Dynamic Tune and Chromaticity Measurements in LEP

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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 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.

The continuous tune measurement is based on a phase-locked loop, implemented as an algorithm on the fast processors. The beam is excited sinusoidally and the frequency of the excitation is forced to follow the tunes by a phase lock. The measured tunes are stored into tables at fixed time intervals and are available for further analysis.

The principal application of this mode is the monitoring of the machine tunes during critical procedures such as energy ramping or beta squeezing. In order to keep the tunes constant deviations of the measured tunes from reference values are used to compute online corrections for the currents of the main quadrupole chains. Further applications of the continuous tune measurement are the observation of magnetic coupling between the CERN SPS and LEP and a dynamic measurement of chromaticity by using a RF modulation and calculating the chromaticity from the observed tune changes.

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.

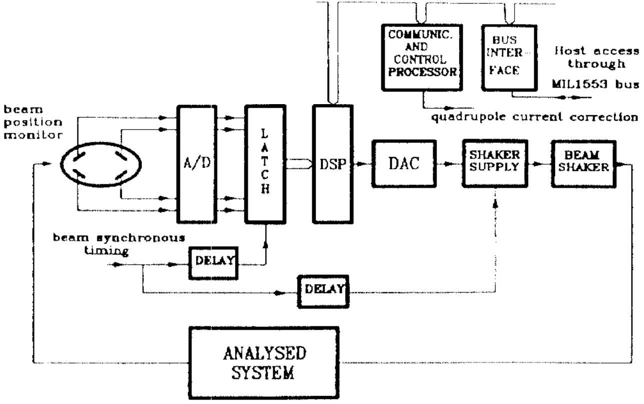

Fig. 1 Main sub-systems of the Q-meter

Figure 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.

The beam position measurement uses the electronics of the wide band beam orbit measuring system [1] with an improved conversion part. 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 MOTOROLA processors are now being replaced by second generation floating point DSP's, which will allow a further upgrading of the instrument.

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].

More details on the conception of the instrument can be found in the design report [3].

2. MEASURING METHOD

The LEP Q-meter can be used in 3 operating modes applying different beam excitations and different data treatment of the observed beam motion.

In FFT-Mode (Fast Fourier Transform) the beam is excited with random kicks and the spectral distribution of the beam motion is obtained by a Fourier Transform.

In SWF-Mode (Swept Frequency) the beam is excited with a sin wave of variable frequency. The frequency is swept according to a staircase function with a programmable frequency increment and the beam motion is treated by Harmonic Analysis.

In PLL-mode (Phase-Locked Loop) the beam is again excited with a sin wave, but by a phase lock the excitation frequency is forced to follow the machine tune.

3. DESCRIPTION OF THE PHASE LOCKED LOOP METHOD

Figure 2 shows the conventional analog implementation of a phase-locked loop consisting of a phase detector, a loop filter and a voltage controlled oscillator.

Once locked in, the frequency of the voltage controlled oscillator will track the frequency of the external signal u_{ext} with certain dynamic limitations which are determined by the loop gain and the loop filter parameters.

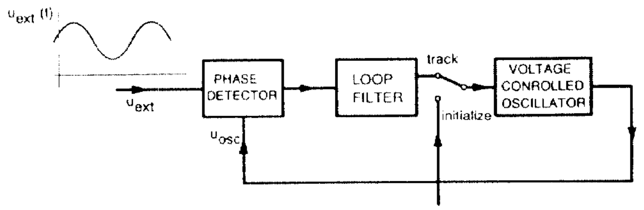

Fig. 2 Analog implementation of a phase-locked loop

A phase-locked loop may be implemented as an algorithm on a digital signal processor. The recursive algorithm is processed every sample period with a new value for u_{ext}. The building blocks of the analog implementation are conserved in their functionality :

The phase detector is a multiplier for discrete (sampled) signals, the loop filter is a numerical phase regulator which responds to the low frequency content of the phase detector output and the oscillator is implemented by computing discrete values of the function $\sin\varphi$. The phase φ is calculated in a recursive (incremental) manner from the previous phase by adding a phase increment $(\omega_0+\Delta\omega)T_S$, where ω_0 is the initial frequency of the oscillator, $\Delta\omega$ the frequency correction determined by the phase regulator output and T_S the sample period.

The tune measurement of LEP requires a continuous beam excitation which is derived from the oscillator output. The resulting dynamic system of two coupled loops shown in Fig. 3 is able to capture and track a resonance of the beam transfer function (i.e. the tune of the collider).

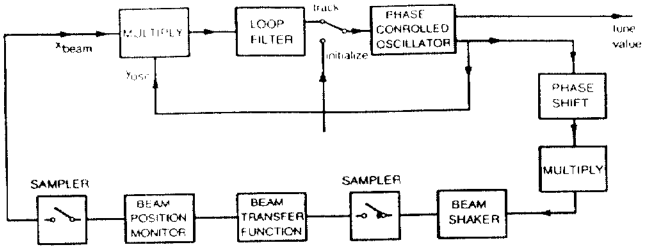

Fig. 3 Phase-locked loop with auto excitation loop

The phase regulator will continuously correct the oscillator frequency until the phase detector output is zero. This condition is only fulfilled when the phase detector input signals x_{beam} and y_{osc} are in quadrature. The phase shift $\Delta\varphi$ has to be intoduced to compensate for the machine phase advance between the beam position monitor and the beam shaker. The value of $\Delta\varphi$ has to be evaluated for each version of machine optics.

The signal processing shown in Fig. 4 may be completed by an amplitude regulation of the beam excitation. This regulation compares the amplitude of the harmonic beam oscillation with a reference value and attempts (through a multiplier) to keep the level of beam oscillation at a constant amplitude (typically a fraction of a mm). The reference value may be selected by the operator. The amplitude regulation is essential to prevent over excitation and consequent beam loss when (during the capture process) the phase-locked loop approaches the betatron resonance.

The tracking performance of a PLL is determined by its bandwidth. With a bandwidth of about 40 Hz, the PLL is fast enough to track all tune variations which can occur in LEP. With this tracking speed the PLL may however jump from the main resonance to another resonance close by. Such a situation occurred under the running conditions of 1991, when due to the even integer horizontal tune strong beam beam resonances appeared above a certain intensity limit.

The new signal processors will allow us to try out higher order and non-linear loop filters which may be able to cope with these difficult beam conditions.

The continuous tune measurement based on the phase-locked loop technique allows a recording of the measured tune every 100 ms (40 ms for special applications). This recording frequency is presently limited by the processing power and the operating system of the local microprocessors.

Three applications of the continuous tune measurement will now be discussed :

4. CLOSED LOOP TUNE REGULATION (Q-LOOP)

The continuous tune measurement is used for a closed loop control of the tunes. See Fig. 4.

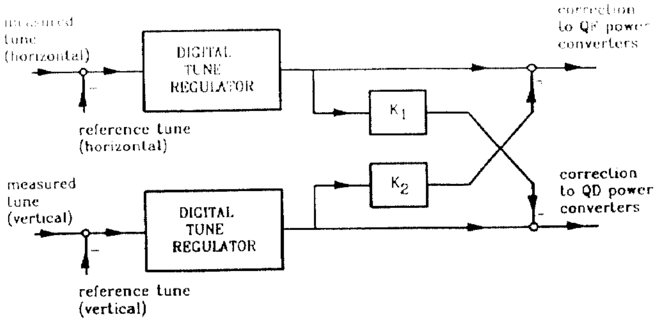

Fig. 4 Structure of the tune regulators

Two numerical regulators (one for each plane) compute on-line corrections for the power converters of the main quadrupoles chains. A correction applied to a single power converter chain, e.g. the focusing chain QF produces a change of both the horizontal and vertical tune. This effect is compensated by applying each regulator output to both power converter inputs. The weighting factors K_1 and K_2 are calculated from well known machine parameters. Due to the integrating characteristic of the tune regulators, an error of K_1 or K_2 will only cause transient but not steady state tune errors.

Figure 5 shows tunes and corrections sent to the power converters while the Q-loop was excited with a large tune shift. This perturbation is completely corrected by the loop.

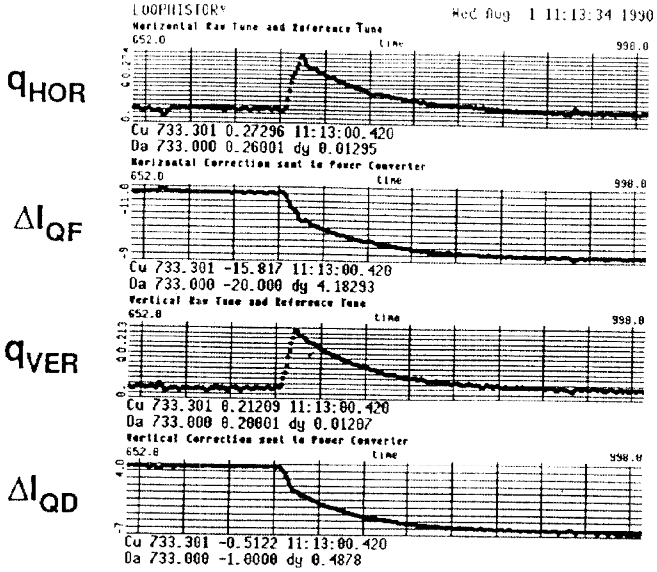

Fig. 5 Q-loop trying to keep the tunes constant while the quadrupole currents were changed

5. THE ANALYSIS OF TUNE MODULATIONS IN LEP

The continuous tune measurement allowed us to observe and analyze a rather unexpected effect of tune modulation. Figure 6 shows a "tune history" i.e. records of the horizontal and vertical tune with a 100 ms sample period.

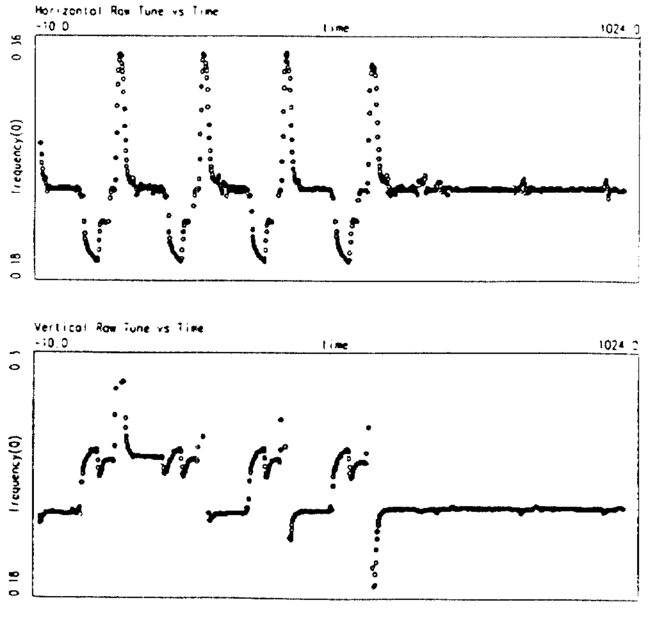

Fig. 6 Tune records showing an undesired periodic tune modulation

These records were taken at constant magnet settings, when one would expect constant tunes. The total duration of the record is 100 s. One can see strong fast tune modulations which are well tracked by the Q-meter. **The modulation** is periodic and exactly synchronous to **the 14.4 sec long** magnetic cycle of the SPS machine. It is caused by magnetic coupling between the two machines.

6. DYNAMIC MEASUREMENT OF CHROMATICITY

Chromaticity is measured by performing an RF frequency shift Δf and measuring the corresponding tune shift Δq. If this measurement is executed from a console as a programmed sequence (i.e. tune measurement - RF frequency shift - tune measurement) it takes about 2 minutes and is therefore too slow to measure chromaticity during critical machine transitions.

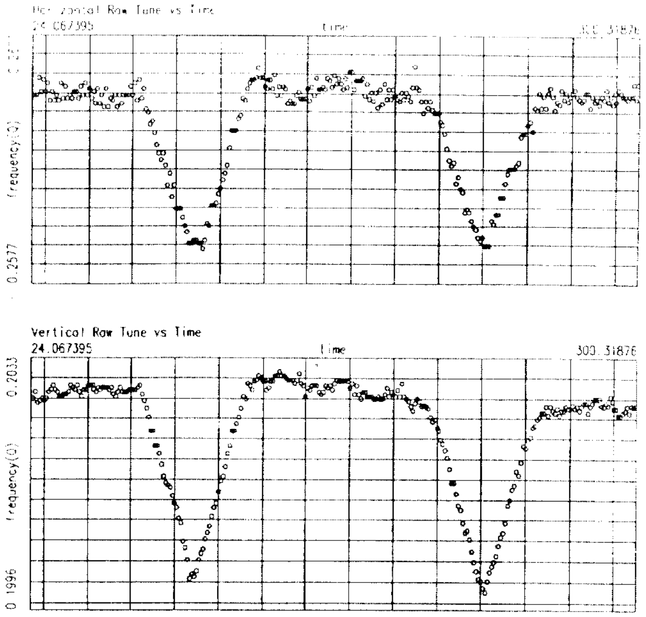

Fig. 7 Tune variations due to a programmed RF frequeny modulation

The tune history function of the Q-meter has been applied to make continuous fast chromaticity measurements : The RF frequency is modulated with a triangular wave form while the tune is recorded in 40 ms time intervals (Fig. 7). The observed tune changes are only about 0.003, but the noise level of the measurement is of the order of 10^{-4}. This method has been used to measure chromaticity changes during energy ramping.

7. REFERENCES

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