV

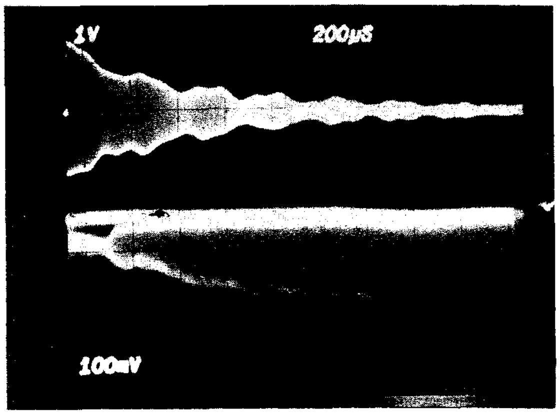

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Fig. 7. $I = 100$ mA; $\xi_x = 2.4$; $V = 225$ kV

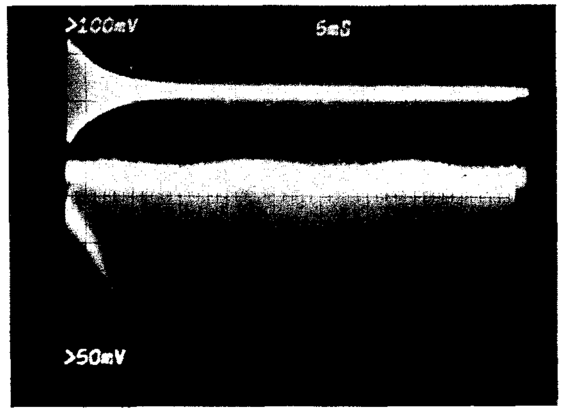

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Fig. 9. $I_{oct} > -3$A

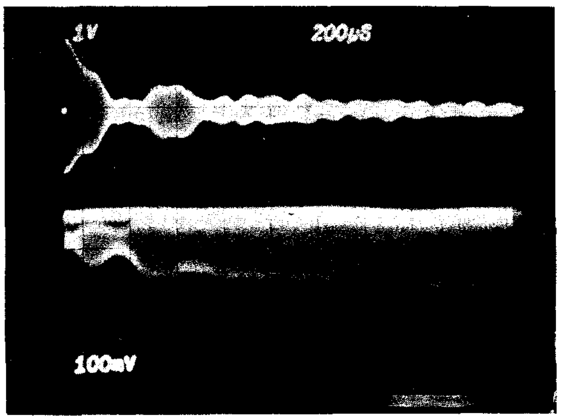

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Fig. 8. $I = 100$ mA; $\xi_x = 4.2$; $V = 100$ kV

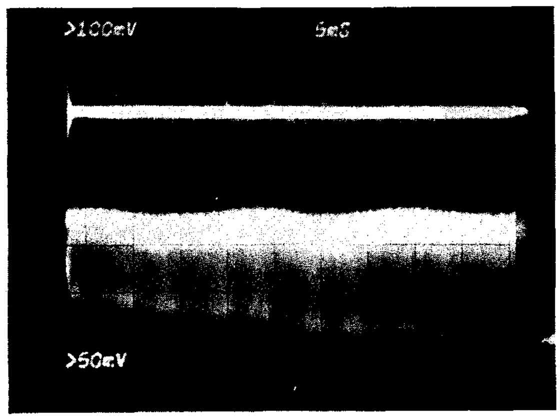

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Fig. 10. $I_{oct} = -5.6$A

For the case where the "Head-Tail" instability theory assumes a hollow bunch in longitudinal phase space, there should be only one frequency for the transverse coherent oscillation of the center of charge. However, if the bunch is not hollow in longitudinal phase space, it is possible to have several transverse coherent dipole modes with slightly different frequencies[2,4] and it is possible that these are what we observe in SPEAR for high current.

Landau Damping

In the SPEAR lattice, there are octupole lenses that can be powered to produce a variation of the transverse oscillation frequency with particle amplitude, a.

The octupole may be powered with up to ±20 amps, which yields up to $(\Delta\nu/a^2) = \pm 0.004/\mathrm{cm}^2$ for an amplitude variation of betatron wave numbers. The fast damping has been observed as a function of the octupole lens strength. It has been found that for a 10-mA beam, the fast damping is independent of the octupole lens strength in the range $-3\mathrm{A} < I_{oct} < 12$ A. On the other hand, if the octupole lens strength is sufficiently negative; i.e., $I_{oct} < -5.6$A, the fast damping disappears. This is shown in Figs. 9 and 10.

In Fig. 9, the $I_{oct} > -3$A, and we see that we have the usual fast damping; however, in Fig. 10, the $I_{oct} = -5.6$A, and we see that the coherent signal decays rapidly and the peak particle density is lower than was obtained for the fast damping case. We have interpreted these results as a Landau damping of the coherent motion. When the Landau damping is sufficient to damp the coherent motion, the resulting beam size is larger (peak particle density smaller) and the oscillation amplitudes are damped by the slower radiation process.

Acknowledgements

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