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Effect of Reactive Feedback on the Transverse Mode Coupling Instability*

(Proposal for a Machine Experiment at PEP)

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1. Introduction

A reactive feedback system has been proposed[1] for LEP which will control the coherent betatron frequency with the aim to increase the threshold for the transverse mode coupling instability. The two particle model[2,3,4,5] has been used[6] to investigate the effect of this feedback system on transverse stability. This analysis predicted a significant increase in the threshold for instability. More recently the two particle model has been extended[7,8] to eliminate some of the more worrying simplifying assumptions. The improved model confirmed the previous predictions that reactive feedback can indeed increase the threshold for transverse instability due to mode coupling.

In parallel with these analytical techniques a multi-particle feedback simulation computer code was developed[9] which included many effects which were not included in the simple analytical models. The results of this simulation program highlighted some conditions[8] under which reactive feedback would not increase the threshold for instability even though the transverse coherent tune shift was perfectly compensated. The reasons for these discrepancies are not yet fully understood, although several likely hypotheses have been proposed and are being actively pursued. In view of the fact that the performance of LEP (and all other large e^+e^- storage rings) is thought to be dictated by this transverse instability, it is considered crucial that the effect of reactive feedback on this instability be known and tested.

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For this reason it is proposed that (as well as and in parallel to computer simulation) a reactive feedback test be performed on an existing large electron positron storage ring. The two largest electron positron storage rings in existence today (PETRA and PEP) have both experienced and suffered from this transverse instability. However, there are two important aspects in which their behavior is different. Firstly, in PETRA the instability occurs in the vertical plane much sooner than predicted by theory, whereas in PEP the agreement with theoretical predictions is reasonably good. Secondly, at the onset of instability coherent signals are not observed in PETRA while the opposite is true in PEP. This second observation indicates that the mode coupling in PEP is between the mode zero (which is controllable by reactive feedback) and the mode −1, whereas in PETRA the mode coupling appears to occur between higher modes. It is therefore apparent that the PEP storage ring is the perfect place to carry out a reactive feedback test.

2. Tune Shift Requirements

The transverse wake fields which are induced by particles at the "head" of the bunch influence particles at the tail of the bunch. Due to synchrotron motion the "head" and "tail" interchange roles once every half synchrotron period. The combination of these two phenomena cause frequency shifts of the natural modes of oscillation within the bunch. A simplified diagram of such frequency shifts as a function of bunch intensity is shown in Fig. 1.

The threshold for instability is reached when two intra-bunch modes have the same frequency. For short bunches the instability usually occurs when the frequency of mode zero decreases to meet the frequency of mode −1, i.e., instability occurs when

$$\frac{\Delta Q_W(n=0)}{Q_S} \simeq \tag{1}$$

Since mode zero is [illegible] the dipole moment of the beam it can be detected by a pick-up and acted upon by a deflector.

The aim of the reactive feedback system is therefore to maintain constant the frequency of mode zero. In order to do this the system must provide a tune shift ΔQ_{FB} given by

$$\Delta Q_{FB} = -\Delta Q_W \simeq Q_S \tag{2}$$

3. Conversion of PEP Feedback from Resistive to Reactive

The only essential difference between resistive and reactive feedback is the betatron phase advance from the pickup to the kicker. A resistive feedback system requires an odd multiple of $\pi/2$ whereas a reactive feedback requires a multiple of π. Usually the feedback "kick" is applied about one turn after detection of the "error" signal. Consequently the PEP resistive feedback system could be converted from resistive to reactive either by (1) increasing the machine tune by $\pi/2$, (2) waiting an additional turn before applying the kick, or (3) choosing a different pickup $\pi/2$ betatron radius away from the present one.

3.1 EXISTING PEP RESISTIVE FEEDBACK SYSTEM

The essential components of the PEP feedback system[10] are

1. Four strip-line pickups (one for each beam in each plane)
2. Electronics[11] to detect and measure the displacement of the center of gravity of each bunch
3. Amplifiers to amplify these center-of-gravity signals, and
4. Two 2.8 m long deflectors (one per plane) to apply the correcting kick.

This system was originally designed to produce a transverse damping time

$$\tau_{FB} = 2.45\,\text{ms at 14 GeV} \quad (700\,\mu s\,\text{at 4 GeV}) \quad . \tag{3}$$

This value determines the overall gain of the system. A reactive feedback system with identical gain (i.e., by simply increasing the phase advance from pickup to kicker by $\pi/2$) produces a coherent tune shift given by

$$\Delta Q_{FB} = \frac{t_{rev}}{2\pi\,\tau_{FB}} \tag{4}$$

Hence at 14 GeV the feedback tune shift is .00048 and

$$\frac{\Delta Q_{FB}}{Q_S} \simeq .01 \qquad (\text{for } Q_s \simeq .05) \tag{5}$$

It is clear from Eq. (5) that a reactive feedback test at 14 GeV using the present resistive feedback gain would be meaningless since the resulting tune shift is nearly two orders of magnitude too low. It is equally clear that this unfavorable ratio may only be improved by increasing ΔQ_{FB} and reducing Q_S.

3.2 INCREASING ΔQ_{FB}

In terms of hardware parameters the tune shift of the PEP reactive feedback system is

$$\Delta Q_{FB} = \frac{-c\ell_0 \sqrt{\beta_K \beta_{pu}}\, S\, A\, K}{4\pi (E/e)} \qquad (6)$$

where

c is the velocity of light

ℓ_0 is the length of the deflector (2.8 m)

E is the beam energy

S is the transfer function of the pickup plus detector circuitry (volts/m)

A is the gain of the voltage amplifier (volts/volts), and

K is the transfer function of the deflector (Tesla/volts)

If it is assumed that the kicker is given and immovable then the feedback tune shift may be increased by

(i) Increasing β_{pu}. This implies finding a pickup in the lattice which is situated at a high β and has the appropriate phase advance. One should also realize that the stripline pickups have been specifically installed to give a high sensitivity. It is hoped[12] that the reduction in sensitivity in going to "button" type pickups may be compensated by improvements in the detector circuitry.

(ii) Reducing the Beam Energy. The test of principle of reactive feedback may of course be done at any energy, however, the minimum energy at which PEP has operated is 8 GeV. It is generally felt that PEP could operate (with some preparation) in the energy range 5 → 8 GeV.

(iii) Increasing the Loop Gain A. The limit in increasing the loop gain A is given by saturation of the power amplifiers and the signal/noise ratio. This may best be explained by reference to Fig. 2 which shows a simplified block diagram of the system.

The displacement of the beam ($\bar{x}_{pu}$) is detected and converted into a voltage signal $S\ \bar{x}_{pu}$. The noise inherent in the detection is represented at V_{n1}. This noise has frequency components coincident with the required signal. This signal is then passed through a suppressed carrier modulator to prepare it for the kicker. Associated with this circuit there is noise (V_{n2}) introduced at the harmonic of the revolution frequency (but not at the frequency of the signal). The input voltage to the power amplifier V_{IK} is given by

$$V_{IK} = A(S\ \bar{x}_{pu} + V_{n1} + V_{n2}) \tag{7}$$

The amplifier saturates when $V_{IK} = \hat{V}_{IK}$. The signal/noise ratio (S_n) can be defined as $(S\ \bar{x}_{pu})/V_{n1}$ since V_{n2} is at a different frequency and does not affect the betatron motion of the beam. Hence

$$\hat{A} = \frac{\hat{V}_{IK}}{V_{n1}(1 + S_n) + V_{n2}} \tag{8}$$

where

$\hat{A}$ denotes the maximum value of loop gain compatible with maximum input signal to the power amplifiers.

It is clear from (8) that the maximum loop gain may be increased by reducing the signal/noise ratio S_n; this implies that the coherent signal $\bar{x}_{pu}$ should be reduced. The A may also be increased by reducing the noise V_{n1} and V_{n2} in the system: V_{n2} may be significantly reduced by filtering since it is at a different frequency, however V_{n2} is inherent in the detector design and is not easily improved upon.

The present values of the parameters in Eq. (8) are[12]

$$\hat{V}_{IK} = 3.0\,\mathrm{V}\ ; \qquad V_{n1} = 50\,\mathrm{mV}\ ; \qquad V_{n2} \simeq 50\,\mathrm{mV} \tag{9}$$

Hence for

$$S_n = 3 \quad \hat{A} = 12 \quad \text{and for } S_n = 8 \quad \hat{A} = 6 \tag{10}$$

3.3 REDUCING Q_S

The idea in reducing Q_S is simply to reduce the coherent tune shift at which the instability occurs. However, reduction of Q_S causes a reduction in the energy acceptance of the rf bucket (and hence the quantum lifetime) as well as an increase in the bunch length. It is known that the threshold for instability can be changed by large variations in the bunch length. However, since the bunch length σ_S is also energy dependent, i.e.,

$$\sigma_S \alpha \frac{\gamma}{\sqrt{J_E}\, Q_S} \tag{11}$$

the already proposed reduction in energy will help compensate for Q_S and maintain the bunch length reasonably constant.

The quantum lifetime due to particles escaping from the rf buckets is approximately given by

$$\tau_q = \tau_E \left(\frac{\sigma_E}{\Delta E}\right)^2 \exp\left(\frac{\Delta E^2}{2\sigma_E^2}\right) \tag{12}$$

where

τ_E is the energy damping time

σ_E is the rms energy spread of the bunch, and

ΔE is the half energy spread of the bucket, and are given by

$$\frac{\Delta E}{E} = \pm \frac{Q_S \gamma_t^2}{h} \left\{\frac{2[2\cos\phi_s - (\pi - 2\phi_s)\sin\phi_s]}{\cos\phi_s}\right\}^{\frac{1}{2}} \tag{13}$$

$$\frac{\sigma_E}{E} = \sqrt{\frac{c_q}{J_E \rho}}\,\gamma \tag{14}$$

Normally for $\Delta E \approx 6\sigma_E$ the quantum lifetime is tens of hours. Imposing this condition in Eqs. (13) and (14) dictates the minimum value of Q_S which will allow a reasonable quantum lifetime, i.e.,

$$(Q_S)_{min} = \frac{6h}{\gamma_t^2} \left\{\frac{2[2\cos\phi_s - (\pi - 2\phi_s)\sin\phi_s]}{\cos\phi_s}\right\}^{-\frac{1}{2}} \sqrt{\frac{c_q}{J_E \rho}}\,\gamma \tag{15}$$

For a ϕ_s of around 140° the term inside the curly brackets is around unity. For the PEP parameters; $h = 2592$, $\gamma_t = 19.6$, $\phi = 140°$, $\rho = 165$ then

$$(Q_S)_{min} = 2.7 \times 10^{-3}\, E \qquad (E \text{ in GeV}) \tag{16}$$

($Q_S = .022$ at 8 GeV and .013 at 5 GeV).

It can be seen from Eq. (15) that Q_S may be decreased (at constant energy and maintaining constant quantum lifetime) by (i) stronger horizontal focusing, i.e., increasing γ_t and/or (ii) decreasing the energy damping partition number J_E.

4. Horizontal or Vertical Test

In order to simplify the experiment it would be helpful to provoke the transverse instability and apply the feedback in one plane only: it would, for example, be confusing for the interpretation of the results if the feedback cured the vertical instability only to find the horizontal instability at a small increment in beam intensity. For this reason, machine configurations were sought which would increase (decrease) the threshold for instability in one plane for above (below) that for the other plane.

The transverse mode coupling instability is governed by the product of the betatron amplitude function β (at the source of the transverse impedance) and the value of the transverse impedance. For an existing machine this means that the instability may be controlled by controlling the β values in the rf cavity regions. Since, in PEP, the cavities are close to some interaction points the first attempt to change their β values was to change the β at the interaction points.[13] For each configuration the sum of the β values in the cavity regions were evaluated in both planes for comparison. These results are shown in Table I.

Inspection of this table indicates that it is relatively easy to increase the threshold for vertical instability far beyond that for horizontal, but not the reverse. *It therefore appears that the test should be prepared for the horizontal plane.* It is also worthwhile to note[14] that with the usual PEP configuration (row 1 of the table) the instability does occur first in the horizontal plane (but at higher intensities than are required to reach the beam beam limit).

Table 1. Comparison of Horizontal and Vertical Instability For Various Configurations[13]

Q_x	Q_y	γ_t	β_x^*	β_y^*	$\hat{\beta}_x$	$\hat{\beta}_y$	$\Sigma\beta_x$	$\Sigma\beta_y$	$\frac{\sum\beta_x}{\sum\beta_y}$	$\beta_{xpu\,20}$
							(over 8 cavities)			(m)
21.25	18.20	19.7	2.7	0.11	191	435	394	110	3.6	145
21.25	18.20	19.7	4.5	0.11	129	435	262	113	23	96
21.25	18.20	19.7	2.7	0.16	191	299	401	128	3.1	145
21.25	18.20	19.7	1.0	0.13	484	368	956	118	8.1	~ 400
25.25	20.20	22.16	3.0	0.11	175	435	145	112	1.3	~ 120
25.25	20.20	22.16	4.5	0.11	130	435	172	112	1.5	~ 95
25.25	20.20	22.16	7.0	0.11	105	435	138	123	1.1	~ 70

It is also worthwhile to underline some of the disadvantages in being compelled to do the test horizontally.

(i) Injection. Injection is performed in the horizontal plane. The coherent beam motion resulting from the injection process may cause premature saturation of the feedback system due to the increased loop gains needed. However it will be seen later that a procedure can be foreseen which will avoid this problem by utilizing the range of $\sum\beta_x$ which is apparent in Table 1.

(ii) Momentum Dispersion. Momentum dispersion is much larger horizontally in the arcs. Hence for pickups placed in the arcs, the effective feedback loop gain will be reduced by coherent energy oscillations. This problem may be alleviated by using a pickup in a dispersion-free region.

(iii) Pickup Sensitivity. S is less by around a factor of two in the horizontal plane. This is simply due to the pickup geometry imposed by the beam aspect ratio and of course reduces the available tune shift proportionately (Eq. (6)).

The main advantage of doing the test horizontally is that the horizontal β value at the symmetry point (where the kicker and the strip-line pickup are situated) is much larger than the vertical one by around a factor of 6.

5. Machine Tune Required For Reactive Feedback

As stated previously (Section 3) the PEP feedback system may be made reactive either by (i) increasing the tune by around .25 to near the half integer, (ii) applying the kick ($\Delta x'$) after two turns instead of one, or (iii) finding a suitable pickup at a tune shift of 0.25 from the present one.

It was also pointed out in Section 3.2 that the feedback tune shift could be increased by using a pickup at a position of high β. Since it is now clear that the test should be done horizontally it appears appropriate to look for an existing button pickup which is located at a high β_x value. For all the configurations of Table 1 the best pickup was found to be the one located 20 m from the interaction point. The β values (called β_{xpu20}) at this pickup are also shown in Table 1 and range from around 100 to 400 in comparison with the β_x at the symmetry point (strip-line pickup) of 30 meters. This pickup at twenty meters from the IP in all configurations is at a ΔQ from the IP of 0.21 to 0.23. Consequently the Q advance from pickup to kicker ΔQ_{PK} is

$$\Delta Q_{PK} = \frac{11 Q_0}{12} \pm 0.21 \tag{17}$$

where the plus (+) refers to use of the pickup upstream (in the direction of the beam) of the IP and the minus (–) to downstream.

Consequently for ΔQ_{PK} to equal a multiple of 0.5 the following Q_0 values are needed.

$$\begin{aligned} Q_0 &= 21.04 \text{ or } 21.59 \quad \text{using upstream pickup} \\ Q_0 &= 20.95 \text{ or } 21.50 \quad \text{using downstream pickup} \end{aligned} \tag{18}$$

These values, close to the half-integer and integer arise since this pickup is approximately 1.5 betatron wavelengths from the kicker and is therefore in an identical betatron phase space position to the strip-line pickup.

If the feedback signal is delayed a further turn, then

$$\Delta Q_{PK} = \frac{23 Q_0}{24} \pm 0.21 \tag{19}$$

In this case the valid Q_0 values are

$$\begin{aligned} Q_0 &= 21.02 \text{ or } 21.28 && \text{using upstream pickup} \\ Q_0 &= 21.24 \text{ or } 20.08 \text{ or } 21.50 && \text{using downstream pickup} \end{aligned} \tag{20}$$

From the possibilities given in (18) and (20) the best using the upstream pickup (which is nearer the kicker by 40 m) is

$$\begin{aligned} Q_0 &= 21.59 && \text{and feedback after one turn} \\ Q_0 &= 21.28 && \text{and feedback after two turns} \end{aligned}$$

Operation of PEP at the latter tune value is clearly possible. However, if the accelerator could be operated for single beams at a tune value of 21.59 this would be preferable for the reactive feedback test as the experimental interpretation would not be further complicated by application of the feedback signal after two complete turns.

6. Estimates of $\Delta Q_{FB}/Q_S$

Repeating Eq. (6) for the horizontal plane

$$\Delta Q_{FB} = -\frac{e\ell_0\sqrt{\beta_K\beta_{pu}}\,S_xA_xK_x}{4\pi(E/e)}$$

where[11]

$S_x \quad \simeq 250\,V/m$ (this is half the vertical value)

$A_x \quad$ will depend on admissible signal/noise ratio (Eq. (8))

$K_x \quad = 30 \times 10^{-6}\,T/V$

$\beta_K \quad \simeq 32$ m

$\ell_0 \quad = 2.8$ m

and repeating (16) for the approximate Q_S dependence on E

$$Q_S = 2.7 \times 10^{-3}E \qquad (E \text{ in GeV})$$

Hence

$$\frac{\Delta Q_{FB}}{Q_S} = \left\{ \frac{c\ell_0 \sqrt{\beta_K}\, S_i \cdot K_z}{4\pi \times 2.7 \times 10^6} \right\} \frac{\sqrt{\beta_{pu}}\, A_z}{E^2} \tag{21}$$

where all parameters which cannot vary significantly are grouped inside the brackets. Inserting values gives

$$\frac{\Delta Q_{FB}}{Q_S} = \frac{1.05 \sqrt{\beta_{pu}}\, A_T}{E^2} \qquad (E \text{ in GeV}) \tag{22}$$

where β_{pu} may be (i) 32 m for the stripline-line pickup, (ii) 145 m for the 20 m pickup with $\beta_z^* = 2.7$, or (iii) 400 m for the 20 m pickup with $\beta_z^* = 1.0$ m, and A_z will be in the range 6 (signal to noise ratio = 8) to 12 (signal to noise ratio = 3), and E may be in the range 5 to 8 GeV.

Table 2 shows the calculated values of ΔQ_{FB} and $\Delta Q_{FB}/Q_S$ over a plausible range of energy and configuration. In addition the threshold intensity for instability has been estimated for each case using the relationship

$$I_{th} \alpha \frac{E Q_S}{\sum \beta_{cav}} \tag{23}$$

and scaled from the measured result $I_{th} = 12$ mA, $Q_S = .042$, $E = 14$ GeV, $\beta_z^* = 2.7$ m configuration.

Conditions under which the threshold current per bunch is less than around 1.0 mA should be avoided due to possible limitations in the detection of the coherent signal from such low intensities.

It is clear from this table that a reasonable experiment can be foreseen over the whole energy range.

7. Experiment Preparation and Procedure

The simplest technique which one would envisage for a reactive feedback test would be to accumulate beam to the instability limit with and without feedback and compare the intensities of threshold for the two cases. However, during injection and accumulation the beam is subjected to excitations (due to injection kickers etc.) which provoke coherent oscillations. In order to satisfy the conditions of $\Delta Q_{FB}/Q_S$ for a reasonable test the gain of the feedback system must be stretched to its limit. Consequently, the injection coherent oscillations are very likely to cause saturation of the feedback system and thereby confuse the interpretation of the results.

Table 2. Parameter Range For Test

Energy (GeV)	Q_S	β_x^*	β_{pu}	I_{th} (mA)	A_x	ΔQ_{FB}	$\frac{\Delta Q_{FB}}{Q_S}$
8.0	.022	2.7	32	3.6	6 12	.012 .024	.56 1.09
		1.0	400	1.5	6 12	.042 .085	1.91 3.86
		2.7	145	3.6	6 12	.026 .051	1.18 2.32
		4.5	96	5.4	6 12	.021 .042	0.95 1.91
7.0	.019	2.7	32	2.7	6 12	.014 .028	.73 1.45
		1.0	400	1.1	6 12	.048 .096	2.57 5.14
		2.7	145	2.7	6 12	.029 .058	1.55 3.09
		4.5	96	4.1	6 12	.024 .048	1.26 2.52
6.0	.016	2.7	32	1.9	6 12	.016 .032	.99 1.98
		1.0	400	0.8	6 12	.056 .112	3.5 7.0
		2.7	145	1.9	6 12	.034 .067	2.10 4.21
		4.5	96	1.9	6 12	.027 .055	1.71 3.43
5.0	.013	2.7	32	1.3	6 12	.019 .037	1.42 2.85
		1.0	400	0.5	6 12	.066 .131	5.04 10.08
		2.7	145	1.3	6 12	.039 .079	3.03 6.06
		4.5	96	1.9	6 12	.032 .065	2.47 4.93

A more clean test would be to accumulate current close to the threshold in one machine condition, then switch on the feedback system (having stopped injection) and then ramp the machine condition towards a less stable condition. The threshold for instability (in the absence of feedback) is given by (Eq. (23))

$$I_{th} \propto \frac{E Q_S}{\sum \beta_{cav}}$$

Consequently, the situation of instability can be influenced by any (or any combination) of the following techniques

(i) Energy. Current could be accumulated at a higher energy and later the energy ramped to a lower value.

(ii) Q_S. At fixed energy the synchrotron tune may be varied by varying the rf voltage. In this case care should be taken to ensure sufficient quantum lifetime at the lower Q_S.

(iii) $\sum \beta_{cav}$. It has been shown in Table 1 that the $\sum \beta_{cav}$ may be varied over a reasonable range horizontally by varying the β_s at the interaction point.

7.1 POSSIBLE PROCEDURE

The experiment may be performed with a single bunch of electrons

1. Set up the more unstable machine "configuration" (configuration u)
2. Inject and accumulate beam; during accumulation measure ΔQ_W as a function of intensity up to the threshold current ($\hat{I}_u$)
3. Set up the more stable machine configuration (S)
4. Inject and accumulate beam and measure ΔQ_W as a function of current up to threshold ($\hat{I}_S$)
5. Reduce intensity $\hat{I}_S$ to around $\hat{I}_u$ + around 10 → 20% ($= I_t$); with intensity I_t (feedback still off) slowly change from the stable towards the unstable configuration and note the conditions at which instability occurs
6. Reset the stable configuration and accumulate to around 1.5 $\hat{I}_u$; measure Q and Q_S
7. Switch on the feedback initially with reduced gain, and slowly increase the gain while measuring Q; when $\Delta Q_{FB} \simeq Q_S$ fix the gain

8. Slowly change from the stable to the unstable configuration. Hopefully the intensity 1.5 $\hat{I}_u$ will still be stable when the unstable configuration is reached, thus showing that the feedback has enhanced the threshold (at this point a short "champagne break" would be appropriate)

9. Reduce slowly the feedback gain until instability occurs

10. Repeat points 6 to 9 with increasing current to find the maximum enhancement factor due to $\Delta Q_{FB} = Q_S$

11. Repeat points 6 to 10 with increasing ΔQ_{FB}.

This is the main part of the test, however if everything goes unexpectedly well, the polarity of the feedback can be reversed for comparison of the two suggested possible modes of operation of reactive feedback.

7.2 EXPERIMENT PRE-REQUISITES

(i) Lattice. A low energy lattice should be prepared which has good injection. In addition it should be possible with this lattice to vary β_x^* continuously in the range 1.0 to 4.5 m. It would also be useful if the same lattice could be maintained during continuous energy change with beam (over a range say of a factor of two).

(ii) rf. The low Q_S and low energy require a low V_{rf} (e.g., at 8 GeV, $Q_S =$ .022, $V_{rf} = 3.6$ MV). It would be useful if V_{rf} could be continuously varied (upwards) over a range of say four. In order not to be bothered by energy oscillations, the longitudinal feedback (phase lock) should be operating.

(iii) Feedback. It would be very useful to be able to use either the stripline pickup or the pickup situated 20 m from the IP (on the feedback side). This should if possible be easily switchable and tested beforehand.

It should be possible to apply the feedback signal after one turn or two turns (or a $\pi/2$ phase shift of the detected signal). This may be necessary if the machine cannot be operated near the half-integer as required for π phase advance between pickup and kicker and a single turn between detection and feedback kick. This should also be tested if possible beforehand.

In order to alleviate somewhat more the possibility of saturation of the feedback loop it may be appropriate to filter out the noise component (referred to as

V_{n2} in Section 3.2) at $96\,f_0$ which results from the suppressed carrier modulation. Once again this should be tested beforehand if at all possible.

8. Simulation

Before the experiment actually takes place, the feedback simulation program will be used to predict the results of the experiment and possibly suggest some improvements to the experimental technique. The exact configuration to be used in the actual experiment will be input to the simulation.

9. Conclusions

An important and realistic test to examine the effect of reactive feedback on the transverse mode coupling instability could be performed at PEP using the existing feedback system with some minor modifications. This test would of necessity take place at low energy and low synchrotron tune.

Such an experiment is of great importance for the design of the LEP reactive feedback system and for the ultimate evaluation of LEP performance.

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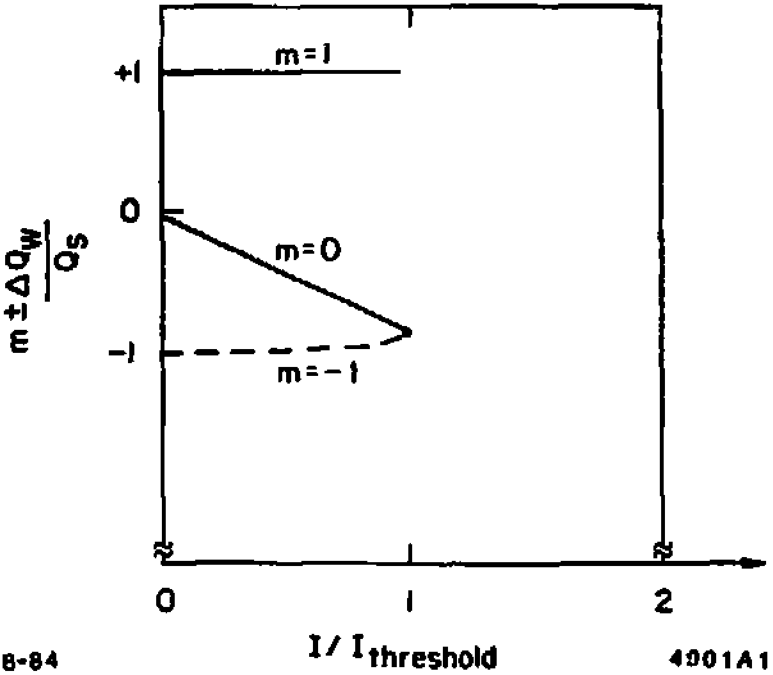

Fig. 1. Approximate frequency shift of head-tail modes with beam current.

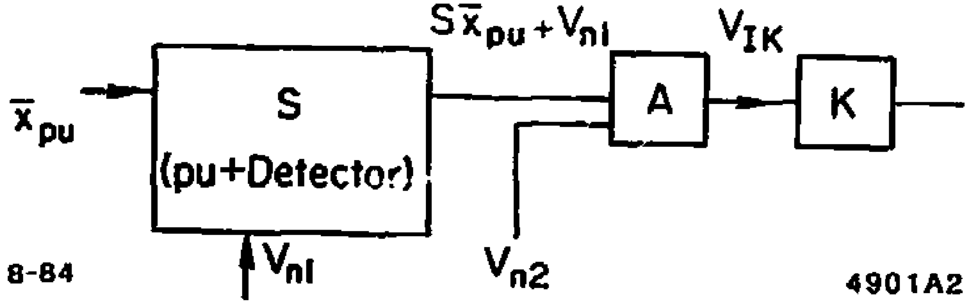

Fig. 2. Simplified block diagram of PEP feedback systems.

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