COMMISSIONING OF THE LEP TRANSVERSE FEEDBACK SYSTEM

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Summary

The LEP collider has been equipped with transverse feedback systems in the horizontal and vertical planes capable of producing coherent tune shifts of the order of 20. Reactive 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 a 90 degree phase advance. Due to the time available between position measurement and applying the kick 80μs (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 40μm in each plane. Measurements have shown that transverse oscillations are damped, and the first results with resistive 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 unit 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 have shown that by compensating the frequency shift of the mode 0 oscillations 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.

![Figure 1](image)

The feedback tune shift \( \mu_{FB} \) is given by:

\[
\mu = \frac{1}{2} \left( g \cdot \beta \cdot \sin[\mu] + g \cdot \beta \cdot \sin[\mu + 2\kappa] \right)
\]

and the damping time \( T_{FB} \):

\[
T_{FB} = \frac{1}{\tau} \left( g \cdot \beta \cdot \sin[\mu] - g \cdot \beta \cdot \sin[\mu + 2\kappa] \right)
\]

For damping \( T_{FB} \) should be negative.

A control program calculates \( g_1 \) and \( g_2 \) 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:

<table>
<thead>
<tr>
<th>Plane</th>
<th>( \mu_1 )</th>
<th>( \beta_1 )</th>
<th>( \mu_2 )</th>
<th>( \beta_2 )</th>
<th>( \mu_3 )</th>
<th>( \beta_3 )</th>
<th>( \mu_4 )</th>
<th>( \beta_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>11.95</td>
<td>110.3</td>
<td>11.93</td>
<td>110.2</td>
<td>11.96</td>
<td>110.4</td>
<td>11.97</td>
<td>110.3</td>
</tr>
<tr>
<td>Horizontal</td>
<td>13.5</td>
<td>133.1</td>
<td>13.46</td>
<td>133.3</td>
<td>13.54</td>
<td>133.5</td>
<td>13.56</td>
<td>133.4</td>
</tr>
</tbody>
</table>

Operational Use of the Feedback System

Although the reactive feedback system was constructed to raise the LEP intensity threshold against the Transverse Mode Coupling Instability, recent experience in operating LEP at higher intensities has highlighted the other important uses of this system. At present the LEP intensity per bunch is thought to be limited by synchrotron resonances. The large split between the coherent intensity dependent tune and the incoherent one makes simultaneous avoidance of these resonances very complex, 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 reactive 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 straight section where the
dispersion is zero, 200m from point two towards point three. The time between e+ and e- is 20us and 200us 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 configured in a configuration which gives a normalized signal with either horizontal or vertical beam position. The transmitted signals are pulse to space modulated, and recombed in the klystron gallery to give an amplitude modulated signal, with a pulsewidth of 290-360ns depending on the bunch intensity.

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 paths have 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 1.1 mA, 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 100° 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 6us converts the position into a digital signal. At the output of the ADC a single bit corresponds to 5um, 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

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 +/- 4 bit and a duration of 1us. Due to the inductive load, the pulse shape is triangular and the power transistors are protected against reverse current. See 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 is a VMEbus crate which we can tap on to control the entire feedback facility. A general block diagram is given below.

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**Acknowledgement**

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**References**