BEAM TRANSFER FUNCTION DIAGNOSTICS FOR BROADBAND MULTIBUNCH FEEDBACK SYSTEMS*

J. M.Byrd[†], W. Barry, H. Gang[‡], G. Stover, LBNL, Berkeley, CA 94720 USA

Abstract

Broadband multibunch feedback systems have been in use for several years at several storage rings for controlling coupled-bunch instabilities. We describe the use of beam transfer function (BTF) techniques for diagnosing the feedback systems and for measuring narrowband ring impedances. We present several example measurements made at the Advanced Light Source.

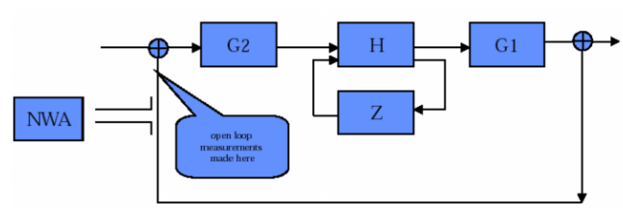
1 INTRODUCTION

Over the past decade, electron storage rings have substantially improved their performance by increasing the stored beam current and beam quality. One of the main factors in this improvement is the ability to store hundreds to thousands of bunches in the ring, keeping the current per bunch relatively small and avoiding single bunch instabilities. However, the presence of so many bunches allows for the possibility of multibunch instabilities via coupling of bunch motion through long-range wakefields excited in parasitic high order modes in the radiofrequency cavities or the resistive wall impedance of the vacuum chamber[1]. One of the approaches for controlling the instabilities has been the development of broadband feedback systems. In order to damp all possible modes of beam oscillation, the bandwidth of the feedback system must be at least one half the inverse of the minimum bunch spacing. For example, for rings with 500 MHz RF systems, the required bandwith is at least 250 MHz which can be technically challenging. Given the complexities of such feedback systems combined with uncertainties in the ring impedance, it is useful to have as many diagnostic tools as possible for proper operation of these systems.

One of the most useful diagnostic techniques for the feedback systems has been measuring the transient behavior in the time domain when the feedback is pulsed on and off[2]. Using this technique, the growth rates and frequency shifts of unstable beam modes can be directly measured, as well as proper phasing and gain of the feedback. This technique is particularly useful in digital feedback systems where the measurement capability is designed into the feedback hardware. In this paper we describe the application of a complementary technique in the frequency domain using a beam transfer function. As we show in a later section, this technique is particularly useful for quantifying relatively small effects that persist over the entire frequency band because the beam response is measured at all beam modes, not just the unstable ones that are growing, such as in the transient response. We also show that this technique can be used to measure the narrowband impedances in the ring. Section 2 gives a general description of beam transfer function measurements. Section 3 describes the broadband transverse and longitudinal feedback systems in use at the Advanced Light Source along with descriptions and measurements of bandwidth limitations in the systems. Section 4 presents the transverse and longitudinal measurements and their results. Conclusions are given in Section 5.

2 BEAM TRANSFER FUNCTIONS

A schematic view of a beam feedback system is shown in Fig. 1. The beam is represented by H and the impedance by Z. Details of the beam and impedance response are presented elsewhere[3]. G1 and G2 represent the response of the feedback system, such as the PU electronics and processing and the amplifier and kicker response. The open loop transfer function of the system is given by G1*G2*H/(1-H*Z). The closed loop response is the given by the open loop response divided by 1-the open loop response.



In this paper, we present only open loop measurements in which the feedback loop is opened directly before the high power amplifier.

3 ALS MULTIBUNCH FEEDBACK SYSTEMS

3.1 Transverse feedback system

A general diagram of the TFB system is shown in Fig.1. The system is identical in both transverse planes. Two transverse x,y pickup signals located ~60 degrees apart in betatron phase are added together with appropriate coefficients to produce a 90 degree betatron phase shift between the pickup signal and the kicker for arbitrary kicker location and betatron tune. The electronics systems consist of two microwave receivers for detecting horizontal and vertical moment $I\Delta x$, a system (shown as two variable attenuators) for mixing the signals from the two pickup stations, a delay, and a power amplifier for driving the kicker. The system uses entirely analog components.

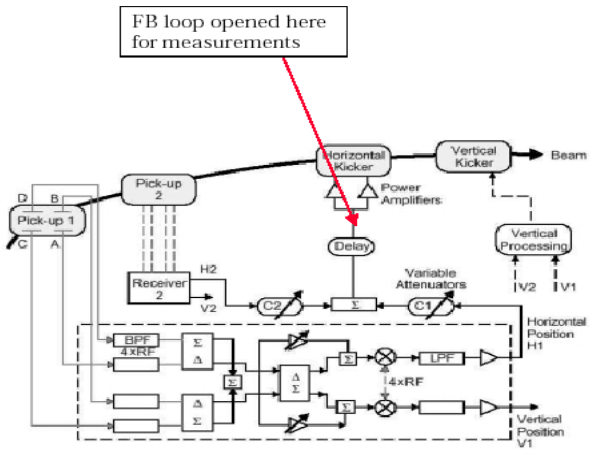


Figure 2. ALS Transverse Feedback System.

Position detection is performed at the sixth harmonic of the RF. The front end receivers detect beam position at this frequency and subsequently demodulate the position signals to baseband for driving the kickers.

Orbit offset at the pickups is removed using a notch filter implemented as the difference of the detected signal with the signal from the previous turn. Horizontal and vertical correction signals are then sent to the 150 W power amplifiers and kickers via ~1 turn delay. Each transverse kicker is a pair of 50 Ohm quarter--wave striplines at 250 MHz operated in difference mode.

3.2 Longitudinal feedback system

The ALS longitudinal feedback system (LFB) is a DSP-based system developed by J. Fox at SLAC[4], initially conceived for the PEP-II B-Factory and first tested and installed in the ALS. A schematic diagram of the system is shown in Fig. 2. Versions of this system have since been installed and commissioned at DAFNE, PEP-II, Bessy-II, and Pohang Light Source.

ıplifier.

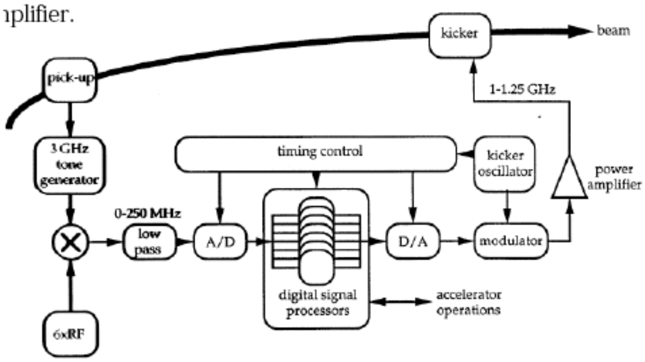


Figure 3: Schematic of LFB system.

The LFB detects the bunch phase at the sixth harmonic of the RF frequency and digitizes the signal at the 500 MHz bunch rate. The signal is processed by a farm of DSPs which implement a digital filter that provides the appropriate phase shift at the synchrotron frequency. The baseband signal is modulated onto a 1 GHz carrier using a QPSK modulation scheme. The signal is amplified with either a 200 W TWT or 500 W solid-state amplifier. The signal is applied to the beam using a drift-tube style longitudinal kicker.

4 MEASUREMENT RESULTS

All of the measurements shown were made with all RF buckets filled equally at a beam energy of 1.9 GeV. The beam current was kept less than 40 mA in order to ensure beam stability with the feedback loops opened.

4.1 Transverse results

Examples of open loop transfer functions measured on the upper and lower vertical betatron sidebands of the 100th rotation harmonic are shown in Fig. 4. Both the amplitude and phase response are simultaneously fitted to a Lorentzian response to determine the gain and phase offset.

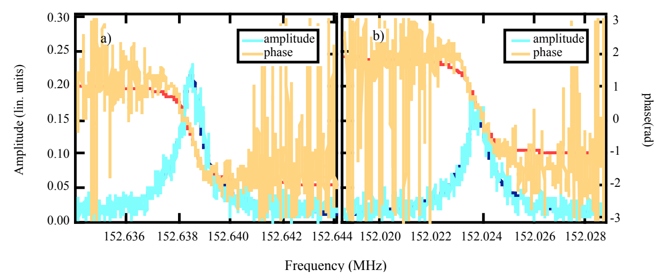


Figure 4: Example of vertical BTFs. Each are fitted to a Lorentzian response to extract the gain and phase.

The results of the BTF measured across the entire 250 MHz band are shown in Fig. 5. The gain shown in the upper plot, indicates a general decrease across the band by about a factor of 4. This is explained by the reduction in stripline kicker gain and attenuation in the notch filter over this band. The phase response is relatively flat except from 200-250 MHz where there is a sudden change. This is explained by the response of the high power amplifier whose nominal frequency range is from 0.1-220 MHz. More rapid fluctuations in the gain at about 105 MHz are due to a known RF cavity impedance.

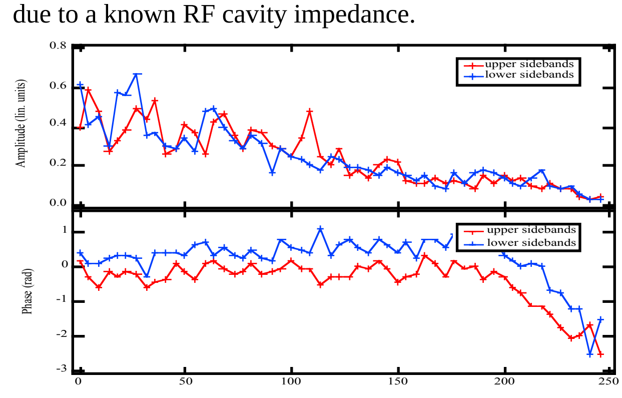


Figure 5: Broadband vertical BTF results. The upper plot shows the amplitude and the lower the phase.

We found the BTF to be useful to calibrate the phase adjustment of the feedback using the two PUs. Shown in Fig. 6 is a polar display of the feedback gain and phase as a function of the variable attenuation of the PUs. The measured gain and phase of the upper sideband of the first rotation harmonic compares well with the calculated values using the nominal betatron phase advances between PUs and kickers and beta functions.

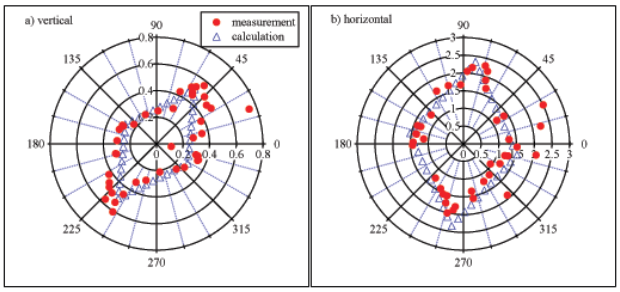


Figure 6: Polar display of the transverse feedback gain and phase as a function of the two PU strengths.

We have also made a series of BTF measurements of the transverse feedback in closed loop at high beam current. This is promising as an online diagnostic since it can be done under running conditions and has very little effect on the beam.

3.2 Longitudinal results

Examples of open loop transfer functions measured on the upper and lower longitudinal synchrotron sidebands of the 100th rotation harmonic are shown in Fig. 7.

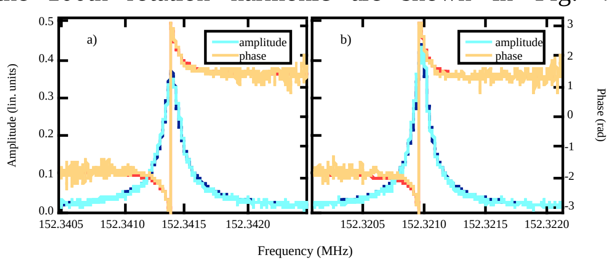


Figure 7: Example of longitudinal BTFs. Each are fitted to a Lorentzian response.

The broadband response of the LFB is shown in Fig. 8. The amplitude shows a small decrease across the band due to the 500 MHz digital sampling. Both amplitude and phase response show a 27 MHz ripple. From this we were able to deduce a small reflection in the system over an 18 nsec section of cable. The other prominent feature is the increased response at frequencies near 145 and 175 MHz. This are due to known impedances in the RF system at these frequencies. We hope to develop this technique for measuring the impedances in situ.

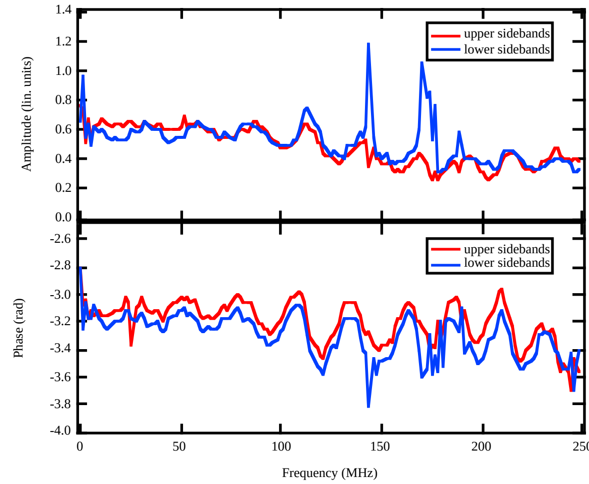


Figure 8: Broadband longitudinal BTF results. The upper plot shows the amplitude and the lower the phase.

4 CONCLUSIONS

Beam transfer function diagnostics provide a complementary approach to time-domain transient techniques. Open loop measurements can be used to diagnose the overall bandwidth of the feedback systems and measure the driving impedance. We have been able to use these measurements to properly adjust the pickup coefficients in the transverse FB and to find small reflections in the LFB. However, open loop measurements require passive beam stability which may require measurements beam currents too low to measure. Furthermore, the low current may make any impedance too low to measure. Closed loop measurements appear to be promising but operation at high gain makes them insensitive to many effects. One promising feature is that closed loop measurements can be made during normal operation with little effect on feedback performance.

We would like to thank John Fox and Dmitry Teytelman for many useful discussions. We would also like to acknowledge the ALS operations staff for assistance with the measurements.

5 REFERENCES

[1] M. Serio, *et al.*, LNF-96-033-PC, EPAC 96, Sitges, Spain.

[2] D. Teytelman, J. Fox, S. Prabhakar , J. M. Byrd, Phys. Rev. ST Accel. Beams **4**, 112801 (2001).

[3] J. M. Byd, et. al., submitted to NIM A, 2002.

[4] J. Fox *et al.*, 9th Beam Instrumentation Workshop (BIW 2000), Cambridge, Massachusetts, 8-11 May 2000.

[5] P. Chou, G. Jackson, PAC95, Dallas, 1995.

[6] W. Barry, *et al.*,, LBL-33269, PAC 93, Washington, DC, 17-20 May 1993.

[7] D. Bulfone, *et. al.*, EPAC2000, 1894 (2000).