INTERACTION OF CESR VACUUM PUMPS WITH STORED BEAM*

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Abstract

The anomalous antidamping of some multibunch modes in CESR has been shown to depend on the distributed ion pumps being powered. The pumps also modify some other aspects of beam dynamics. These effects were observed in connection with studies of the behavior of the pumps thmeselves, which is affected in a complicated manner by the circulating beams. The results of some preliminary observations are reported.

Introduction

Since 1983, when CESR began operating with multiple bunches in each beam,[1] the damping rates of the various horizontal coupled-bunch modes were seen to behave anomalously, exhibiting a highly non-linear dependence on bunch current. Since some of the modes become unstable, the effect was labeled anomalous antidamping (AA). However, the instability can be controlled by head-tail damping or by feedback, so that in practice CESR operation is not seriously affected.

Our studies of the mechanism underlying AA have been reported previously.[2] Though they failed to identify the source of the interbunch (long-range) coupling, they documented its characteristics in detail. Most of the damping-rate measurements were made by shock-exciting the beam with a pulsed magnet and measuring the decay constant, $\alpha \equiv 1/\tau$, of the resulting coherent oscillation with a logarithmic, tuned detector. Known contributions to α (from radiation and head-tail damping)[3] were subtracted, leaving the long-range contribution, α^*.

A beam of b equal, uniformly spaced bunches has b modes which can be labeled by an index p (= 0,1,...b-1). As sampled by a short, position-sensitive detector, any given mode p delivers a signal spectrum

$$f_p = (Q + bn + p)f_0$$

where Q is the betatron tune, f_0 is the revolution frequency, and n takes on any integer value. By suitable choice of the detector frequency one can thus observe any desired mode. Other parameters available for control are b (we used b = 1,3,5,7, and 8) and Q (varied from 9.15 to 9.70). The principal observations are summarized below.

1. The interbunch coupling primarily affects horizontal motion. It is similar for e^+ and e^- except for minor differences which may be attributable to ion capture by an e^- beam.

2. Expressed as a transverse impedance, its long range implies a narrow bandwidth, suggesting either one (or a few) high-Q resonators or an impedance peaked at low frequency (similar to but about two orders of magnitude larger than the well known resistive wall impedance). The low-frequency peak can more naturally account for the observed damping rates as a function of b, p, and Q; the transverse impedance, $\mathrm{Re}\{Z_{AA}\}$, would have to vary roughly as $f^{-1/3}$.

3. A linear coupling impedance would produce a damping rate proportional to current, $\alpha^* \propto I$. This is far from the observed behavior. A plot of the damping rate due to AA only, α^*_{AA}, versus I (for a given b) shows a characteristic S-shape, including a sign reversal. This shape, though it varies slightly for different values of b, is more nearly a function of I than of bI. For any given I, however, α^*_{AA} scales roughly with b. Figure 1 displays α^* (which includes α^*_{AA} and damping due to other coupling impedances) versus I for a positron beam with Q = 9.42, b = 3, and coupled-bunch modes, p = 0 and 2.

4. The decay of coherent multi-bunch motion is exponential over a large range of amplitudes, indicating that the wakefields responsible for AA are proportional to bunch displacement.

5. AA is a reproducible phenomenon, with the same behavior over long periods of time despite significant changes in the CESR lattice, the number of RF cavities, and special vacuum elements (such as ceramic sections), and under various operating conditions (bunch length or vacuum pressure bumps).

Present Observations

In the Spring of 1988, in conjunction with studies of CESR vacuum pump behavior, we learned that AA disappeared when the distributed vacuum pumps (DP) in the ring were switched off. The evidence for this is presented in Fig.2, where α^* is plotted versus I for the same two modes and for the same conditions as in Fig.1, except that the distributed pumps have been turned off. The anomalous current dependence of the damping has disappeared.[4] The mechanism whereby the DPs interact with the beam is not apparent from these preliminary observations, but some significant features were noted:

1. The interaction appears to depend on the presence of an electrical discharge, not just on pump pressure. When power is turned off and on again, AA disappears and reappears with the time constant of the power-supply filter capacitors; there is no evidence of any AA effect from either the residual getter-pumping or from the pressure burst usually associated with a pump powerup transient.

2. The magnitude of AA scales roughly with the total length of DP turned on, with the exception, however, that the DPs installed in the "hard-bend" regions of CESR have little or no effect. These pumps have an extra slotted copper shield, intended to absorb the larger amounts of synchrotron radiation produced in the high-field magnets. This shield may also provide better RF isolation of the pumps and the beam.

At the same time as these damping measurements we measured the coherent tune shifts as a function of I for single-bunch beams, to see if the DPs had any effect on the reactive part of the impedance. The tune-shift curves may generally be represented as straight lines whose slope, dQ/dI, parametrizes the reactive impedance. With the DPs off dQ/dI is very nearly the same for e^- and e^+:

$$(dQ/dI)_H = -1.8\times10^{-4}/\mathrm{mA}\ ;\quad (dQ/dI)_V = -6.7\times10^{-4}/\mathrm{mA}$$

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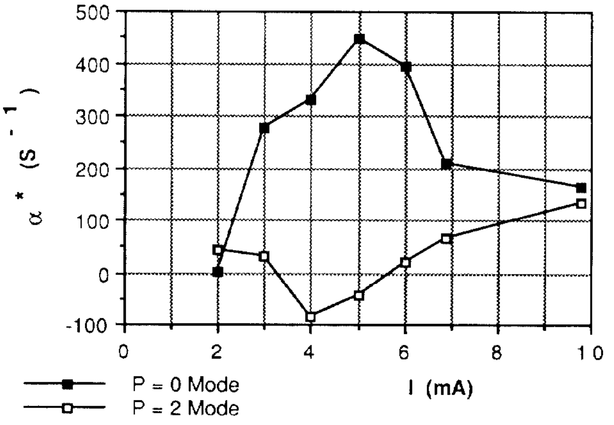

Figure 1. Damping Rate vs. Bunch Current for 2 of 3 Horizontal Dipole Coupled Bunch Modes for All Vacuum Pumps ON

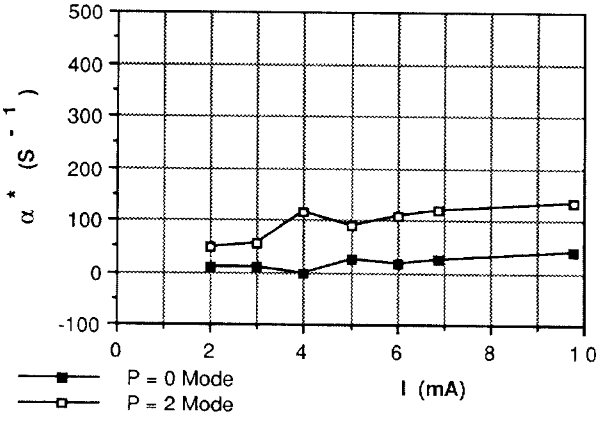

Figure 2. Damping Rate vs. Bunch Current for 2 of 3 Horizontal Dipole Coupled Bunch Modes for Distributed Vacuum Pumps OFF

With the DPs turned on there is a change of dQ/dI, different for the two polarities of beam. The <u>increments</u> in dQ/dI caused by the pumps are:

	H	V	
e^+	-1.2	+0.4	) $\times 10^{-4}$/mA
e-	-0.1	+0.9	)

There are two other dynamical effects worth noting. With the DPs off we observed a single-bunch vertical m=1 head-tail instability for both e^+ and e^- beams. This instability does not always appear, but when present it is suppressed immediately by turning on the DPs. With the DPs off we also observed that the RF voltage required to achieve a given quantum lifetime was reduced by 30-40%.

Vacuum Pump Behavior

In addition to the DPs which are part of the guide-field magnet vacuum chambers, CESR has commercial Vacion pumps ("lumped pumps", LP) which are installed in the straight sections of the ring. In total there are about 95 LPs and 85 DPs (10 of the latter in the hard-bend regions). The DPs communicate with the beam chamber via the conventional slots (two rows of slots, placed symmetrically above and below the median plane and separated by about 12 mm; each slot is about 25 mm long and 3 mm high). In the hard-bend region the DPs are further shielded by a mask whose slots are offset relative to the DP's conventional slots and provide total optical isolation in addition to added RF shielding. A few of the LPs are partially shielded from the beam RF by perforated screens which, unlike the hard-bend screens, provide no optical isolation.

A study of the CESR vacuum system was undertaken after the start of seven-bunch operation, which required an increase of total beam current (so far to about 160 mA). Although beam lifetime is not at present limited by the ring pressure, in anticipation of still higher beam currents it became desirable to estimate the lifetime effect from the increased gas load produced by irradiation of the vacuum chamber walls.

Under stored-beam conditions most of the vacuum pumps in CESR draw currents from their power supplies at least an order of magnitude higher than what would correspond to the pressure in the ring, if the normal current-vs-pressure curves for the pumps were applicable. Our best pressure estimates are about 5×10^{-9} torr with no beam, increasing to less than 10^{-8} torr at a stored beam of 80 mA. To corroborate these estimates, residual pressure was deliberately raised by turning off all the DPs in the ring; after continuous operation with a beam of 80 mA for 20 minutes, lifetime decayed to a value consistent with an average pressure of only 10^{-8} T.

In general, pump currents are complicated functions of the total beam current (bI) and the number of bunches (b) as well as depending on the polarity of the stored beam. Although there is a large variation in the scale and functional dependence for different pumps, pumps of similiar type and in similiar location exhibited the same characteristic behavior. Some of our observations are tabulated below:

1. The e^- and e^+ data is significantly different for the same pump (see fig 3B and C).

2. Data for LPs near bends and DPs is characterized by an enhanced pump current scale (figure 3A,B,C). Full scale for these graphs would represent a vacuum of 1×10^{-7} if normal pump-vs-pressure calibrations were used. These pumps also exhibit a large linear term α bI. A marked exception to this is found in the DPs in the hard bend region which have shields and show almost normal response to stored beam.

3. Data for LPs far from bends (especially when there are intervening LPs) have almost normal currents and slopes but still show a bunch dependence.

4. e^+ data for DPs (except for the hard bends) exhibit a strong bunch dependence α positive bI^2. (See fig. 3A.)

5. e^- data for LPs near bends exhibit a strong bunch dependence α negative bI^2. (See fig. 3B.)

6. e^- data for DPs and e^+ data for LPs near bends show little bunch dependence. (See fig. 3C.)

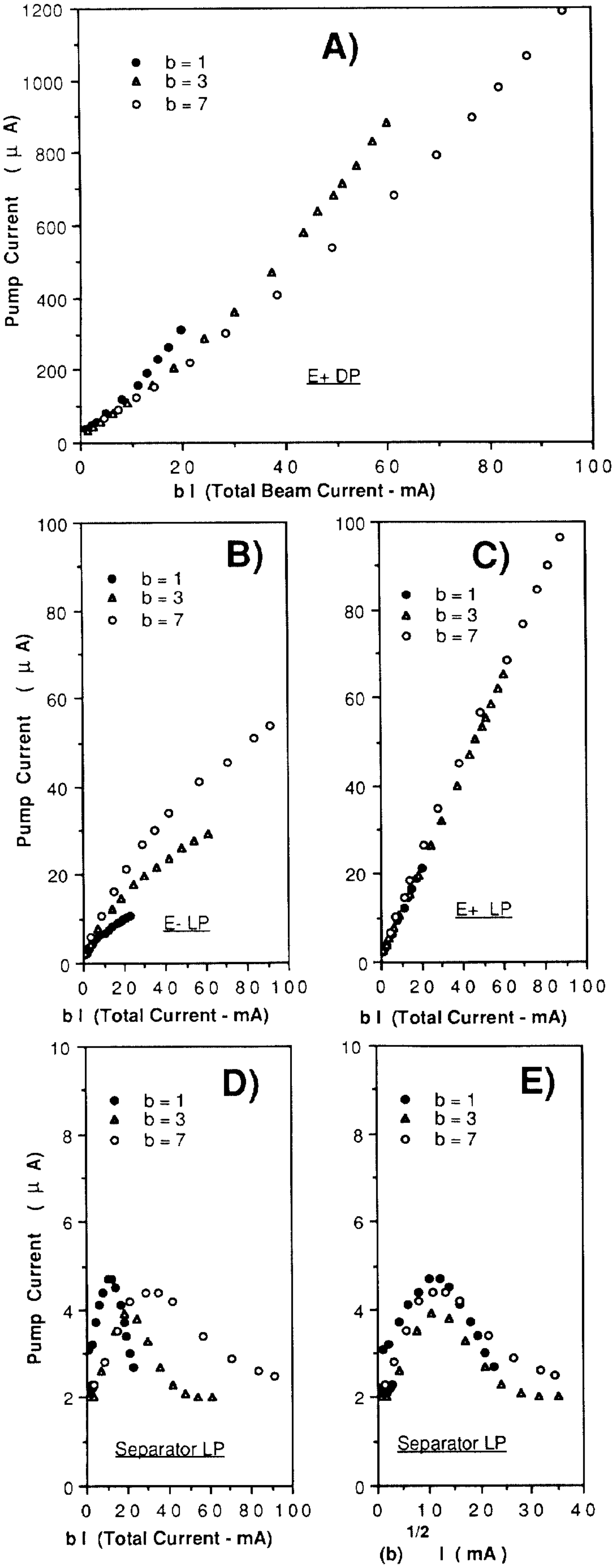

Figure 3. Vacuum Pump Current Versus Beam Current

7. LPs in environments susceptible to large amounts of RF (such as in the vertical separator in figure 3D) tend to show a very non-linear dependence on bI^2. The evidence for bI^2 dependence can be seen in figure 3E, where data for different bunch numbers, b, are plotted versus $b^{1/2}I$, rather than bI, and thereby exhibiting rather similar functional forms independent of b.

So far we cannot claim to understand the dependence of pump current on beam. There are however several mechanisms which could be relevant to an explanation of the observations and deserve consideration.

1. Fluorescent radiation coming from synchrotron radiation in and around the bending magnets could produce photocurrents proportional to bI.

2. The beam radiates large amounts of RF power over a spectrum extending to very high frequencies (several GHz, depending on bunch length; currently, σ_t = 60 ps). These RF fields, or fields produced by their interaction with plasma present in the vacuum pumps, could cause heating of elements within the pumps (a positive bI^2 dependence). These RF fields and their interaction with the pump could also be responsible for other observed non-linear effects as well as interfering with the actual pumping speed of the pump.

3. The pump-current-pressure calibration is likely to be different for ionized and neutral gas and should be considered.

4. e^+ and e^- beams interact differently with ions; this may need to be taken into account as affecting both the vacuum dynamics and the radiated RF fields.

These mechanisms, among others, provide a basis for further study and experimentation when CESR resumes operation. It is however already clear that the influence of beam RF is very pervasive, suggesting a possible link with the AA effect here shown to be attributable to the pumps.

References and Notes

[1] R. Littauer, "Multi-bunch Operation of CESR," IEEE Trans. Nucl. Sci., NS-32, No. 5, p. 1610-1613, Oct. 1985.

[2] L.E. Sakazaki, et al, "Anomalous, Non-linearly Current Dependent Damping in CESR," IEEE Trans. Nucl. Sci., NS-32, No. 5, p. 2353-2355, Oct. 1985.

[3] In CESR, $\alpha_r = 34\ s^{-1}$; $\alpha_{HT} = IQ'(7\ s^{-1}/mA)$, where the chromaticity $Q' \equiv dQ/(dE/E)$ and I is the current per bunch.

[4] Some long-range coupling does remain, as evidenced by the fact that the two coupled-bunch modes have different damping. However, the residual coupling is much smaller, has a different dependence on b and p, and is consistent with proportionality to I.