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OPERATION OF PEP LONGITUDINAL FEEDBACK SYSTEM*

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Introduction

In order to suppress longitudinal coupled-bunch oscillations which might limit the capabilities of PEP, the 18 GeV e^+e^- storage ring at SLAC, a longitudinal feedback system is utilized. The design has been described in a paper in the proceedings of the 1979 Accelerator Conference.[1] A frequency domain feedback system was chosen with the frequency spectrum of the stored beam being sampled close to a symmetry point in the ring where the feedback cavity itself is also located. The symmetry point chosen is symmetry point 5 which lies half-way between interaction regions 4 and 6. The system has been installed in PEP and is now operational. However, at stored currents up to the maximum stored in PEP to date at 14.5 GeV (approximately 40 mA in 6 bunches), the ring has been stable to all modes of longitudinal coupled bunch oscillations both barycentric and the other fundamental modes. By deliberately detuning the main accelerating cavities, small multibunch oscillations can be introduced which, in turn, can be damped by the feedback system. Under optimized beam conditions the feedback system could be adjusted to positive feedback and excite oscillations with relatively small power to the feedback cavity. This will be described along with other details of the system.

Klystron and Cavity

The system described in Ref. 1 has been built. The cavity is a 3-cell slot-coupled π-mode cavity, fabricated from aluminum 6061 alloy. The coupling factor β is 12 and the loaded Q is 1400. The resonant frequency is 849.912 MHz which is the 6237 harmonic of the ring frequency. The cavity response is shown together with the beam frequency spectrum in Fig. 1. The barycentric mode, 0, is shown together with the other possible modes, 1 through 5. The upper sidebands shown with the downward arrow are the ones which would be anti-damped by the parasitic impedances in the ring. A photograph of the cavity installed in the ring at symmetry point 5 is shown in Fig. 2. The cavity is powered by a TV klystron VA-995A which is capable of 55 kW output power. The klystron power supply and the feedback electronics are computer controlled and the system can be operated from the PEP control room.

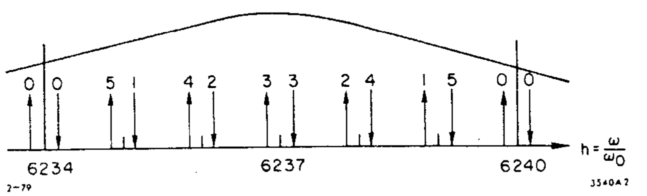

Fig. 1. Current spectrum at symmetry point.

Feedback Electronics

In the frequency domain feedback system certain sidebands excited by the multibunch oscillations are filtered out and individually processed, so their respective amplitudes and phases can be varied. They are then recombined and applied to the three-cell feedback cavity which accordingly exerts an accelerating or decelerating force on each bunch.

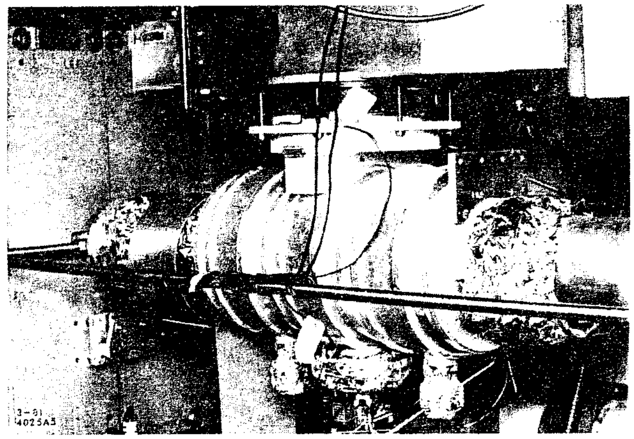

Fig. 2. Photograph of cavity in tunnel.

Details pertaining to the required instrumentation are described here (Fig. 3). Single sideband mixing techniques are used to allow processing of single frequency lines. The carrier frequency of 849.912 MHz is produced by a local oscillator which could be locked to the PEP RF master oscillator frequency of 353.210 MHz by dividing the PEP frequency by 32 and then locking to the 77th harmonic.

The frequency spectrum of the stored beams is picked up by a horizontal beam position monitor button at the symmetry point between two interaction regions. A 10 MHz-wide band of frequencies is then filtered out and mixed with the local oscillator in a single sideband type mixer. The desired sidebands appear on two IF outputs in quadrature in a frequency band of 1 to 300 kHz. A total of five pairs of active band pass filters further separate the sidebands into five channels. Each provides an adjustable gain of 0 to 60 dB and limits the signal amplitude by an active feedback circuit to prevent overdriving the following mixers. The signals are then upconverted in single sideband modulators where the local oscillator is applied through a 360° phaseshifter which allows adjustment of the phase of the sideband.

After combining five signal channels in a stripline combiner the signals are amplified in solid state amplifiers and a 55 kW klystron and applied to the three-cell feedback cavity.

The maximum total gain available including conversion loss of the mixers is 135 dB.

Two components in the signal path warrant a more detailed description: a) The IF Active Filter circuit is shown in Fig. 4. It uses two stages of amplification. Since a gain of 60 dB is desired at the highest frequency of 278 kHz, wideband RF amplifiers of the type MC 1590 Motorola were chosen. They provide a gain control input which is used to apply feedback to limit the amplitude of the output signal to 0.4 V_p as well as providing a manual gain adjustment. Two resonant circuits are stagger tuned as band pass filters with a typical 3 dB bandwidth of 10 kHz and 15 dB insertion loss at twice the bandwidth. A 10 kHz low pass filter circuit is used instead of a resonant circuit for the lowest frequency band of 1-10 kHz.

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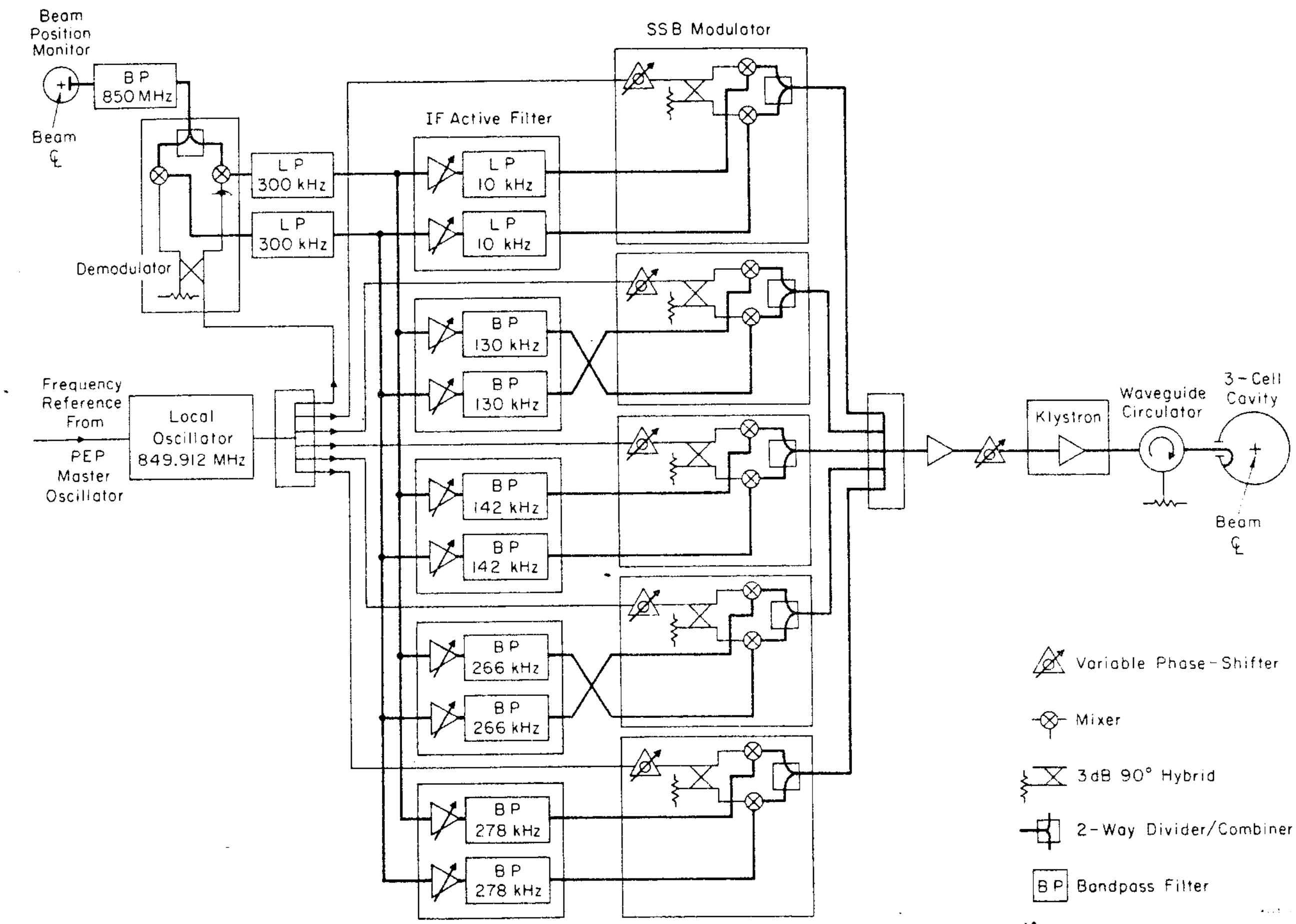

Fig. 3. Block diagram of system.

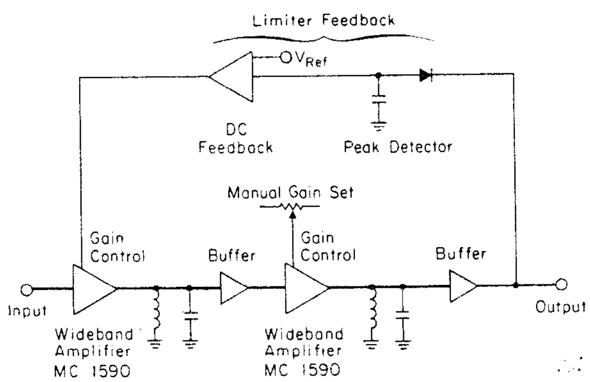

Fig. 4. IF active filter circuit.

b) The single sideband modulators (Fig. 5) use commercially available printed circuit mixers. A microstrip circuit board was laid out which includes a power divider, a 90^{o} hybrid, and two 180^{o} electronic phaseshifter modules in series to provide 360^{o} phase shift. The phaseshifters are of the same type used elsewhere in PEP using varactor diodes and a parallel inductance.[2,3] For test purposes a 20 dB coupler was added on the stripline circuit board.

Operation Results

The system, as installed, is intended to stabilize the five possible fundamental modes of oscillation, other than the barycentric mode, since theory indicated that damping of the barycentric mode by detuning the main RF cavities has the effect of anti-damping the other modes.[4] At currents up to about 40 mA in 6 bunches at 14.5 GeV this has not proven to be the case and the stored current is not subject to multibunch longitudinal oscillations. An experiment was made to excite multibunch instabilities by detuning the main accelerating cavities to frequencies above the driving frequencies and thus exciting strong barycentric mode oscillations. The experiment was performed with 6 bunches stored and 27 mA total current at 14.5 GeV. In this condition with the sidebands associated with the barycentric mode (0 mode sidebands) about 20 dB down from the corresponding 6240th harmonic of the beam, other

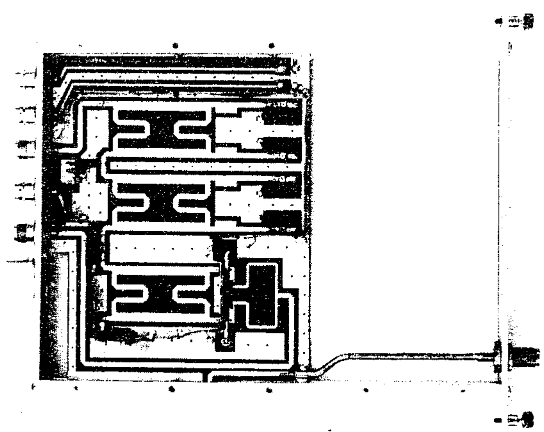

Fig. 5. Photograph of Single Sideband Modulator.

fundamental modes appeared with their sidebands about 50 dB down from the same beam harmonic. These sidebands could be individually reduced by 6-7 dB by applying feedback through the appropriate feedback channel. The power applied to the cavity in each case was about 3-4 kW. Response time measurements could not be performed due to the signals being close to the noise level. With the same 6 bunches stored at 27 mA but damped barycentric mode, Fig. 6 is an example of the current spectrum at the harmonic number 6237. The sidebands of mode 3 are at least 40 dB below the main signal at that harmonic number. An attempt was made to excite these sidebands to oscillation by appropriately phasing the feedback channel #1, which would carry the 6 kHz synchrotron frequency signal. This is shown in Fig. 7, where it is noted that the upper sideband shows the greater increase. This is a typical example and similar effects can be seen on the other modes by phasing the appropriate feedback channels. When a single bunch is stored in the ring any of the feedback channels can be used to excite the single bunch into oscillation, since the current spectrum repeats at each harmonic of the range frequencies. These signals were measured by directly observing the signal on a beam position monitor on a Fast Fourier Transform Analyzer (Fig. 8). The upper trace shows the signals with the phase of a feedback channel set for minimum synchrotron oscillation. The lower trace is the effect of shifting the feedback channel by 180° in phase so that it is now anti-damping. A large effect is noted, indicating strong anti-damping by the feedback system, with phase adjusted for positive feedback.

Conclusions

The feedback system as installed is capable of controlling longitudinal instabilities in the five fundamental modes other than the barycentric mode. At 14.5 GeV the PEP ring is stable longitudinally at least up to about half the design current in the magnet configuration presently in use. However, theoretical prediction[4] indicates that the risetime of possible modes of instability increases as the energy decreases with almost a factor of five between energies of 15 GeV and 5 GeV. Since instabilities might be present at unexplored regions of energy and current the fast feedback system may still find its use. Until that time, the feedback system will not be used during normal ring operation.

Acknowledgement

The key contributions of A. Millich, CERN, to the early design of the system are gratefully acknowledged.

References

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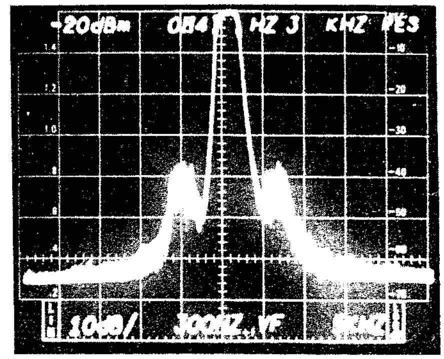

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Fig. 6. Current spectrum at harmonic number 6237 -- six bunches stored, total current 27 mA.

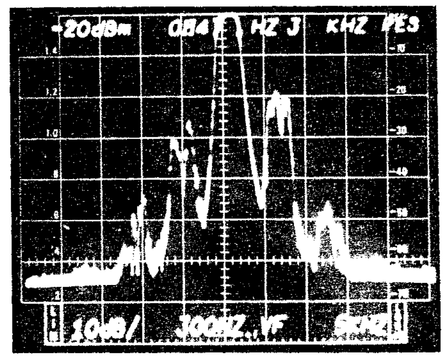

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Fig. 7. Current spectrum at harmonic number 6237 -- excited to oscillation by feedback channel #1.

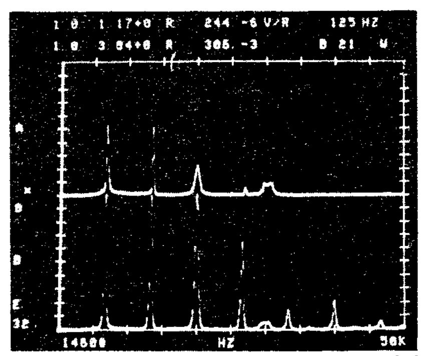

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Fig. 8. Current spectrum displayed by Fast Fourier Transform Analyzer. Single bunch e^- 2 mA. Top trace is with feedback channel #1 optimized for damping and lower trace is feedback channel #1 shifted by 180° in phase.