Transverse Feedback and LEP Performance

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Abstract

The LEP collider has been equipped with a transverse feedback system in order to increase the threshold current for the transverse mode coupling instability (TMCI). The system consists of parallel plate magnetic kickers driven by current pulses. The feedback excitation signal is obtained by combining the beam signal from two electro-static pick-ups placed ~ $\pi/2$ betatron phase advance apart. In "reactive" mode a positive Q-shift of 0.045 (half the synchrotron tune) has been set and measured in the vertical plane. In "resistive" mode, where the system damps coherent oscillations a damping rate of 100 s^{-1} has been obtained. It is planned to use the feedback in reactive mode initially to equalize the coherent and incoherent tune values so as to increase the region in tune space for avoidance of synchro-betatron resonances, and ultimately to increase the threshold for the TMCI. In resistive mode the system has been used to stabilize the bunches with the chromaticity deliberately set negative so as to eliminate higher order head tail instabilities. For the planned increase of the number of bunches in LEP to eight per beam [1] the electronics has been modified to permit faster data processing. The transverse feedback kickers are also being successfully used for resonant depolarisation of electron beams for energy calibration [2].

1. INTRODUCTION

A beam transverse feedback system can damp coherent oscillations by generating an angular deflection (at a "kicker") proportional to the measured displacement at a pick-up placed at an odd multiple of $\pi/2$ betatron phase advance from the kicker. In this configuration the magnitude of the displacement at the pick-up is directly proportional to the angle at the kicker. Hence the kicker applies an angular kick which is proportional to the angle itself. This of course results in exponential damping or anti-damping of the *coherent* motion of the beam. If the phase advance is a multiple of π then the kicker gives an angular kick proportional to the displacement at the kicker. This results in a change in the *oscillation frequency* of the coherent motion or a change in the coherent tune. The tune shift is approximately

$$\Delta Q_{coh} = -\sqrt{\beta_k \beta_{PU}}\,\frac{\Delta y'}{y}$$

Since the pick-up and kicker detect and act upon centre of gravity or coherent motion the feedback system has no effect on the single particle or incoherent motion. If the kicker is combined with two pick-ups each approximately $\pi/2$ apart then by adjusting the gains associated with each pick-up a combination of damping and tune shift is possible. The LEP feedback system is based on this scheme.

2. PERFORMANCE

There are three main ways in which the transverse feedback system can improve the performance of LEP.

Firstly, acting as a damper (resistive mode) the system can stabilize the m=0 mode of transverse motion even when the chromaticity is deliberately set negative. This mode of operation has been used when it was observed that with higher positive values of chromaticity, the higher order head-tail modes were unstable. When the chromaticity is negative the higher order head-tail modes are stabilized while the 0 mode becomes unstable requiring stabilization by the feedback system.

The second mode of operation is related to the excitation of synchro-betatron resonances. In LEP it has been observed that both the coherent and incoherent tune values are important for excitation of synchro-betatron resonances. The transverse impedance causes a large split between the coherent and incoherent tune values as the intensity is increased. In reactive mode the feedback system can change the coherent tune value while leaving the incoherent value unchanged. In this way the space charge coherent tune shift can be compensated.

Lastly, the fundamental limitation to the single bunch intensity is set by the transverse mode coupling instability. The onset of this instability occurs when the frequency of the m=0 mode (centre of gravity mode) is shifted downwards and couples to the m=-1 mode. The reactive feedback system can maintain the m=0 mode constant thereby avoiding coupling to the m=-1 mode. This was shown to be successful in a machine experiment in the PEP machine [3] but has not yet been systematically tried in LEP due to the fact that the intensity of LEP is prematurely limited by other effects.

In addition to the above mentioned modes of operation the kickers of the feedback system are also being used for resonant depolarization of the electron beam for energy calibration. For this application where the maximum kicker strength is required it is of outmost importance to keep the harmonic distortion of the kicker pulses very low to avoid simultaneous excitation of betatron resonances.

The performance of the feedback system might be limited by coherent signals from higher modes which are regularly seen from a transverse pick-up at high bunch intensities (fig. 1). If the phases of the higher mode signals are very different from the phase of the 0 mode antidamping is possible. Experiments to test this hypothesis have not yet been done.

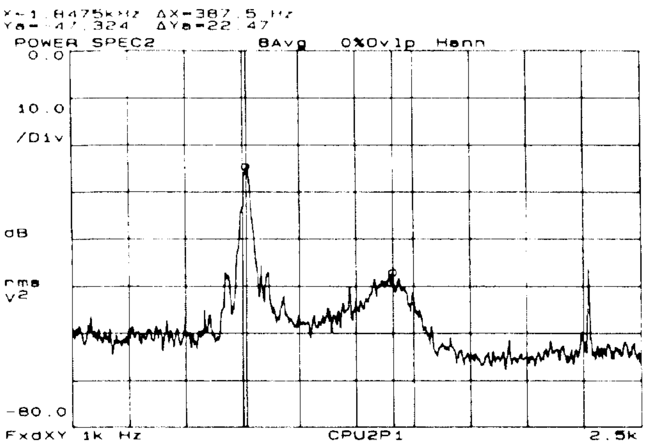

Fig. 1 Spectrum from a vertical pick-up of a 500 μA bunch showing clearly the m = -1 mode at 1.44 kHz.

3. Experimental Results

LEP has been operated with very different optics and for each optics the phase relationships for the feedback system are different. For a given optics the pick-up phases can be calculated but they are also measured. For each pick-up the phase is found by open loop beam transfer function measurements with an Fast Fourier Transform (FFT) network analyzer (fig. 2). The phase at the centre of the response is a direct measure of the pick-up phase.

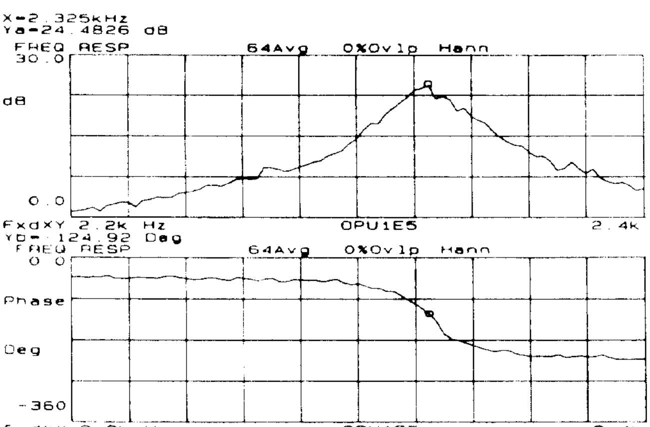

Fig 2 Example of an open loop beam transfer function measurement. From the phase response the pick-up phase is found to be -124°.

Once the phases have been measured the gain combination for damping, Q-shift or any combination thereof is found by vector calculations. When the feedback loop is closed, the beam transfer functions show the tune shift and the presence of damping. The damping time is calculated from the tune shift using the relationship between feedback Q-shift and damping [4].

Adjusted for reactive feedback a tune shift of 0.045 has been measured for positrons and 0.024 for electrons in the vertical plane. Fig. 3 shows the vertical tune history when the feedback system is switched on and off. When used resistively the damping rate is sufficient to keep the beams stable if the chromaticity is zero or slightly negative.

The horizontal system has only been adjusted for damping because tune shifts have not yet been required.

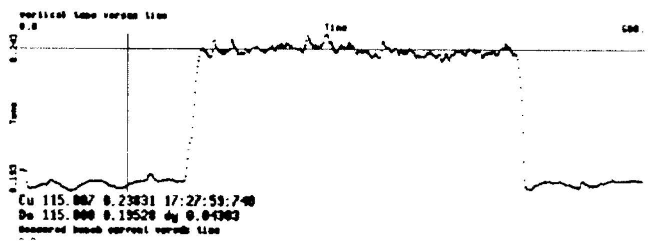

Fig. 3 Q-history of positrons in the vertical plane when feedback is switched on and off. In this example the tune shift was 0.045 (half the synchrotron tune).

The kicker strength has been calibrated by kicking with constant amplitude current pulses at exactly the revolution frequency and compensating the orbit distortion with a corrector magnet. With this method it was found that the magnetic field was 5 Gm for a current of 38 A in each of the two kicker tanks. The calculated field for the same current was 5.2 Gm.

4. Upgrade for Eight Bunches

For the eight bunch Pretzel scheme the hardware has been modified and is ready for tests with beam. Due to the higher number of bunches the time used for parameter calculation and data transmission is too long for the existing digital signal processor (DSP).

A complete new hardware has been developed and integrated in a VME crate to be directly accessible from the main processor and reduce access time for the remote control system.

The beam position and data sampling electronics have partly been modified. The normalizer and pre-amplifier are unchanged. With the data stored after the analogue-to-digital conversion, the number of signal channels per plane has been reduced (fig. 4). Previously four channels were used for one type of particles from one pick-up. At present four channels are used for the bunch signals of all e^+ and e^- bunches from both pick-ups instead of the 32 channels that would have been needed with the present operating system if used for eight bunches. The channel reduction has made other facilities necessary to monitor the frequency spectrum of single bunches. A new feature has been implemented to enable the observation in time or frequency domain of one e^+ and one e^- bunch from each pick-up at any time as well as all bunches simultaneously.

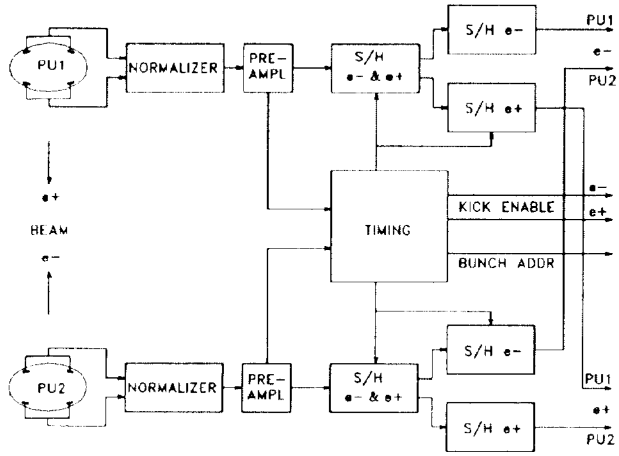

Fig.4 Block diagram of the analogue signal processor.

The timing circuits have been modified and improved. The clock rate is increased from 1/20 to 1/5 of the 352 MHz RF frequency and the bunch address field has been widened to cope for the eight bunches. The system which detects the number of bunches present in LEP has been changed and the feedback system can handle any number from one to eight per beam. A flexible control of the individual excitation of the bunches has been added, a facility which is used during experiments.

The digital signal processor functions have been separated into three parts (fig. 5):

1. Gain settings are performed by a dual multiplying digital-to-analogue converter.

2. The look-up tables have been replaced by a dual port RAM.

3. The final pick-up signals are summed before the 12 bit analogue-to-digital converter inserted to permit data transmission to the kicker power amplifier located 150 m from the low power electronics.

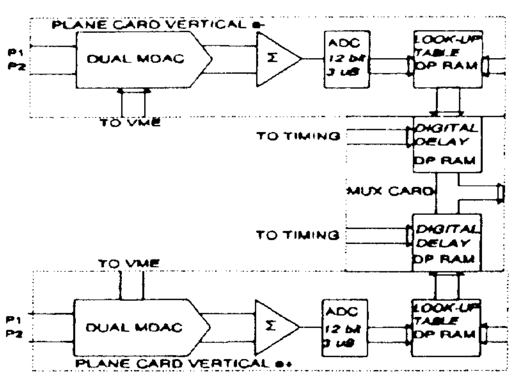

Fig. 5 Block diagram of the digital signal processor.

This process reduces the data manipulation time by a factor of five and maintains the system flexibility.

The output is sent to a common storage area used as a digital delay to synchronize calculated data with the bunch timing.

Due to the inductive behaviour of the kicker tanks the exact time for maximum current depends on the pulse amplitude. this effect is taking into account by modulating the timing with the current pulse amplitude.

The new hardware is compatible with the already installed system (data transmission protocol, power amplifiers and drivers).

5. DEPOLARISATION WITH FEEDBACK KICKERS

The feedback system has been used to depolarise the electron beam for energy calibration. A simplified version of the hardware is going to be installed and used as dedicated depolarizer with kickers which were installed in the end of last year. In this way simultaneous excitation for resonant depolarisation and damping with feedback are made possible.

For this specific use an external signal source is necessary to excite the spin rotation resonance. A synthesized signal generator is connected to the control system via a slave processor on the VME crate accessing the GPIB bus. The software for operational use has been written. Single bunch polarisation has been made possible in order to save time by successively depolarising different bunches without having to wait for repolarisation.

6. CONCLUSION

The LEP transverse feedback system has been commissioned in the vertical plane in both resistive and reactive mode. In the horizontal plane the system has been used for damping. In the different modes of operation the system contributes to increase the LEP performance with four or eight bunches per beam. The same system is used for resonant depolarisation for energy calibration.

7. REFERENCES

[1] J. Jowett, "Description of the Eight Bunch Pretzel Scheme", Proc. of the 1st Workshop on LEP Performance, Chamonix, January 1991, pp. 297-318.

[2] L. Arnaudon et al., "Energy Calibration by Resonant Depolarisation at LEP", Submitted to Physics Letters B.

[3] S. Myers, "Stabilization of the Fast Head-tail Instability by Feedback", Proc. of the IEEE Particle Acc. Conf., Washington D.C., March 1987, pp. 503-507.

[4] L. Arnaudon, S. Myers and R. Olsen, "Commissioning of the LEP Transverse Feedback System", Proc. of the EPAC Conference, Nice, June 1990, pp. 901-903.