DESIGN OF THE PEP-II TRANSVERSE COUPLED-BUNCH FEEDBACK SYSTEM*

W. Barry, J. Byrd, J. Corlett, M. Fahmie, J. Johnson, G. Lambertson, M. Nyman, Lawrence Berkeley Laboratory, Berkeley, CA 94720, and J. Fox, D. Teytelman, Stanford Linear Accelerator Center, Stanford, CA 94309.

The design of a 250 MHz bandwidth, bunch-by-bunch feedback system for controlling transverse coupled-bunch instabilities in the PEP-II Asymmetric B-Factory is described. Relevant system parameters and specifications[1] are discussed along with the design of key system components. In particular, the design of the front-end receivers, baseband processing electronics, and kickers are presented in some detail.

I. INTRODUCTION

The PEP-II B-Factory, now under construction, is a high-luminosity, asymmetric electron-positron collider for studying and determining the origin of CP violation in the B-meson system[2]. The collider basically consists of a 9 GeV high-energy storage ring (HER), and a 3.1 GeV low-energy storage ring (LER). Because of the high average beam currents (1 A HER and 2.14 A LER) in the rings, active feedback systems for controlling longitudinal and transverse coupled-bunch instabilities are required. The storage rings are designed to accommodate a large number of bunches, up to 3316 in buckets separated by 2.1 ns (476 MHz RF). As a result, a broad and dense spectrum of transverse coupled-bunch modes are driven by the higher-order transverse modes of the RF cavities and the transverse resistive-wall impedance. In order to effectively damp and control growth of these modes, a broad-band bunch-by-bunch feedback system, modeled after the ALS transverse feedback system[3], has been designed.

Nominally, PEP-II will operate with every other bucket filled and a small ion clearing gap. In this case, the minimum required bandwidth for the feedback system is 119 MHz. However, the feedback electronics have been designed to have a bandwidth of 250 MHz in order to accommodate the possibility of operating the storage rings with every bucket filled. In this paper, the major accelerator parameters which drive the design of the feedback system are discussed as well as the key electronic components of the system.

II. SYSTEM REQUIREMENTS

The transverse feedback systems are conservatively designed to handle a worst-case scenario which assumes a 3 A beam in the LER at a fractional tune of 0.9 (nominal LER current and tune are 2.14 A and 0.64 respectively). In this case, the fastest growing coupled-bunch mode is the m = 0 mode driven by the vertical resistive-wall impedance. Some major accelerator parameters pertinent to the design of the system for this case as well as some resulting feedback system specifications are given in table 1.

Parameter	Description	Value
E	Beam energy	3.1 GeV
f_{rf}	RF frequency	476 MHz
I_b	Average current	3.0 A
f_0	Orbit frequency	136.3 kHz
β_{av}	Average β	10 m
ν_f	Fractional tune	0.9
τ_b	Bunch spacing	4.2 ns
Z_{rw}	R-wall impedance	4.85 MΩ/m
α_0	Growth rate of m = 0 mode	3200 sec^{-1}
$\partial V/\partial x$	Req'd feedback gain	14.6 kV/mm
R_s	Kicker shunt impedance	24 kΩ
P_k	Available kicker power	240 W
V_{max}	Max. available kick	3.4 kV
y_{max}	Max. mode amplitude	0.23 mm
V_{mode}	Voltage to excite y_{max}	71.3 kV-turn
Δf_{min}	Req'd bandpass	13.6 kHz-119 MHz
–	Electronics bandpass	10 kHz-250 MHz
–	Kicker bandpass	DC - 119 MHz
σ_y	Vert. beam size	0.16 mm
-	Req'd dynamic range	23 dB
-	Actual dynamic range	42 dB
y_{os}	Allowable effective orbit offset	1.8 mm

Table 1. Accelerator and feedback system parameters for assumed worst-case transverse coupled-bunch mode.

Several notes to Table 1 are in order. The nominal bunch spacing of 4.2 ns is specified because the machine will operate in this configuration for some period of time. As a result, the kickers, which are simple striplines, have been designed to cover the DC - 119 MHz band because they are more power efficient than shorter versions which would cover the DC - 238 MHz band. However, the remainder of the electronics is designed to cover the 10 kHz - 250 MHz band so that 2.1 ns bunch-spacing operation

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can be accommodated by simply installing shorter kickers and possibly additional power amplifiers.

In this worst-case scenario, the maximum controllable mode amplitude (assuming linear feedback) is 0.23 mm for the available kick voltage. Under normal operating conditions, the controllable amplitude is considerably greater. In any case, if the feedback system is operating from the time filling of the storage rings begins, one is hard pressed to identify a mechanism which would cause the accumulated modal voltage of 71.3 kV required to reach the amplitude limit of 0.23 mm. It should also be noted that simulations indicate[1] that any expected injection transients are easily damped by the feedback system. This is because the amplitudes of the normal coupled-bunch modes corresponding to the Fourier decomposition of the transient are extremely small. Injection transients can however produce large transient voltages which can saturate the feedback system. For this reason, damping of injection transients usually starts out in saturated mode where a fixed kick is given to the injected bunch until it is damped to a point where proportional or linear feedback takes over.

As a final note to Table 1, the required dynamic range is based on the requirement that the amplitude of betatron oscillations be damped to 0.1σ. For the case in Table 1, a 23 dB dynamic range is required to cover mode amplitudes ranging from the maximum of 0.23 mm down to $.1\sigma_y$ = .016 mm. The actual dynamic range of the system corresponds to that of an 8 bit digital system, 42 dB. From the required and actual dynamic ranges, the maximum allowable effective orbit offset of 1.8 mm can be inferred. This quantity represents a static signal with frequency components at the orbit harmonics which passes through the feedback system reducing the dynamic range available for damping betatron oscillations. The effective orbit offset signal depends on the true closed-orbit offset, various electronic gain imbalances, fill pattern, and the effect of any offset rejection circuitry.

III. FEEDBACK SYSTEM OVERVIEW

The PEP-II transverse feedback system concept matches quite closely that of the current ALS system after which it is modeled[3]. Therefore, characteristics common to both systems will be described only briefly with more emphasis placed on design issues that are unique to the PEP-II system. The overall feedback system is shown in figure 1. The system utilizes two sets of button pickups, separated by approximately 90 degrees in betatron phase, for detecting beam moment, $I\Delta x$. By summing moment signals from the two pickups in proper proportion, a correction signal that is in quadrature with beam position at the kickers is obtained. This condition results in optimal damping and is adjustable to allow for changes in tune.

The beam moment signals are detected at the third harmonic of the RF (1.428 GHz) in order to exploit the good sensitivity of the button pickups at this frequency. The signals are then demodulated to baseband with heterodyne receivers that also contain orbit offset rejection circuitry. Baseband processing consists of a system (shown as x and y attenuators) for proportional summing of the two pickup signals and a digital system that provides the necessary pickup-to-kicker timing delay . In addition, the digital electronics features circuitry for changing the sign and gain of the feedback for a single given bunch. This feature is used to trim the charges of single bunches to obtain a uniform fill or kickout an unwanted bunch in its entirety.

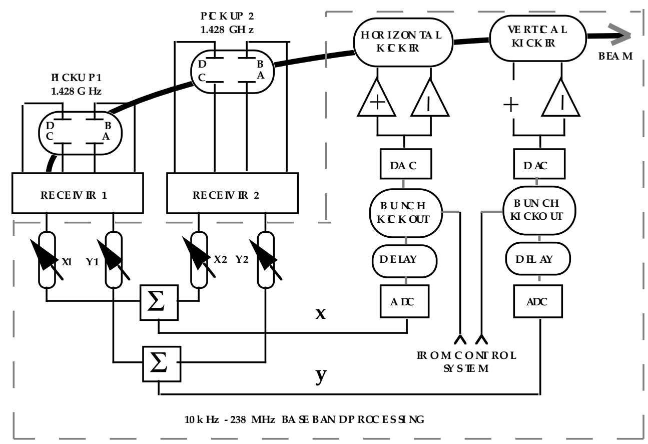

Figure 1. PEP-II transverse feedback system concept.

Finally, separate horizontal and vertical stripline kickers are used to apply the baseband correction kick to the beam. The kicker electrodes are individually driven with opposite polarities by 120 W (minimum), 10 kHz - 250 MHz, solid-state, Class-A, commercial amplifiers. Over most of the band, these amplifiers provide greater than 200 W.

Major components of the PEP-II systems not common to or differing from the present ALS system are the digital electronics and the receivers described below.

IV. RECEIVER DESIGN

The PEP-II transverse feedback system receiver design is shown in figure 2. Beam signals induced on each pickup are first bandpass filtered then differenced and summed in the monopulse comparator to produce true x and y beam moment signals at the 1.428 GHz carrier frequency. Subsequently, these signals are down-converted to baseband using standard heterodyne detection.

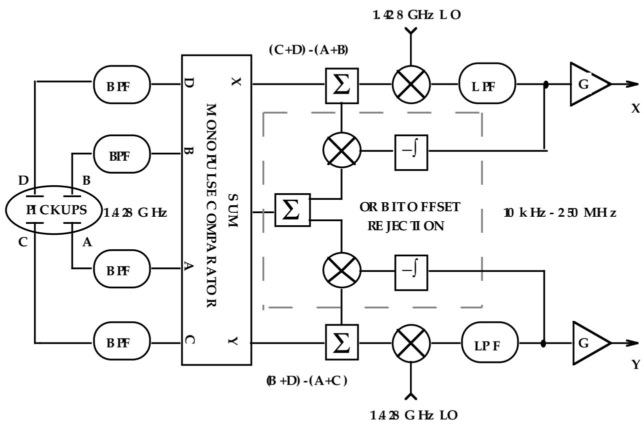

Figure 2. Receiver design.

Of special interest is the orbit offset rejection circuitry in the dashed box. In general, the x and y moment signals contain unwanted components due to static beam orbit offset and, equivalently, imbalances in the gains of the button pickups and the electronics associated with them. These offset signals are independent of the betatron motion and have spectral components only at harmonics of the orbit frequency. In addition, the spectrum of the offset component of the moment signal is, apart from amplitude, identical to that of the signal derived from the sum of all four pickups. Thus, to remove the offset component of the moment signal, some fraction of the sum signal from the comparator is added to or subtracted from it. As shown in figure 2, this process is automated in a feedback loop in order to accommodate changes in closed-orbit offset. Based on an assumed 1 mm closed-orbit offset and worst case 3 dB imbalance in pickup gains, this system must provide 11 dB of offset rejection in order to meet the 1.8 mm effective offset limit set forth in table 1. Early tests of this technique indicate that at least 10 dB of rejection is obtainable.

V. DIGITAL COMPONENTS

The digital components of the system basically consist of a pickup-to-kicker timing delay and circuitry for changing the sign and gain of the feedback for a given bunch. In addition, a digital output of the feedback signals will be available for diagnostic purposes.

For the delay, the baseband signal is sampled at 476 megasamples per second into 8 bit bi-polar digital form and stored in a circular buffer. The buffer is implemented with a fast ECL RAM array and EClips ECL logic devices. On alternate memory cycles, the RAM is written (into incrementing addresses) with the digitized correction signal then a previously stored value is read out from an offset address. The address offset is programmable and determines the amount of delay applied to the correction signal.

The delayed data is then directed through two parallel paths. In one path, the data remains unaltered. In the other path, the data undergoes a sign and possible gain change for bunch kickout/trim. A fast multiplexer at the input to a digital-to-analog converter chooses between the normal feedback path and the kickout path on a bunch-by-bunch basis. In this manner, any number of selected bunches may be kicked out or trimmed simultaneously.

VI. CONCLUSION

A broadband feedback system for controlling transverse coupled-bunch instabilities in the PEP-II B-Factory has been designed. The system is modeled after the present ALS transverse system which is presently nearing the completion of a successful commissioning[4]. The design philosophy, as with the ALS system, has been one of simplicity and user friendliness. Given our ALS experience, we look forward to the successful commissioning and operation of the PEP-II systems.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

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