DESIGN AND FUNCTIONALITY OF THE LEP Q-METER

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ABSTRACT

The LEP Q-Meter allows the excitation and observation of transverse beam oscillations. The instrument is used for continuous tune measurements but also for single shot precision measurements of spectra which contain all beam resonances. As the repetition rate of signals at LEP is low, the Q-Meter has been conceived around two fast processors treating the beam data on-line at the pace of the LEP revolution frequency.

1. INTRODUCTION

The LEP Q-meter measures the fractional part of the betatron tunes by observing coherent transverse oscillations in the horizontal and vertical planes with a single dedicated beam position monitor. The oscillations are excited by small kicker magnets, called beam shakers, which act selectively on one bunch. Bunch selection is also provided for the beam position measurement.

Fig. 1 shows the main sub-systems of the Q-meter for one plane (horizontal or vertical): The beam position measurement (pick-up electrodes, preamplifiers and A/D conversion electronics), the signal processing part (DSP) and the beam shaker with its pulsed power supply.

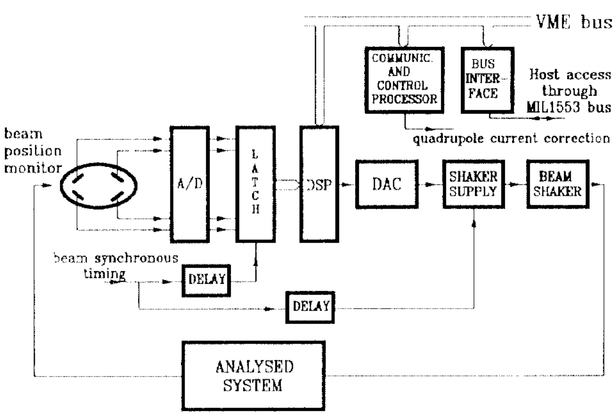

Fig. 1 Hardware components: Beam position measurement, signal processor (DSP) and beam shaker.

The beam position measurement uses the standard electronics of the wide band beam orbit measuring system[1]. The long revolution period of LEP (89 μsec) allowed us to use a fully digital approach for the signal processing part, with the advantage of great accuracy and flexibility. The processors are MOTOROLA 68020 based VME bords with access to the processor through a secondary bus (VSB). The real-time computation load is shared between two processors, one for each plane.

The beam shakers are single turn ferrite magnets built around a ceramic vacuum chamber with a thin internal metallisation. Their pulsed power supplies are located in the support frame of the shakers. Because of the moderate requirements of driving voltage and commutation speed, fast MOSFET power transistors are used in a current regulated amplifier circuit[2].

The beam shakers were designed for tune measurements but they will also be used for bunch equalization and for depolarisation of the beam. More details on the conception of the instrument may be found in the design report[3].

2. METHODS OF MEASUREMENTS

Due to the flexibility offered by digital signal processing, one may excite the beam and analyse the resulting beam motion in different ways. The three methods described below have been implemented and tested on the collider:

2.1 FFT mode

The beam is excited with noise (random kicks) and the resulting beam motion is acquired over 256 to 4096 revolutions. These samples are subjected to a Fast Fourier Transform (FFT). The resulting amplitude spectrum shows the tunes as a very distinct peak, but gives in addition much more information about the state of the machine (synchro-betatron coupling, transverse coupling, damping times). For this we found it important, that the spectrum amplitudes are displayed in calibrated units (millimeters). The accuracy of this method is determined by the following parameters and conditions:

a) The number of samples of the beam position measurement n_s determines the binning Δq of the calculate spectrum:

$$\Delta q = 1 / n_s$$

Due to the use of an interpolation algorithm, the actual tune measurement resolution is further improved.

b) The signal to noise ratio of the beam position measurement. The tune measurement was conceived to operate with a small beam excitation in order to avoid beam losses. The beam oscillation amplitudes, presenly achievable with random kicks are of the order of 0.05 to 0.5 mm, depending on the collider energy and chromaticity. These oscillations are observed with a beam position monitor noise of 1 to 3 μm, depending on beam intensity and gain settings. This noise is the dominating error of the Q-measurement in FFT mode.

The above mentioned and other statistical errors can be reduced by taking the average of successively measured spectra. The measuring times (acquisition time plus FFT calculation) as a function of the number of samples are given in table 1:

Number of samples	Measuring time [ms]
256	170
512	410
1024	860

Table 1 Measuring time in FFT mode.

These times do not include the communication times between the signal processors and the operator console.

The FFT mode may be used in two submodes:

a) Single (one shot) measurement of the horizontal and vertical amplitude spectrum, either simultaneously or one plane after the other. The two resulting spectra are displayed on the operation console.

b) Continuous measurement of the horizontal and vertical tune with permanent beam excitation in both planes and repetitive FFT's. The refresh period of this measurement depends on the number of samples for the FFT (see table 1). In this submode, the user may either read the last measured tunes q_H and q_V or a so called tune history record $q_H(t)$ and $q_V(t)$ stored in a circular buffer of the instrument. This implies that the tunes are calculated on-line from the amplitude spectra with the help of a tune finding algorithm. Due to the coupling of horizontal and transverse oscillations in LEP, one gets often spectra with two resonances of comparable amplitude and it may well happen, that the maximum amplitude of the vertical beam motion occurs at the frequency of the horizontal tune. To resolve these ambiguities, we applied the following strategy: The operator makes a first measurement with a single shot FFT and determines himself the tunes on the spectrum display. The resulting values q_H and q_V are down loaded into the instrument when a continuous measurement is requested and they are then used as starting values for an automatic peak search in a small tune band. The centre of the search band is updated after every measurement.

2.2 Swept frequency mode

This method is commonly used in frequency response analysers. The beam excitation is a (sampled) sinewave of variable frequency. The frequency is swept according to a staircase function with a programmable frequency increment. The (sampled) beam response is analysed by standard techniques (Harmonic Analysis) over a large number of signal periods. The harmonic excitation may always produce beam oscillations of sufficient amplitude. This eleminates the problem of poor signal to noise ratio encountered with the FFT mode. With 1000 samples per point, we obtain an accuracy of $\delta_q = 2.10^{-4}$ for the tune measurement. This error is smaller than the short term (10 minute) stability of LEP. Fig. 2 shows an accurately measured beam transfer function. The frequency sweep was programmed to zoom a small domain around the horizontal tune.

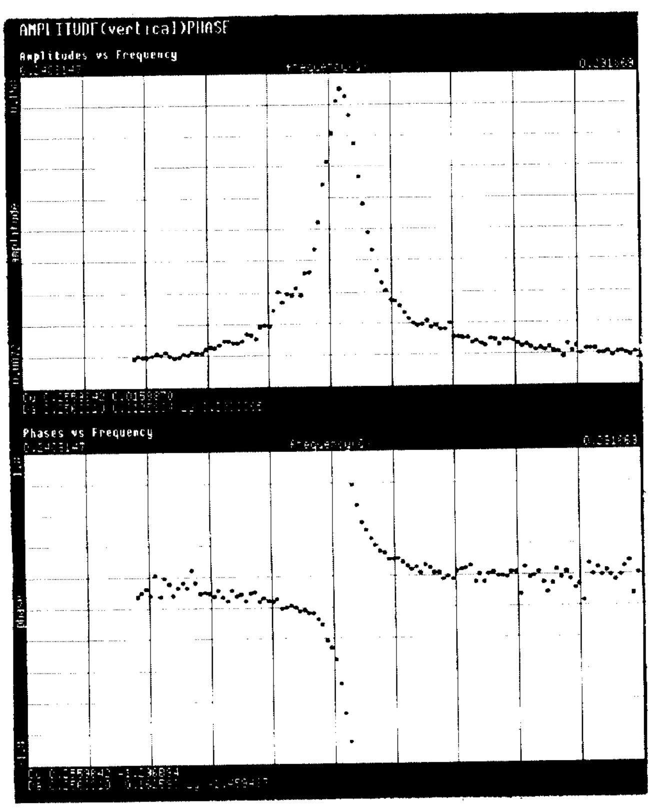

Fig. 2 Beam transfer function measured in swept frequency mode.

The time of a swept frequency measurement is determined by the long acquisition time (number of frequency steps x number of samples per step x LEP revolution period).

2.3 PLL mode

A block diagram of this method is shown in Fig. 3. The beam oscillations are tracked by a phased locked loop consisting of its classical building blocks: The phase detector, the loop filter and the voltage controlled oscillator or its digital equivalent, a phase controlled oscillator (PCO). The PCO output is used for a harmonic excitation of the beam through the beam shaker.

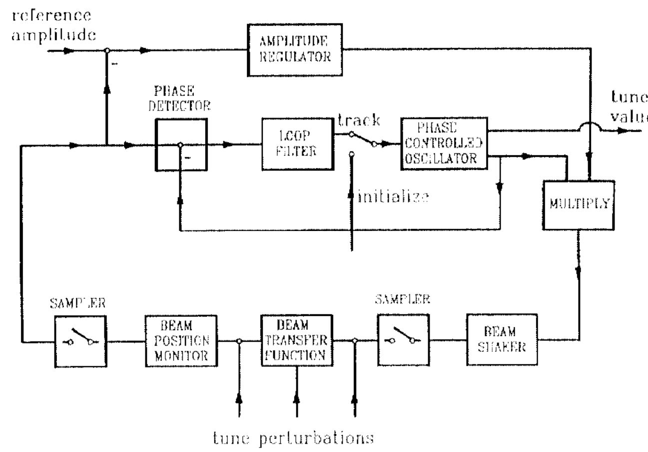

Fig. 3 Signal flow diagram for PLL mode.

This coupling between the PCO and the PLL input variable (the transverse bunch position phase) constitutes a very particular loop configuration. PLL's are normally used to track external signals, not to react back on them. With a correctly chosen phase shift between the PCO output and the beam shaker, the PLL will track and even capture a resonance. The amplitude regulation, shown in Fig. 3 is necessary to avoid an over excitation and loss of the beam when approaching the betatron resonances.

This mode is the most delicate one, because its accuracy and stability depends on machine parameters like beam damping times, phases of the betatron function and coupled resonances. Its commissioning is not yet terminated. The presently achieved measuring accuracy is 0.5% for the fractional part of the tune. With a bandwidth of 40 Hz, the measurement is much faster than possible tune changes due to current variations in the LEP magnets.

Fig. 4 shows a tune history record based on a continuous tune measurement in PLL mode. While this record was taken, the tune was deliberately shifted down and up again by 0.015 and one can see that this change is perfectly tracked by the PLL. One can also recognize a periodic tune perturbation (small peaks) which is related to the magnet cycle of the SPS.

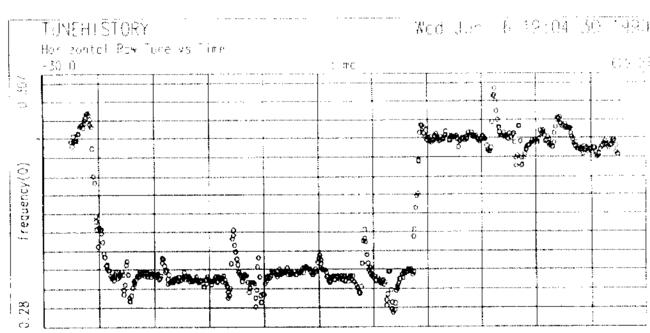

Fig. 4 Tune history record (tune versus time) measured in PLL mode

3. FREE SELECTION OF EXCITED AND OBSERVED BUNCH

The beam position measurement and the beam excitation are synchronized to the beam with a standard LEP timing signal, the turn clock. A fine adjustment and also the bunch selection is possible through programmable delay units (see Fig. 1). Usually, the observed bunch will be the same as the excited bunch, but one may also observe another bunch in order to study bunch-bunch coupling of the transverse oscillations.

4. THE CLOSED LOOP TUNE REGULATION

A continuous tune measurement in PLL or FFT mode may be used for a closed loop control of the tune by acting on the currents of the main quadrupoles. This automatic control is of particular interest during acceleration. Fig. 5 shows the signal flow of this two-variable feedback system. The difference between the tunes q_H and q_V and the reference tunes is processed by two digital regulators. The regulator outputs act on correction inputs of the power converters for the focusing and defocusing quadrupoles (Q_F and Q_D). We have chosen a correction input which responds to control signals by a **relative** current change dI / I_{actual} which produces a tune change independent of the absolute current and therefore independent of the collider energy.

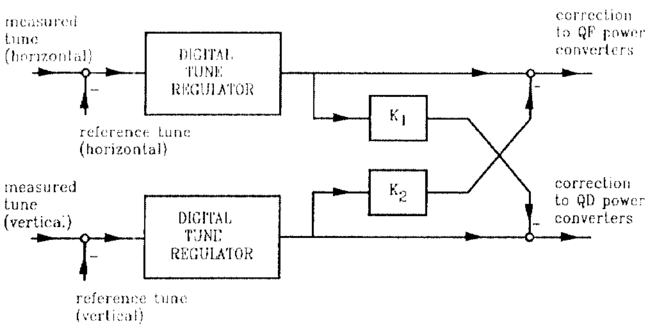

Fig. 5 Closed loop tune regulation

A correction applied to one of the power converters causes always a change of both the horizontal and the vertical tune. This coupling between process variables is undesirable for the closed loop control. It has therefore been compensated by linking both regulator outputs to both current correction inputs with the proper signal ratio.The first tests of this tune regulation have been done with a tune measurement in FFT mode and with simple digital PI-regulators. The purpose of the tune regulation is to correct small unpredictable errors which occur during acceleration. The maximum correction of the regulators is therefore limited to 0.1%. After clipping, the regulator recovers instantly due to its anti wind-up algorithm.

A "tune loop history" record stored in a micoprocessor of the Q-meter allows easy diagnostic and optimization of the loop operation.

REFERENCES

[1] J. Borer, C. Bovet, D. Cocq, H. Kropf, A. Manarin, C. Paillard, M. Rabany, G. Vismara, **"The LEP Beam Orbit Measuring System"**, Proceedings of the IEEE Particle Conference, March 16-19, 1987.

[2] M. Desroziers, **"Amplificateur de puissance pour 'shaker' de mesure de Q"**, Internal Note LEP/BI/MP/Note 89-5, CERN, Geneva.

[3] K.D. Lohmann, M. Placidi, H. Schmickler, **"Q-Monitoring in LEP"**, Internal Note LEP/BI/MP/Note 88-45, CERN, Geneva.