COMMISSIONING OF THE LEP TRANSVERSE FEEDBACK SYSTEM

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Summary

The LEP collider has been equipped with transverse feedback systems [1] in the horizontal and vertical planes capable of producing coherent tune shifts of the order of Qs (0.1) and of damping the transverse oscillations of each of the eight bunches. Reactive and resistive feedback is made possible by linearly combining position values of two pick-up electrodes separated by 90 degree phase advance. Due to the time available between position measurement and applying the kick 89µs (1 turn), it has been possible to make the calculating part of the system digital, using Digital Signal Processors (DSP), one dedicated to each type of particle. The bunches are treated individually, this means 16 channels in total.

The beams are given angular kicks by parallel plate magnetic kickers with an inductance of 1.5µH. Two units of 1.5m, length in the vertical plane and 3 units in the horizontal plane have been installed. The kickers are pulsed with triangular pulses of maximum +/- 40 Amps by IGBT power transistors giving a maximum kick of 4Gm in each plane. Measurements have shown that transverse oscillations are damped, and the first results with reactive feedback have been obtained. More work still remains to be done to make the system fully operational from the PCR.

Introduction

Theory predicts that the LEP performance will be limited by the Transverse mode Coupling Instabilities. The onset of this instability occurs when the frequency of the head tail mode 0 is shifted sufficiently to couple to the -1 mode. Roughly speaking, for short bunches, this happens when the frequency shift is equal to the synchrotron frequency. Computer simulation programs and experiments[2] have shown that by compensating the frequency shift of the mode 0 oscillation by reactive feedback, the bunch threshold current can be increased.

Computation of the required system parameters is obtained by evaluating the transfer matrix for the particles over a single machine turn with the effect of the feedback kicks included. The eigenvalues of the transfer matrix allow calculation of the required loop gains associated with each pick-up by introducing the required tune shift and damping coefficients.

The meaning of the different parameters are shown graphically on fig.1.

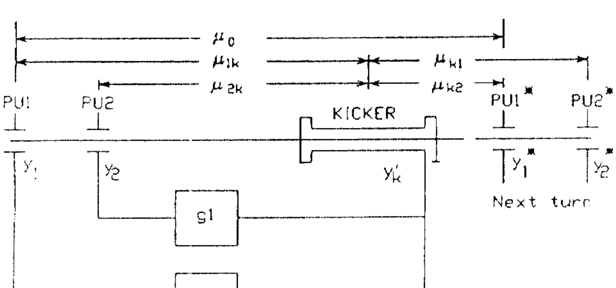


fig.1

The feedback tune shift μ_{FB} is given by:

$$\mu_{FB} = \frac{1}{2}\left[g_1 \cdot \sqrt{\beta_1 \cdot \beta_k} \cdot \sin\left[\mu_{k1}\right] + g_2 \cdot \sqrt{\beta_2 \cdot \beta_k} \cdot \sin\left[\mu_{k2}\right]\right]$$

and the damping time τ_{FB}:

$$\frac{2}{\tau_{FB} \cdot f_{rev}} = g_1 \cdot \sqrt{\beta_1 \cdot \beta_k} \cdot \sin\left[\mu_{1k}\right] - g_2 \cdot \sqrt{\beta_2 \cdot \beta_k} \cdot \sin\left[\mu_{2k}\right]$$

For damping τ_{FB} should be negative.

A control program calculates g1 and g2 for different choices of feedback tune shift and damping time and converts the gain values into the DSP gains which take into account the sensitivity of the pick-ups, the gain of the electronics and the conversion factor for current to field strength at the kicker.

For the most commonly used machine tune, the Twiss parameters are :

	$\frac{\mu_1}{2\pi}$	$\frac{\mu_2}{2\pi}$	$\frac{\mu_k}{2\pi}$	β_1	β_2	β_k
Vertical q = 0.18	10.758	11.041	11.936	83.265	83.304	113.745
Horizontal q = 0.28	10.131	10.311	10.663	86.410	115.361	113.135

Operational Uses of the Feedback System

Although the reactive feedback system was constructed to raise the LEP intensity threshold against the Transverse Mode Coupling Instabilitiy, recent experience in operating LEP at higher intensities has highligthed two other important uses of this system. At present the LEP intensity per bunch is thought to be limited by synchrobetatron resonances [3]. The large split between the coherent intensity dependent tune and the incoherent one makes simultaneous avoidance of these resonances very complex[4], particularly when different bunches have different intensities. The reactive feedback system can be used to provide an intensity dependent tune shift for each individual bunch and thereby make coherent and incoherent tune values equal. This will greatly facilitate accumulation of higher intensities.

The resistive feedback can also be used to ensure stability of higher intensity beams in the absence of positive chromaticity. This is particularly important during the energy ramp when the induced eddy currents in the vacuum chamber produce a chromaticity jump.

Hardware

Fig.2 is a schematic diagram of the horizontal plane of the transverse feedback system.

Pick-ups

The two bunch position sensing pick-ups for each plane are situated near the RF straights section where the

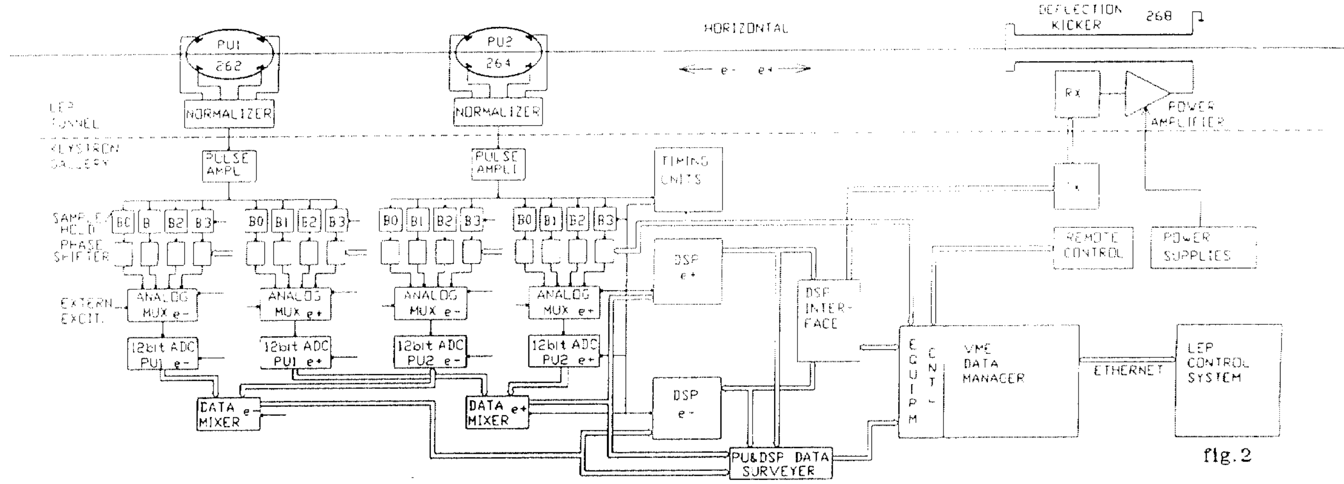


fig.2

dispersion is zero, 200m from point two towards point three. The time between e- and e+ is 2µs and 20µs to the next e-.

The standard LEP narrow band pick-up system is used for position measurements and for signal transmission to the klystron gallery. For our use the pick-up buttons are connected in a configuration which gives a normalized signal with either horizontal or vertical beam position. The transmitted signals are pulse to space modulated, and recombined in the klystron gallery to give an amplitude modulated signal, with a pulsewidth of 200-300ns depending on the bunch intensity .

Electronics

In the LEP klystron gallery where the feedback electronic racks are situated, the bunch position signals are amplified and TTL synchronization signals are created for each pick-up. This information is used for timing and logical purposes. The e+ and e- bunch signal path has to be separated, so the correct bunch is sampled and treated at the right time. For the system to work properly each bunch must contain a minimum current of 10 µA, and the bunches should be in the correct RF bucket otherwise the timing is wrong and the applied kicks are not correct. The analog bunch signal is delayed to allow the sample/hold control signal to arrive before the corresponding analog one. The sampling time is 200ns which means that the end of the sampling is in the middle of the analog position pulse. The sampled signal is fed to its own phase shifter. The phase shifter produces shifts up to 180°, and can be manual or computer controlled. The pulse amplifier, sample/hold and the phase shifter have a gain of 30dB. An external input is provided to mix an excitation signal to the beam signal to allow measurement of the transfer function. Each plane has 16 different channels, 4 e+ and 4 e- coming from the two pick-ups. The 4 e+ and 4 e- bunch signals from each pick-up are separately multiplexed. Four 12bit ADC with a conversion time of 6µs converts the position into a digital signal. At the output of the ADC a single bit corresponds to 5µm, which is much less than the resolution of the system. Later the accuracy of the position signal will be improved. The ADC data from the pick-ups are combined so each data path contains the position value of two pick-ups of either e+ or e-.

Digital Signal Processor

A digital signal processor TMS32010 from Texas Instruments is used as processing unit. The task of the processor is to multiply the position value with the gain factor for each pick-up and bunch. The multiplication is done with look-up tables. In each plane there are eight tables, one for each pick-up and bunch. These tables are on two pages with only one in use at any time. While one page is in use the other page can be updated with new gain values, and later switched to be the active one. The tables for each bunch can be constructed individually and have any form, which means different gain for each bunch. The processor subtracts the closed orbit from the position signal, by continuously averaging the last 1000 values of the position data. The data is converted into the special code used by the power amplifier driver and is transmitted as parallel data together with the kick timing pulse.

Power Amplifier

A digitally controlled pulse amplifier drives each kicker tank. See fig.3

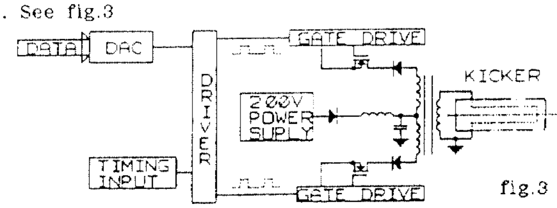


fig.3

FEEDBACK POWER AMPLIFIER

Information coming from the D.S.P. are locally converted into a pulse of variable amplitude but fixed position. The pulse range is +/- 40 Amps for each amplifier with a resolution of +/- 8bit and a duration of 1µs. Due to the inductive load, the pulse shape is triangular and the power transistors are protected against reverse current. See fig.4

VERT.
10Amps/div

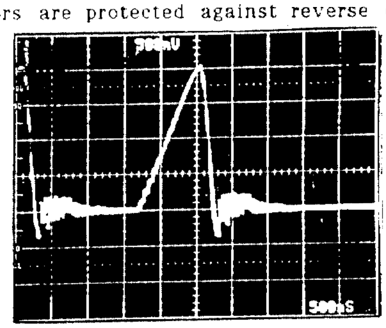


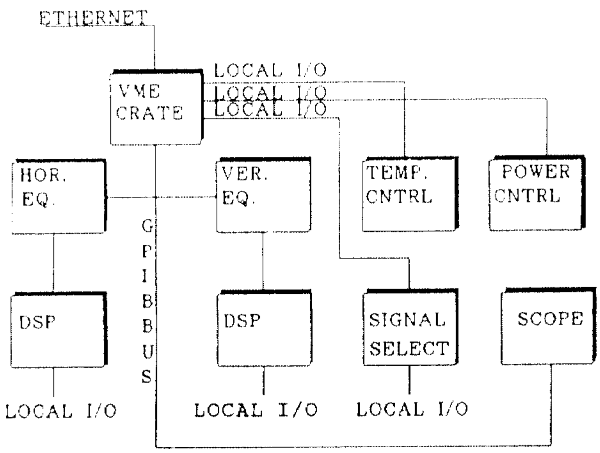
fig.4

The amplifiers are fitted into a lead box directly under the kicker in order to be as close as possible to the load and shielded against radiation.

Clamped on the output connector there is a current transformer which measures the output pulse amplitude during calibration.

Datamanager and remote control

The so called Data Manager [5] is a VMEbus crate which we can log on to control the entire feedback facility. A general block diagram is given below.



The master processor is a 68020 with 4Mbyte of ram, ETHERNET driver,60Mbyte hard disk and local terminal on RS232.

A 68000slave processor is used to control non intelligent I/O located on a G64bus.

This solution gives flexibility, cost and development time reduction by using existing low cost G64 I/O boards. We can consider the control system as three sub-systems:

Horizontal Plane System: controlled by a G64 crate connected to the VME via GPIBbus mainly used for D.S.P. parameter transmission.

Vertical Plane System: same as Horizontal.

Control and Monitoring System: directly under VME control used for data collection and on/off facility.

At the present state of development the human interface is a simple command interpreter which is forseen to be easily integrated in the existing LEP RF control system. This approach gives the facility of retrieving data (eg Pickup data, D.S.P. data, system status, kicker current etc.) for off line manipulation on a higher level workstation.

Commissioning and result with beam

The first tests of the system were done mainly in the vertical plane where the instabilities are expected to occur first. The feedback was set-up to give resistive feedback (damping). This means that the pick-up which has phase advance closest to 90 degree to the kicker is contributing strongest.

The vertical tune of the machine was 0.28. This working point gives under normal operation small vertical oscillations, the inherent stability of the beam is strong. For our tests the stability was reduced by decreasing the chromaticity. With transverse feedback switched off, no current could be accumulated, with feedback on, normal accumulation was achieved. When the feedback was switched off again the accumulated current was lost.

Another test was to apply feedback only to one of the four e+ bunches, the current could be accumulated in this bunch, in the three others the current stayed low.

This year the the operational working point has changed to Qv of 0.18, at this point much more coherent oscillations are present, probably due to the increase in beam intensity.

Transfer functions have been measured. Fig.6 shows the system adjusted for resistive feedback in the vertical plan, top trace open loop, bottom trace is the closed loop which gives a reduction of 6dB, with the chosen gain values. More reduction has been achieved with higher gain.

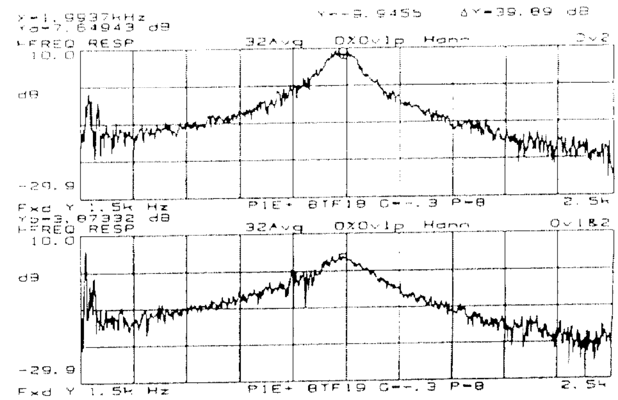


Fig.6

The top trace of fig.7 shows resistive feedback, bottom trace the Q-shift introduced by reactive feedback, the shift is 0.01, upto 0.067 has been achieved with other gain values.

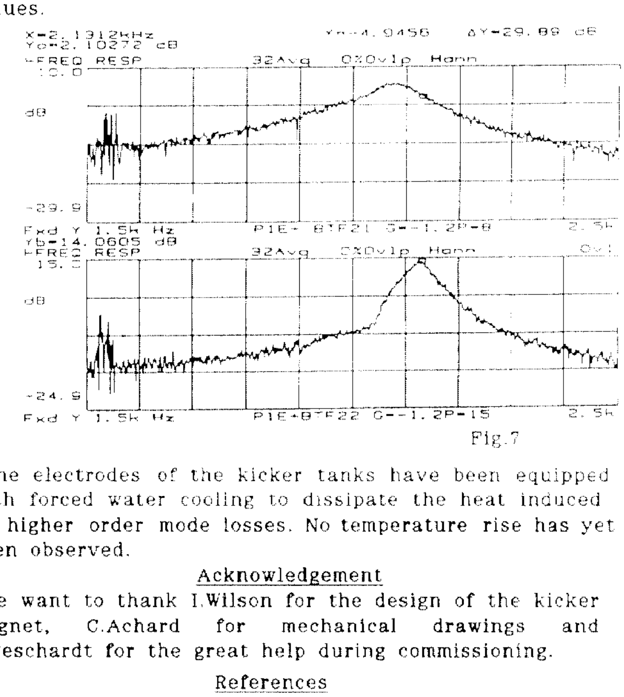


Fig.7

The electrodes of the kicker tanks have been equipped with forced water cooling to dissipate the heat induced by higher order mode losses. No temperature rise has yet been observed.

Acknowledgement

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References

[1]S.Myers, R.Olsen and I.Wilson, 'Hardware for the LEP Reactive Feedback System' Proc. of IEEE Particle Accellerators 1987.

[2]S.Myers, 'Stabilization of fast head-tail instability by feedback' Proc. of IEEE Particle Accellerators 1987.

[3]A.Hofmann et al. 'Synchrobetatron Resonances in LEP' submitted to this conferance.

[4]S.Myers, 'The LEP performance and future development' submitted to this conference.

[5]E.Ciapala P.Coller, 'Dedicated multi_process controller for an RF UNIT' Proc. 1989 IEEE Particle Accellerators Conference P1583.