Presentation 74

Longitudinal Feedback Systems

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74.1 Present System

74.1.1 Introduction

Longitudinal oscillations were not expected in LEP before the bunch current was approaching the nominal value of 0.75 mA. However during the commissioning strong coupled dipole oscillations were seen at bunch currents higher than about 0.15 mA. As a separate wideband damping cavity system has not been installed in LEP, a system which acts on the phase in the accelerating cavities was improvised. A fundamental limitation of such a system is the small bandwidth of these cavities. For a four-bunch beam in LEP the maximum modulation frequency is 21.6 kHz with a synchrotron tune of 0.08. At this deviation from the carrier the LEP RF cavities attenuate the signals about 13 dB. For LEP operating with four bunches this is not a serious limitation. However, with two counter-rotating beams and the cavities located near an intersection point the time between the passage of an electron bunch and a positron bunch is only between 1.0 and 1.6 μs. A signal which acts on one bunch will unavoidably excite a bunch of the counter-rotating beam. As particles only respond to longitudinal excitation near their synchrotron frequency or a harmonic thereof, this unwanted coupling can be reduced by making the synchrotron tune different for the two beams.

This is possible in LEP because the cavities are excited at two frequencies, f_1 = 352.20904 and f_2 = 352.29900 MHz. With the cavities aligned for one frequency, f_1, the phase error for the second frequency increases linearly with the distance from the nearest intersection point. When the RF phases are correctly adjusted (Figure 74.1) the error is the same for electrons and positrons and the voltage loss is only 3.5%. If all the RF voltage vectors are aligned for, say positrons, the RF sum voltage seen by electrons is 13.3% lower and the phase oscillation frequency shifted downwards. The nominal synchrotron tune of 0.08 is decreased to 0.074.

74.1.2 System description

The longitudinal dipole oscillations are detected with a phase measurement between the sum signal from a pick-up and the RF frequency (Figure 74.2). The bunch signal is processed with bandpass filters centred at the 352 MHz RF frequency, amplifiers and an automatic gain control loop. The resulting signal, a 352 MHz burst, is phase compared with the RF frequency and the phase difference derived from a peak-to-peak detector.

The time constant is chosen to be such that the signal decays in the time interval between the passage of two bunches. This permits phase measurement of all four bunches with one system and with only minor modifications the system can be used for eight bunches.

The logic, triggered by the pick-up signal and the analogue switch, determines whether electrons

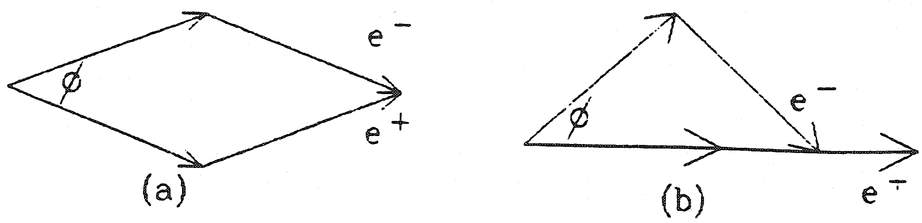

Figure 74.1: Vector diagrams showing the addition of the voltage vectors for two RF units located symmetrically around an intersection point. In (a) the RF phases are correctly adjusted and the total voltage is equal for electrons and positrons. In (b) the phase of f_2 for one unit has been adjusted to maximise the voltage for positrons. The sum voltage for electrons is decreased by a factor cos(f) = 0.734 for an average cavity position. As half the RF power is generated at f_2 the voltage loss for electrons is 13.3 %.

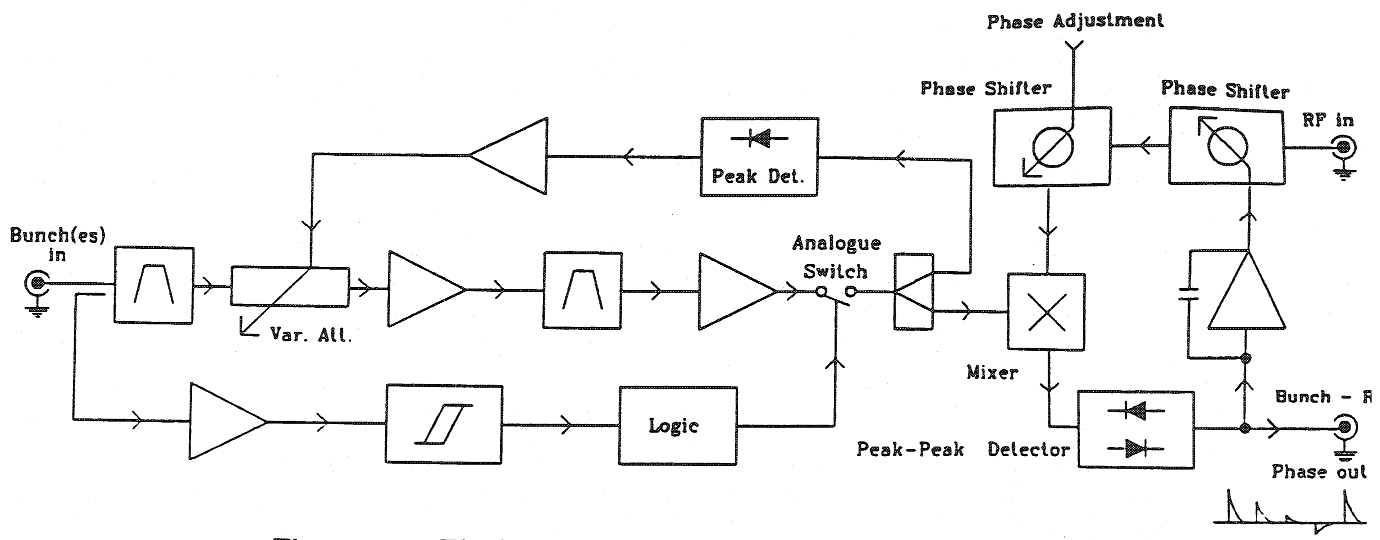

Figure 74.2: The bunch-RF phase measuring system

or positrons are selected. The phase of the RF input to the mixer which is used as a phase detector is automatically adjusted with a loop for maximum phase detector sensitivity. The AGC loop enhances the dynamic range. Phase differences of less than 0.1 degree at 352 MHz can be measured for bunch currents between 5 μA and 2.5 mA (Figure 74.3). Expressed in energy variations the resolution is 11 ppm.

The phase detector signal is processed using the time domain approach (Figure 74.4). With the sample and hold amplifiers the signal from each bunch is separated. After filtering and phase adjustments the four channels are recombined in analogue gates. The timing is arranged to be such that the phase information from one bunch is used for correction of the same bunch one turn later. This timing is derived from the pick-up signal.

The correction signal is applied to a voltage-controlled phase shifter which modulates the klystron drive signal. The same phase shifter is used in the klystron phase loop which compensates for phase variations in the power generation system. Two systems have been installed in LEP, one for electrons and one for positrons. Each system acts on two RF units. Common mode dipole oscillations are damped in one unit and coupled dipole oscillations in the other unit.

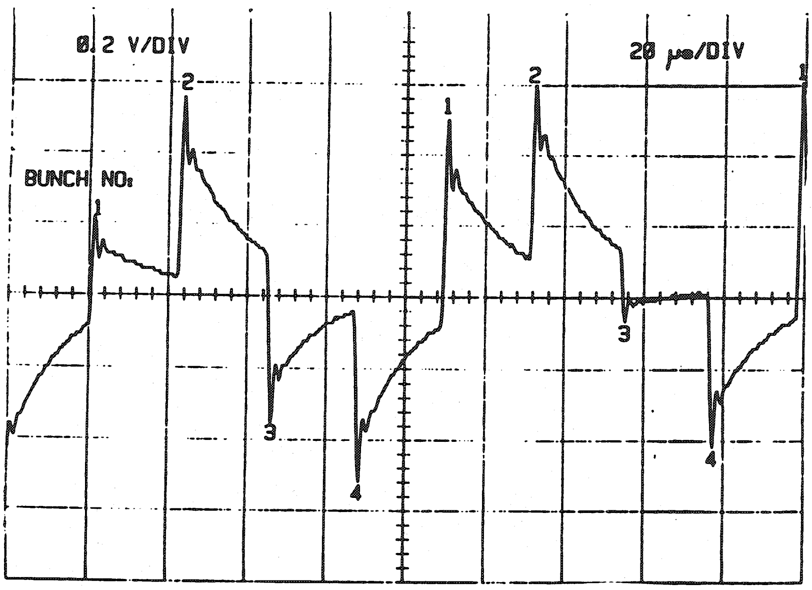

Figure 74.3: Oscillogram of the signal at the output of the phase detector. The sensitivity is 250 mV/degree and the resolution better than 0.1 degree.

74.1.3 Operation and limitations

Longitudinal feedback is used routinely during operation. The two systems are switched on at low bunch currents after RF de-phasing by software. When the beams have been accelerated to the physics energy of about 45 GeV the feedback is switched off again and the RF units re-phased. The system has two fundamental limitations:

1. Due to the accelerating cavity bandwidth (copper cavities) operation with more than four bunches is not possible. For the damping of all modes of oscillation the required modulation frequency is proportional to the number of bunches.
2. If the RF system is operated with only superconducting cavities the bandwidth is too small for any number of bunches. In addition the synchrotron tune can not be made different for electrons and positrons.

Therefore it has been decided to construct a dedicated wideband feedback system with an operating frequency of about 1 GHz.

74.2 1GHz System

74.2.1 Introduction

The performance of the present longitudinal feedback system which acts on the phase of some of the accelerating cavities is limited by the cavity bandwidth. The decoupling between the electron and positron system is obtained by dephasing the RF system in such a way that the electron and the positron synchrotron tunes are different. This decoupling cannot be made sufficiently wide to avoid crosstalk completely, it adds an operational complication and it is not possible with super-conducting cavities. Therefore it has been decided that a dedicated feedback system will be constructed. If a frequency of about 1 GHz is chosen, main hardware components (klystron, circulator and cavities) which have already been developed can be used.

74.2.2 System requirements

The cost of the feedback system is mainly determined by the necessary RF power which is calculated from the required bandwidth and voltage. High frequency operation is advantageous because for a

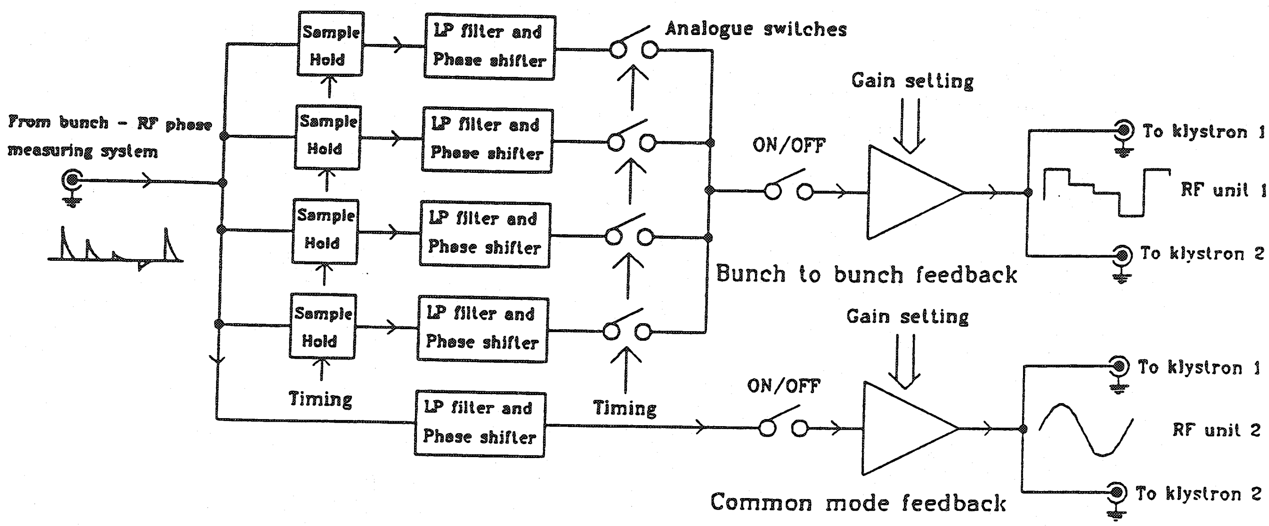

Figure 74.4: Schematic diagram of the signal processor

given bandwidth, cavity length and voltage, the required power decreases with frequency.

74.2.2.1 ***Bandwidth*** In order for the energy error of each bunch to be corrected individually, the cavity field has to change in the time interval between the passage of two bunches. In the case of two counter-rotating beams of four bunches colliding in the intersection points this time interval would be maximum if the feedback cavities were located in the middle of an arc. This is obviously impractical and would not allow operation with more than four bunches/beam. Instead the feedback cavities can be installed in one of the small empty straight sections between the arcs and the dispersion suppressors. At this location, 435 m from an intersection point, the minimum time between bunch passages, t_{min}, is 2.9 μs. Assuming that in this time interval the cavity field should reach 90% of the set value, the cavity filling time is:

$$t_f = -t_{min}/ln(0.1) = 1.26\mu s$$

and the bandwidth:

$$B = 1/(\pi t_f) = 253 \text{ kHz}$$

With this bandwidth and properly adapted low power electronics the system can be used with any even number of bunches up to 12. If the cavity bandwidth is increased to 300 kHz, 18 bunch operation is also possible.

74.2.2.2 ***Frequency*** The 1 GHz cavities which are planned to be used, can be tuned from 998.7 to 1002.5 MHz. Within this range the exact frequency is determined by the number of bunches in LEP. If the harmonic number is a multiple of 360 the feedback system allows operation with any possible number of bunches. The following parameters are then found:

$$h = 88920$$

$$f_{FB} = 999.9498 \text{ MHz} = 247/87 \cdot f_{RF}$$

The RF harmonic number does not allow 14 or 16 bunch operation.

74.2.2.3 Cavity voltage It is planned to use four seven-cell cavities for the feedback system. The main cavity parameters are:

Aperture	120 mm
Length	1200 mm
Q_0	27000
R/Q	350 W
Frequency	1000 MHz
Tuning range	-1.3 to +2.5 MHz

The 253 kHz bandwidth is obtained by lowering the loaded Q-value with strong over-coupling. A cavity voltage of 625 kV for 40 kW at the input coupler is expected. With a generator power of 200 kW and 20% waveguide losses the total voltage for four cavities is:

$$U_{FB} = 2.5\text{MV}$$

For phase modulation with a modulation index of $\pi/2$ the relationship between feedback voltage, U_{FB} and damping coefficient, α_{FB} is given in [1]:

$$U_{FB} = \frac{2\alpha_{FB}E_0}{ef_{rev}}\left(\frac{\Delta E}{E_0}\right)$$

where f_{rev} is the LEP revolution frequency and $\Delta E/E_0$ the maximum likely coherent energy oscillation. For $E_0 = 20$ GeV and $\Delta E/E_0 = 10^{-3}$ the feedback voltage is:

$$U_{FB} = 3.5\ 10^3\ a_{FB}$$

For linearity reasons it is preferable to limit the phase excursions to one radian. The feedback voltage is then:

$$U_{FB} = 4.2\ 10^3\ a_{FB}$$

With the previously found cavity voltage its seen that the maximum damping rate for the system is:

$$\alpha_{FBmax} = 600\ s^{-1}$$

This damping rate should be sufficient for eight bunches/beam and 1.5 mA/bunch when LEP has been equipped with 128 Cu- and 192 SC-cavities but, if necessary, the feedback voltage can be doubled by increasing the klystron output power to 400 kW and adding four cavities.

74.2.3 System description

The dipole oscillations are detected with the system which has already been developed for the present feedback system [2]. The only required addition is a time multiplexing scheme which combines the signals from the positron and electron bunch oscillation detector in such a way that the signal detected from one bunch is applied to the cavities during the passage of the same bunch one turn later.

The feedback signal can be applied to the beams by either phase or amplitude modulation. In this scheme phase modulation has been chosen. By operation of the klystron with constant output power the drive-level-dependent phase shift in the klystron is eliminated and the cavity tuning system is not disturbed.

A schematic block diagram is shown in Figure 74.5. The phase without feedback is adjusted with the 352 MHz phase shifter. The 1 GHz signal is generated in a voltage controlled crystal oscillator locked to the bunch frequency. The feedback signal is added in a fast phase shifter incorporated in the klystron phase loop which compensates for phase variations in the power generation system. The cavity voltage is controlled by a loop which acts on the klystron drive level.

The maximum output power of the klystron is 400 kW at a cathode voltage of −60 kV. A circulator is needed because most of the power at the cavity input coupler is reflected due to the strong overcoupling.

74.2.4 Time schedule

The development time and cost is greatly reduced by choosing a frequency for which a high power system has already been developed.

A cavity test stand is being prepared. High power tests are foreseen for May and June 1991. Installation of the main hardware components will be done in the winter shutdown in 1992 and the system should be ready for commissioning with four or eight bunches/beam in April 1992.

References

[1] S. Myers, "A first look at longitudinal feedback for LEP", LEP note 366.

[2] J. C. Juillard, E. Peschardt, "Damping of longitudinal coupled dipole bunch oscillations in LEP", Proc. 1990 European Particle Accelerator Conf., pp. 1554-56.

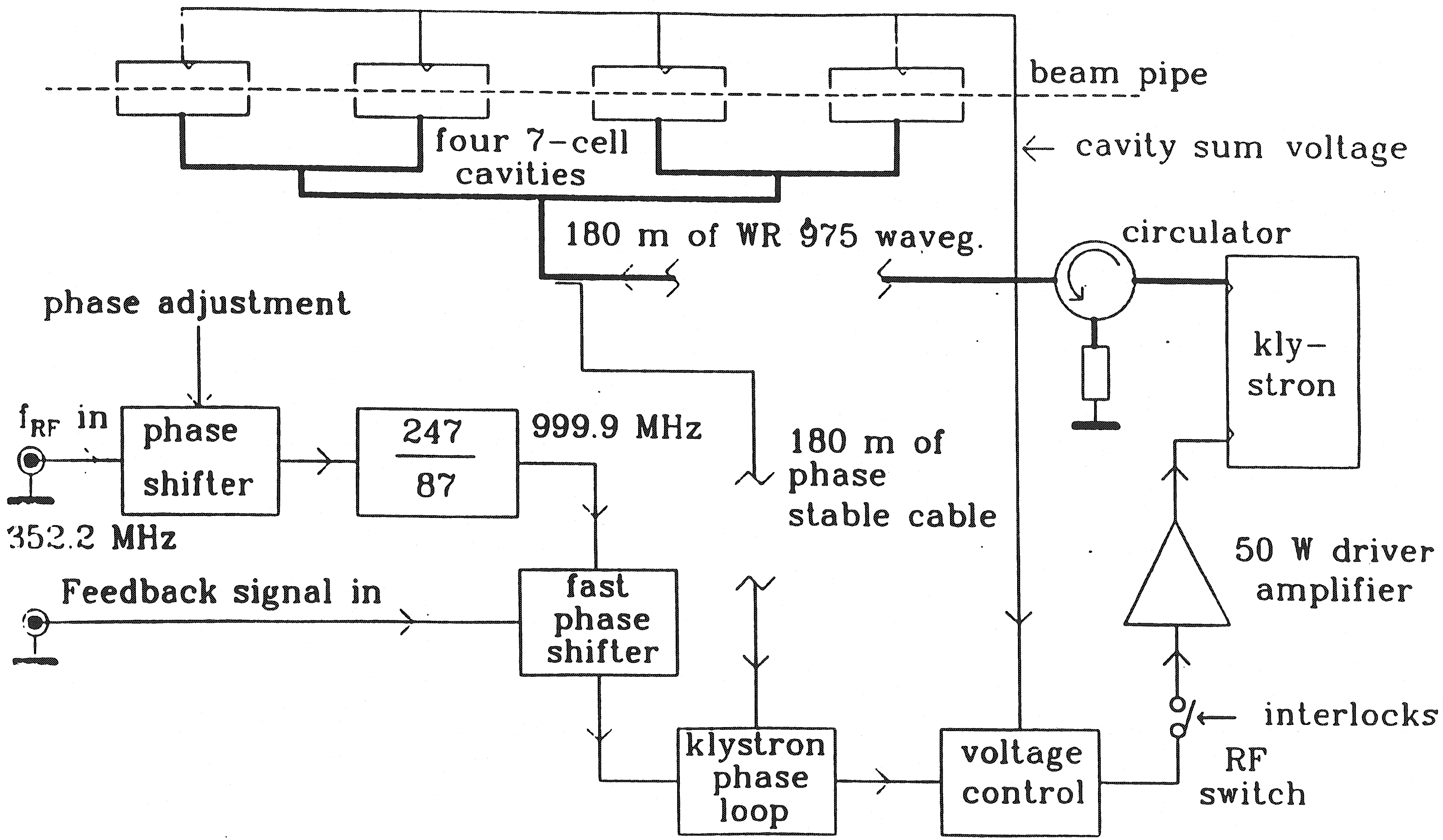

Figure 74.5: Schematic Block Diagram of the 1GHz System