CONTROLLING THE VERTICAL MODE COUPLING INSTABILITY WITH FEEDBACK IN THE ADVANCED LIGHT SOURCE

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Abstract

We present the results of experiments to control the mode coupling instability in the vertical direction using a feedback system. Presently, we can raise the instability threshold from ∼20 mA to 35 mA. The maximum current threshold is reached when the feedback is operated in a resistive mode.

1 INTRODUCTION

The transverse mode coupling instability (MCI) has been studied for some time[1, 2]. In a simple physical picture of the instability, transverse oscillations of the head of a bunch resonantly drive oscillations of the tail through the short range transverse wakefield. The constant interchange of the bunch head and tail via synchrotron oscillations prevents buildup of the oscillations and allows them to damp. However, when the growth time of the tail oscillations becomes comparable to the synchrotron period, the bunch motion becomes unstable, resulting in a dramatic increase in the emittance. This can cause sudden beam loss or a limit to the bunch current.

A normal mode analysis of the instability expresses the bunch motion as a series of modes. The lowest modes are the dipole and head–tail, known respectively as the m=0 and ±1 modes. The oscillation frequency of the m=±1 modes appear as upper and lower sidebands of the m=0 mode. The typical instability occurs when the frequency of the dipole mode (m=0 mode) shifts downward as a function of current and coincides with the $m = -1$ mode as illustrated in a calculation using the MOSES code shown in Figure 1. As the m=0 and m=-1 modes become mixed there is a rapid increase in the growth rate with current.

For the present vacuum chamber configuration of the Advanced Light Source (ALS), the MCI is observed in the vertical direction with a single bunch current of ∼20 mA. For a typical multibunch filling pattern, the single bunch current does not exceed 1-2 mA and thus the instability is currently of interest only to users who require high single bunch current. However, as small vertical gap (10 mm) vacuum chambers have been installed in straight sections to accommodate insertion devices, we have observed a decrease in the MCI threshold. So far, two small gap sections have been installed and the threshold has dropped by ∼25%. The prospect of further vacuum chamber modifications has prompted further interest in studying the effect.

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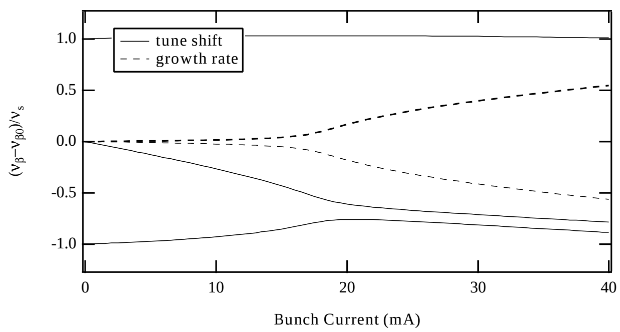

Figure 1: Example calculation of mode coupling instability using the MOSES code. The solid lines show the tune shift of the m=0,±1 modes. The dashed lines show the growth (and damping) rates of the coupled modes above threshold.

Transverse feedback (TFB) has been used to control the MCI in the past[3, 4, 5, 6, 7]. For these experiments, the TFB has been operated in both resistive and reactive modes. In the resistive mode, the TFB acts only to damp or antidamp coherent betatron oscillations. In reactive mode, the TFB shifts the coherent betatron frequency either up or down but does not actively damp coherent oscillations. For avoiding MCI, the FB in reactive mode is adjusted such that the slope of the downward frequency shift with current of the m=0 mode is reduced, thus reducing the coupling to the m=-1 mode and delaying the onset of the instability. Typically, the TFB can be adjusted to have any combination of resistive and reactive components. Experimentally, both modes have had some success in raising the threshold but there is no clear evidence indicating an optimal configuration or a clear theoretical understanding of the interaction of the instability and the TFB.

We have recently begun experiments to control the MCI with TFB in the ALS. Our studies employ a TFB system designed for damping coupled bunch oscillations. We modified the system slightly for use with high single bunch currents as described in the next section. Experimental results and conclusions are given in sections III and IV. General parameters of the ALS are given in Table 1. A summary of measurements of single and multibunch collective effects is given elsewhere[8, 9].

2 TRANSVERSE FEEDBACK SYSTEM

A schematic diagram of the ALS TFB system is shown in Figure 2. Detailed description of the system in given elsewhere[10]. The x, y moments of the bunch are detected

Parameter	Description	Value
E	Beam energy	1.5 GeV
C	Circumference	196.8 m
f_{rf}	RF frequency	499.654 MHz
σ_ϵ	RMS $\delta E/E$	7.1e-4
h	Harmonic number	328
α	momentum compaction	1.594e-3
Q_s	Synchrotron tune	0.0075
σ_ℓ	RMS bunch length	4.5 mm
$Q_{x,y}$	Betatron tunes (x,y)	14.28, 8.18

Table 1: Nominal ALS parameters.

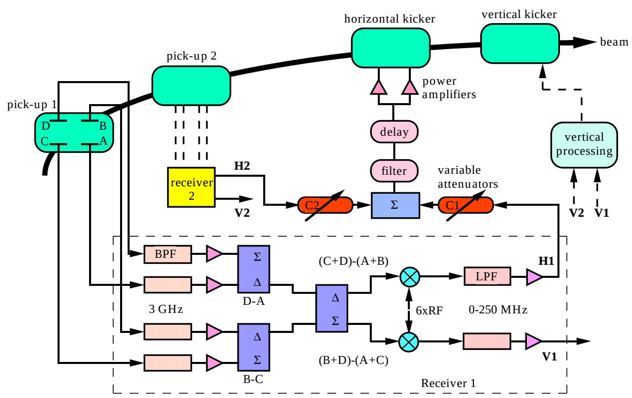

Figure 2: Block diagram of transverse FB system. The system is identical for horizontal and vertical directions.

at two points in the ring, with nominal betatron phase differences (modulo 2π) of approximately 65 and 245 degrees in the x, y directions. The beta functions at the two pickups are equal. The two signals can be combined in any proportion. This signal passes through a single turn notch filter to remove the DC orbit offset and is then delayed the appropriate amount and amplified with a 150 W solid state amplifier. The kicker is a single plate of a pair of stripline kickers. The other plate is used independently for driving betatron oscillations for tune measurements.

The detection of the transverse moment ($I\Delta x$) rather than the position (Δx) makes the TFB gain linearly dependent on current. The summing of the signals from two pickups allows the FB signal to have an arbitrary phase with respect to the betatron oscillation, allowing arbitrary combination of resistive and reactive components in FB. Ordinarily, the FB is adjusted to be purely resistive, maximizing the damping rate.

The TFB system as shown in Figure 2 is intended for damping transverse coupled bunch instabilities for a minimum bunch spacing of 2 nsec and is not optimized for damping high current single bunches. For our experiments in damping the MCI, we modified the system by attenuating the input signal to the receiver by 20 dB in order to not saturate the front end electronics at high single bunch current. A 26 dB gain preamplifier was also inserted immediately before the high power amplifier for some of the

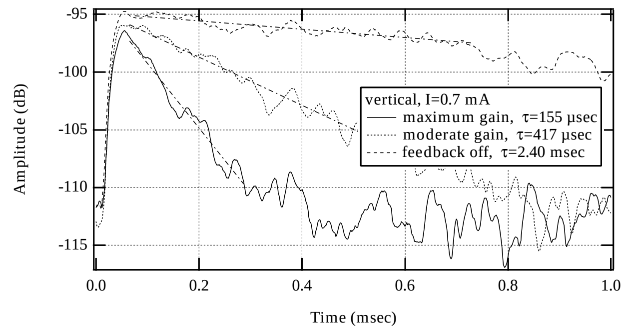

Figure 3: Vertical transients for several settings of FB gain for single bunch current of 0.7 mA. Transients are expected to be 10-20 times faster with the preamplifier in the FB loop.

data shown below. Only the vertical FB loop was closed during the experiments.

We characterized the damping rate of the TFB by measuring directly measuring the transient response of the vertical betatron oscillations in response to an impulse excitation. We can generate a small amount of vertical kick using the pulsed horizontal kicker magnets used for injection. We used a spectrum analyzer tuned to a vertical betatron line in tuned receiver mode. Shown in Figure 3 are several vertical damping transients for high, moderate, and zero FB gain for a single bunch current of 0.7 mA. These measurements were made in the nominal configuration of the FB system with no preamplifier and no front–end attenuation. The damping rate with no FB is dominated by head–tail damping from the small positive chromaticity of the lattice.

Unfortunately, we have not yet succeeded in making damping rate measurements for the conditions used in the MCI studies because of a drop in the signal/noise as we increase the resolution bandwidth of the spectrum analyzer to accommodate the faster damping rates. However, if we scale the measured damping rate by the expected increase in gain used in the MCI studies, we expect damping times on the order of 15-50 μsec, faster than the synchrotron period of 90 μsec. We are currently working to directly measure the damping rate of the FB for very high gain operation.

3 RESULTS

To date we have used TFB in two conditions to control the VMCI. In the first, the FB was configured as described in the previous section except without the preamplifier. As the bunch current surpassed the instability threshold, the FB gain and phase were empirically adjusted to maximize the stable threshold. The maximum stable single bunch current was 27 mA. An example of the spectrum of a vertical monitor signal is shown in Figure 4. The signal spectrum without FB above the MCI threshold for a bunch current of 22 mA is shown on the left and the spectrum with FB on at the same current is shown on the right. In both cases the signal is excited using a tracking generator driving the vertical kicker plate not used by the FB. At this bunch current, the $m = 0$ mode signal has shifted from the zero current betatron frequency at the center of the frequency span to nearly 3/4 the synchrotron frequency. The $m = -1$ signal appears at the synchrotron sideband and does not depend on external excitation. The signal at the zero–current vertical betatron tune is not understood but may correspond to a radial mode. When the vertical FB loop is closed, the $m = -1$ mode signal dissappears and the $m = 0$ signal is depressed. The vertical beam size also returns to the nominal size as observed on the transverse beam size monitor.

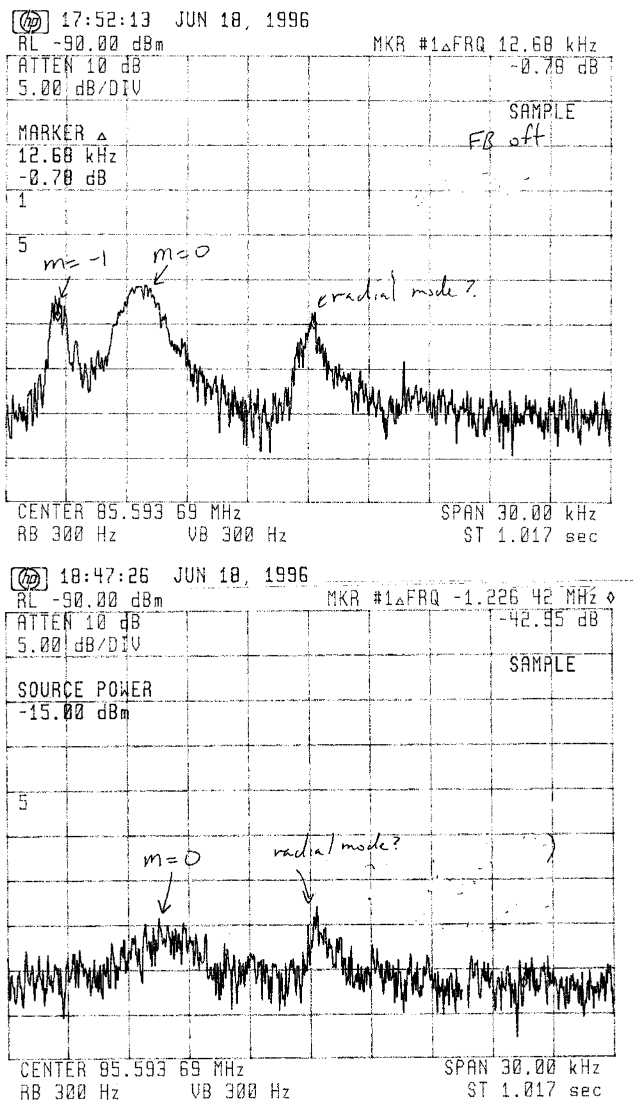

Figure 4: Spectrum of vertical monitor signal just above threshold (I=22 mA.) The left plot is with FB off and right with FB on. The $m = -1$ mode signal dissappears with FB on and the $m = 0$ signal is depressed. The signal at the zero current vertical betatron tune is not understood but may correspond to a radial mode.

Unfortunately we were not able to directly measure the FB phase and determine the combination of resistive and reactive FB. However, measurements of the tune shift with current for the case of FB on and off are identical, indicating that the FB was in a resistive mode.

In the second configuration, a preamplifier was added before the power amplifier. In this configuration, the maximum stable bunch current was 37 mA. Unfortunately, it was not possible to measure the betatron tune above $\sim$6 mA because the strong FB damping depressed and broadened the signal below the noise floor of the spectrum analyzer. However, tune shift measurements below 6 mA with and without FB are identical, indicating that the FB phase appears to be purely resistive.

We are currently trying to understand the reason for the current limitation with FB. We believe the limit results from the maximum FB voltage available.

4 CONCLUSIONS AND ACKNOWLEDGEMENTS

We have used TFB in the resistive mode to damp the MCI in the vertical plane and raised the instability threshold from $\sim$20 mA to 37 mA. Future plans include measurement of the threshold with TFB as a function of FB phase, development of beam transfer function measurements to directly measure FB gain and phase.

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