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OPERATION OF THE PEP TRANSVERSE BEAM FEEDBACK*

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Abstract

The PEP Storage Ring has been equipped with a wide band beam feedback system capable of damping the vertical and horizontal motion of six bunches. The oscillation detection is done at a symmetry point on the Storage Ring and feedback is applied at the same location one orbital period later. The signal is synchronously gated and the system appears as twelve independent feedback loops, operating on the two coordinates of each of the six bunches. Two beam deflection electrodes are driven each by a low-Q push-pull amplifier which is tuned at the 72nd harmonic of the revolution frequency and suppressed-carrier modulation is generated by a sequence of the detected bunch oscillations. The design parameters are reviewed as well as the salient features of the hardware, and the impact of this system on the machine operation is evaluated in the light of experimental results.

Introduction

Many circular accelerators and storage rings have used, in the past, some kind of beam feedback technique to provide damping or anti-damping for their coherent transverse instabilities. In some cases, feedback can be more than a diagnostic tool and becomes indispensable to the proper operation of the machine.[1]

While the criteria for selecting the loop gains of these systems are not very different between one and another, the hardware design can differ considerably depending on the number of bunches and the number of modes one wants to damp, and also it can differ simply because of the particular inclination of the designers. There are possibly three areas where they can exercise their ingenuity or their preference: the beam oscillation detection circuits, the information storage and phasing element, the amplifier chain and the beam kicker. For instance, the Refs. 2-5 describe, among others, systems which have been commissioned over the past five years and offer quite a variety of approaches in the three above-mentioned areas. Keeping with this tradition, we present here the design for a wide band feedback system treating two beams on a bunch by bunch basis. We chose to use a system in which the beam-deflecting electrode is driven by a radiofrequency amplifier operating on a carrier at 9.8 MHz; this frequency is the 72nd harmonic of the beams' orbital frequency. Double-sideband, suppressed-carrier modulation is used so the carrier is in fact not present in the electrode and there is no deflecting current when the beams are not oscillating coherently. This scheme results in low power dissipation when the beams are quiet. The modulation program is furnished by a set of normalized oscillation detectors and the unfiltered bunch position information is held until the next machine turn in an analog memory.

System Description

The deflecting electrodes are situated at a point on the circumference of the storage ring equidistant between two interaction points, a location at which the six bunches of the two PEP beams pass at equal intervals of a little more than one microsecond. The bandwidth of the system, 0.82 MHz, is chosen so that each bunch is treated nearly independently, or to put it another way, so that the normal mode frequencies of the ensemble of six bunches all fall within the passband of the system.

The damping rate required of the feedback determines the loop gain. We designed for a damping time of 700 microseconds at a beam energy of 4 GeV or equivalently 2.8 milliseconds at 16 GeV. The maximum current which can be driven by the final amplifier into the deflecting electrode, determines the maximum amplitude of coherent beam motion which can be acted on by the system without saturation. The PEP feedback system is designed to handle amplitudes up to 2 millimeters which produce electrode currents up to 20 amperes.

The vertical and the horizontal systems are of course identical and each one contains 6 independent signal paths, one for each bunch. These signal paths are alternately enabled for 1.2 μs; this time is approximately equal to three output-circuit decay time constants. Figure 1 depicts one of these signal paths; some such as the multiplexer, the modulator and the power amplifier are common to the five other loops. The beam signals are obtained from a pair of strip lines, one pair for each beam. When they reach the support building where the processing circuits are installed, the pulses are bipolar with peaks measuring approximately ±1 volt per mA of average current per bunch for the vertical pick-up electrode, and perhaps half as large for the horizontal pick-up electrode which is further away from the beam. The time between the positive and the negative excursion of the pulse is of the order of 1.5 ns, and the amount of modulation observed on the crest of the pulse as a result of beam oscillations in nearly 3% per millimeter for the vertical pick-up and half this amount for the horizontal pick-up. Each of these signals is split three times in order to be simultaneously applied to three detectors.

The circuit for the Normalized Detector has been analyzed elsewhere[6] but we reproduce on Fig. 2 a block diagram and on Fig. 3 a typical set of input-output waveforms for one bunch. Together with the pick-up electrode this detection system has a sensitivity of 500 mV/mm (vertical system) and the automatic gain control circuit can operate reliably with

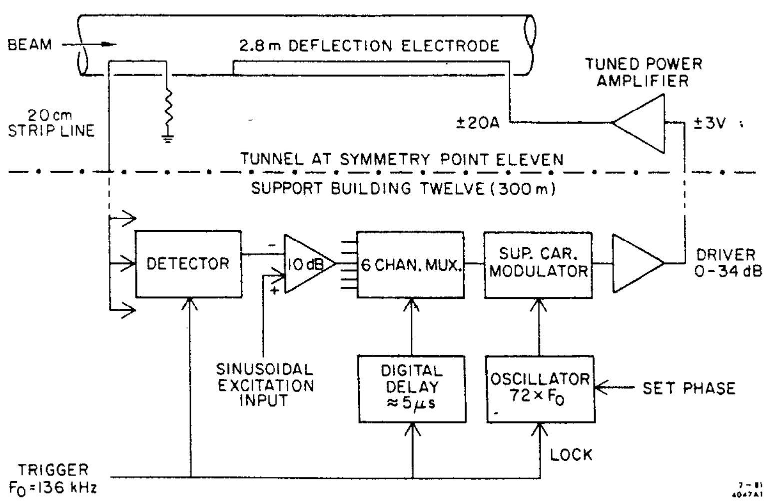

Fig. 1. PEP Transverse beam feedback system. The block diagram depicts a one-beam, one coordinate system only.

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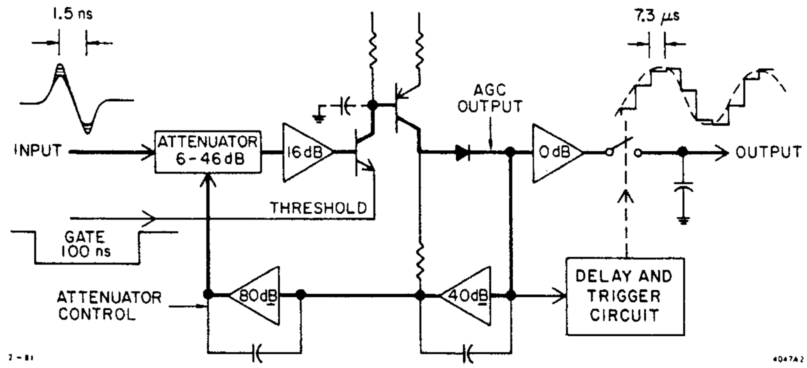

Fig. 2. Principle of the beam oscillation detection.

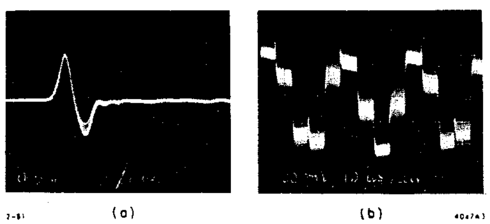

Fig. 3. Detector typical input-output waveforms: (a) Input beam pulse; the modulation has been set 10 times larger so as to be visible on the photograph. (b) Detector response to 3%, 30 kHz modulation; each step corresponds to a machine period. The modulation frequency and the revolution frequency are not synchronized.

beam currents in the range of 0.5 to 15 mA average per bunch.

Figure 4 shows time-domain waveforms for the modulator. Figure 4(a) represents a superposition of samples of the detector output (Fig. 3(b)). These samples are associated with the oscillation of one bunch only; the time positioning of the multiplexer pulse along the detector output permits the adjustment of the proper delay for each loop. Figure 4(b) is a superposition of 9.8 MHz RF bursts with varying amplitudes; this pulse is applied to the power amplifier and is timed in such a way as to arrive at the kicker electrode 1.2 μs before the bunch. Twelve RF cycles elapse during the pulse width, and the beam is kicked at the peak of the last half cycle.

We now turn to a description of the power amplifier circuit.

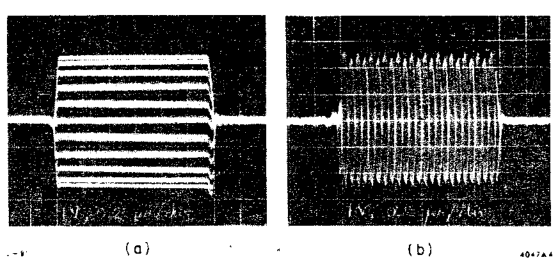

Fig. 4. (a) Multiplexer output for one bunch. The modulation is not synchronized with the machine revolution frequency. (b) Modulator output for the above input. The carrier frequency is equal to the 72nd harmonic of the revolution frequency.

Power Amplifiers

The two power amplifiers are located in the tunnel as close as possible to the deflection electrodes. To minimize the length of the RG17 connecting cables, and since the amplifiers are mounted below the beam pipe, we made the two assemblies mirror images of one another (Fig. 5).

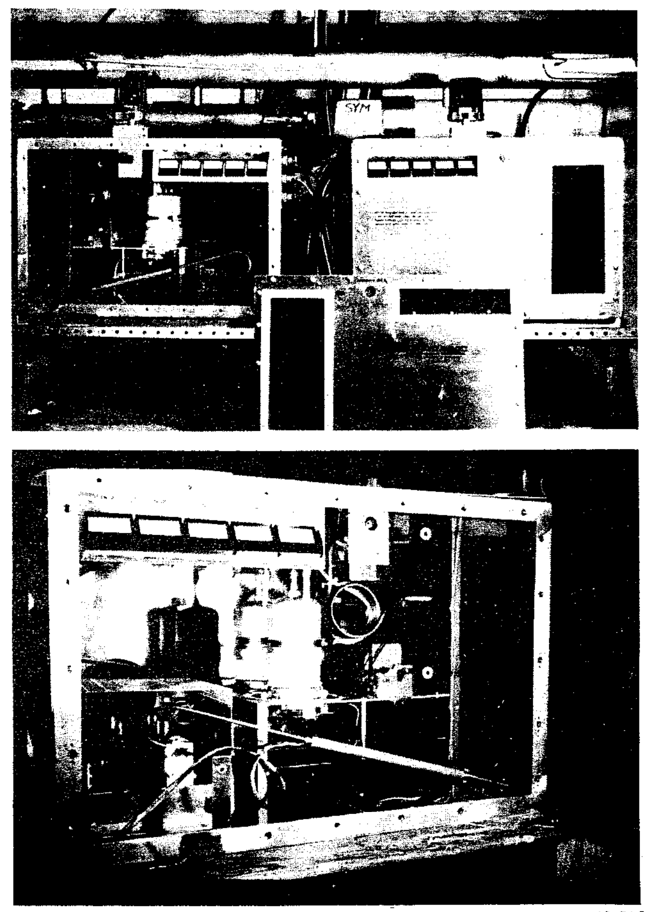

Fig. 5. Two views of the power amplifiers in the tunnel.

Each circuit consists of three push-pull stages as shown in Fig. 6. All tank circuits are resistively loaded to reduce their Q and obtain the required over-all bandwidth of 820 kHz.

Figure 7 shows the input and output waveforms of the power amplifier for a square-wave phase modulation. The maximum power dissipated in the deflection electrode is of the order of 300 watts; to this power one must add some higher-order mode losses and, as a result, water cooling was deemed necessary.

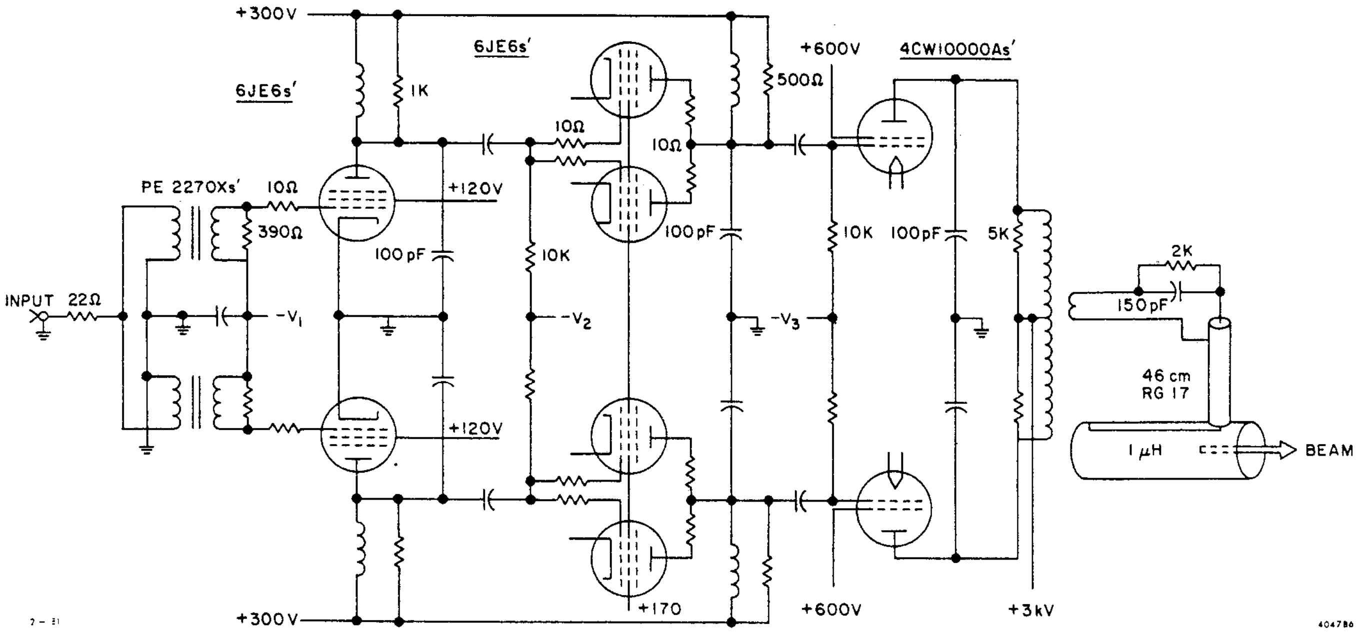

Fig. 6. Circuit diagram of the power amplifier.

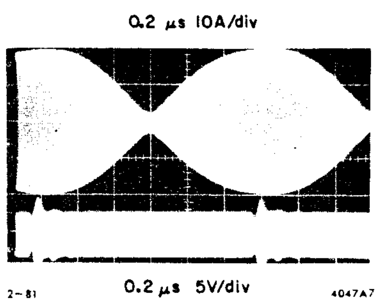

Fig. 7. Response of the power amplifier to a square wave phase modulation.

Performance and Improvements

The transverse feedback system has been used to control unstable coherent beam oscillations when they have arisen in PEP, although such oscillations have seldom been troublesome in routine operation. With the system off and with the beams free of unstable coherent oscillations, the noise-driven spectrum of beam motion reveals peaks at the horizontal and vertical betatron frequencies which are routinely used to measure these frequencies. Turning the feedback system on at high gain obliterates the peaks and produces broad notches at these frequencies instead.

At times, the feedback system has failed to damp unstable coherent oscillations when we expected that it would succeed. When this has happened the system turned out to be saturated by a signal not at the frequency of the unstable transverse oscillation, but at the (much lower) synchrotron oscillation frequency. We plan to ameliorate this problem by rolling off the low frequency response of the oscillation detectors to discriminate against the synchrotron frequency.

Presently both the vertical and the horizontal power amplifiers are tuned to the 72nd harmonic of the revolution frequency. In the future we plan to tune one of the amplifiers to the 96th harmonic (13 MHz), to minimize the effect of the coupling between the vertical and the horizontal deflection electrodes.

Acknowledgements

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