PERFORMANCE OF THE LEP Q-METER DURING OPERATION AND MACHINE STUDIES

I. Farago, K.D. Lohmann, M. Placidi, H. Schmickler
CERN, CH-1211 Geneva 23. Switzerland

Abstract The Measurement of the transverse tunes and precise observations of transverse tune spectra is a basic demand of accelerator operation and machine development. This contribution describes some experiments performed during the first year of activity of LEP using the Q-Meter in its 3 operation modes (PLL = **P**hase **L**ocked **L**oop, FFT = **F**ast **F**ourier **T**ransform and SWF = **SW**ept **F**requency analysis).

Items like difference between e^+ and e^- tunes, precise chromaticity measurements for energy calibration, beam-beam studies, optimization of beam overlap at the interaction points using the beam-beam transfer function and other applications from the period of machine commisioning to the actual machine status are presented and discussed. Special emphasis is given to the obtained measurement accuracies under different machine conditions.

1 Introduction

The LEP Q-Meter measures the fractional part of the betatron tunes by excitation and observation of coherent transverse beam oscillations. Fast kickers and a gated position monitor allow for selective bunch excitation and observation. Due to the flexibility offered by the digital signal processors of the instrument, one may excite the beam and analyze the resulting beam motion in different ways [1] [2]. Three operational modes have been implemented and can be selected according to the machine status, the available measurement time and the required accuracy.

The FFT mode includes wide band noise beam excitation and a Fourier Analysis of the beam coherent motion. The amplitude spectra for the horizontal and vertical planes give the betatron tunes as very distinct peaks, but also provide additional information on damping times (width of peaks), betatron and synchro-betatron coupling. The measurement times in this mode are of the order of seconds.

In The SWF mode the beam shakers are driven with a sinewave excitation and the amplitude and phase of the beam motion are recorded. By proper sweeping the excitation frequency over small steps the amplitude and phase spectra can be measured with very high precision. Depending on the frequency span and the step size the measurement can take from several seconds to minutes and is therefore devoted to precise machine development studies.

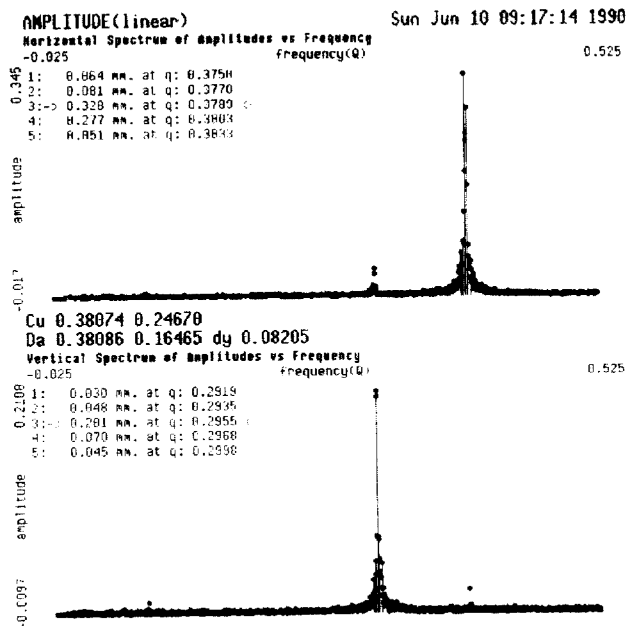
In the PLL mode the beams are again excited with a sinewave oscillation, but now the shaker excitation frequency is locked by a feedback system to the resonance of the beam. By detecting the shaker frequency permanent tune readings down to time intervals of 50 msec can be recorded. This mode is of particular interest to continuously monitor the tunes during normal operation or to detect rapid tune changes during critical machine operations (acceleration, β-squeezing etc.).

In the following chapters we have selected different examples of tune measurements performed by exploiting the 3 modes of operation of the instrument under different machine conditions.

2 The Q-meter during operation

Tune and Chromaticity

The requirements during operation are fast and reliable tune measurements, obtained by using the instrument in the FFT mode. The desired frequency resolution δq of the measurement can be programmed by selecting the number of position measurements N_s of the input to the Fourier Transform, since $\delta q = 1/N_s$. The statistical measuring errors can be reduced by taking the average of successively measured spectra. Fig. 1 shows an amplitude spectrum of the beam oscillations in the horizontal and vertical planes based on data from 2048 beam revolutions and an averaging count of 4.



The chromaticity of the machine is measured using the Q-Meter in the same mode. Tune readings are taken for different settings of the RF frequency and the linear chromaticity Q' is obtained from

$$Q' = \frac{\Delta Q}{\Delta P/P} = -\alpha_c \frac{\Delta q}{(\Delta f/f)_{RF}} = -1.362 \cdot 10^5 \frac{\Delta q}{(\Delta f)_{RF}} . \qquad (1)$$

where $\alpha_c = -3.866 \cdot 10^{-4}$ is the momentum compaction of the machine, Δq the change in the fractional part of the tune and $f_{RF} = 352254172.9$ Hz is the RF value on the central orbit recently determined with high accuracy [3].

Continuous tune monitoring and tune regulation

Betatron tunes can be monitored at very short time intervals during particular phases of the operation.

During the acceleration phase from the injection energy to the value required by the experiments the nominal machine tune is perturbed by the tracking errors of the magnetic elements and by the effect of induced currents in the vacuum chamber. Unwanted tune variations also occur at the flat-top energy during the transition to the low-β values used in collision to provide the best luminosity.

In both cases the information on the time evolution of the tunes (tune history) is of great help to detect any misfunctioning in the two processes and is essential to provide useful diagnostics. A continuous tune measurement in PLL or FFT mode may be used for closed loop tune control by acting on the currents of the main quadrupoles. This so-called **Q-loop** keeps the tunes on their reference values during the two operational phases. A horizontal tune-history display during acceleration is shown in Fig.2 with and without Q-loop feedback.

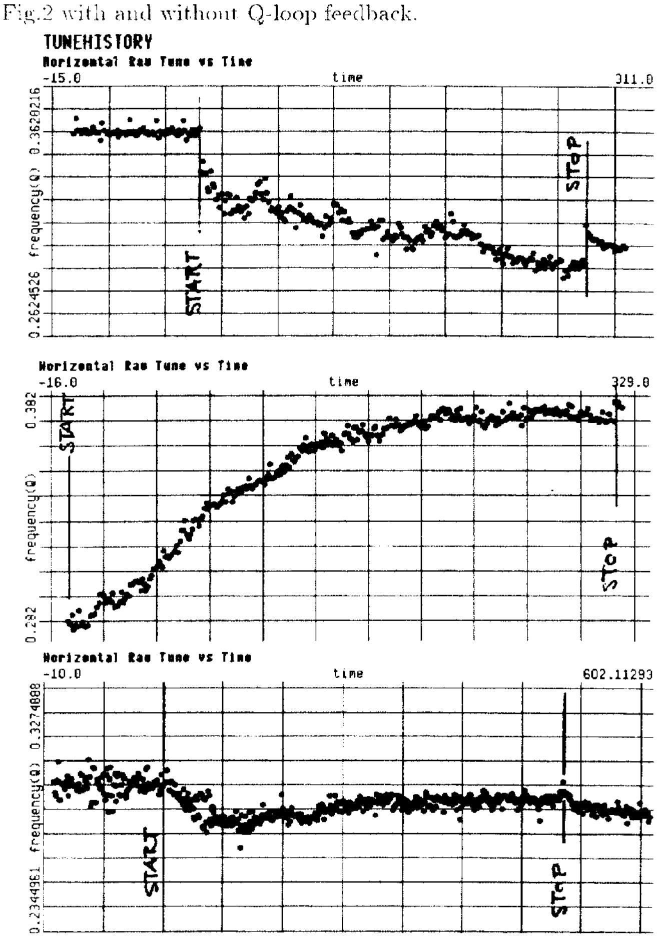


Figure 2: Time evolution of the horizontal betatron tune during acceleration. The original behaviour (top) is modified with software correction in the "ramp editor" (middle) and the final tune evolution obtained with the closed loop tune regulation is shown in the bottom.

3 Applications to accelerator physics

The wide possibilities offered by the Q-meter have been of great help during the commissioning of the collider as well as in the successive periods of machine developement and studies. Examples are given in the following of some interesting applications to the operation of LEP for accelerator physics.

$e^+ e^-$ tunes

Differences in the betatron tunes for electrons and positrons mainly occur from horizontal separation of e^+ and e^- orbits in sextupoles, originated by different energy histories around the ring from unsymmetrical energy gain in the RF cavities. Quadrupolar fields associated with orbit offsets in the sextupoles produce additional tune shifts which integrate out differently around the ring. The observation of e^+e^- tune differences in the early phase of LEP commissioning contributed to the final adjustment of the parameters of the RF stations in IP2 and IP6.

Beam-beam tune shift

The tune shift between the σ- and the π-modes of oscillation of "rigid" bunches colliding in storage rings [4] is one of the most interesting diagnostic tools to evaluate the performance of a collider. Each mode generates a pair of "visible frequencies" [5] often referred to as "fast-wave" and "slow-wave" signals [6]. The observation of the $\sigma - \pi$ tune shift in LEP makes use of the Q-meter both in FFT and in SWF modes. The latter one is clearly more precise and an ultimate accuracy of better than 10^{-4} can be attained. An example of measured $\sigma - \pi$ mode tune shift is given in Fig.3.

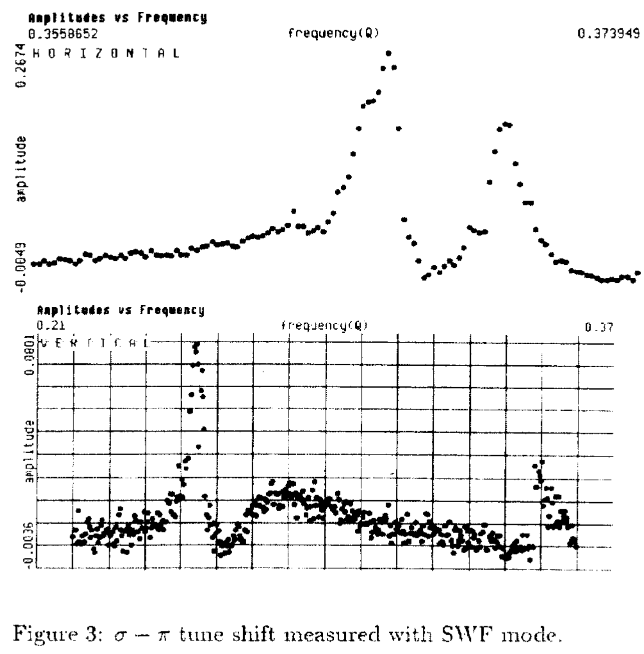


Figure 3: $\sigma - \pi$ tune shift measured with SWF mode.

Beam-beam transfer function

The beam-beam transfer function [7] is the response of one bunch to deflections induced by variable electromagnetic fields from the interaction with a counter-rotating bunch subject to small amplitude transverse excitation. Its effect is proportional to the luminosity and this property can be used to optimize the beam overlap at the interaction points down to beam separations of the order of $0.1\,\sigma_v$. By proper selection of the excited and of the observed bunches, the beam-beam transfer function can be measured with the Q-meter both in FFT or in SWF mode. A typical example is given in Fig.4 where the response of the "observed" bunch is compared to the situation when the interacting one is excited or not.

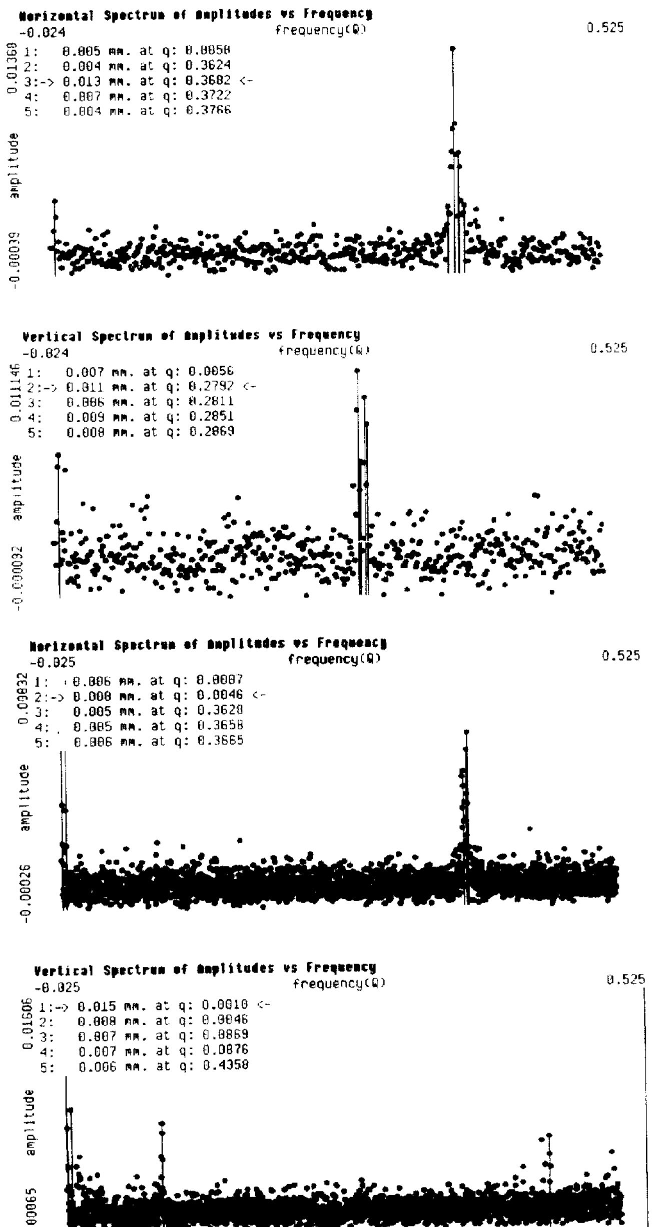


Figure 4: Beam-beam transfer function with FFT mode. Response of the "observed" bunch when the interacting one is shaked in both planes (top) compared to the situation when the latter is not excited in the vertical plane.

Dynamic aperture

LEP dynamic aperture can be measured by exciting the beams in SWF mode and using the amplitude calibration for the measured spectra. During the measurement the excitation amplitude is increased until weak beam losses are observed. A collimator is then inserted to slightly increase the losses. This position is assumed to be the aperture taken by the beam for coherent oscillations.

Accuracy estimate

By measuring the beam tunes with very stable machine conditions the accuracy of the device has been experimentally estimated. Successive tune measurements taken in FFT mode during physics runs, when the only varying parameter is the beam current, have shown that the present accuracy of the instrument can be quoted to a $2 \cdot 10^{-4}$ level.

4 Conclusions

The use of the LEP Q-meter has proved to be a precious tool both for the operation of the collider and for precise accelerator physics studies. The three modes of operation of the instrument together with a large choice of parameters, derived from the flexibility offerd by the digital signal processing allow the instrument to be used in a wide range of applications. The accuracy of the instrument has been measured to be $2 \cdot 10^{-4}$ and is presently limited by the noise in the beam position measurement.

5 Acknowledgments

The authors are indebted to C. Reymermier for the mechanical realization of the kickers and to M. Desroziers for the conception and the construction of the pulsed power supplies and the special electronic developments. J. Borer and D. Cocq helped us to make the best use of their beam position measuring electronics.

References

[1] K.D. Lohmann, M. Placidi, H. Schmickler, Q-Monitoring in LEP. CERN/LEP-BI/88-45, (1988).

[2] K.D. Lohmann, M. Placidi, H. Schmickler, Design and Functionality of the LEP Q-Meter, this Conference.

[3] A. Hofmann et al., LEP Energy calibration, this Conference.

[4] A. Piwinski, IEEE Trans. NS-26, (4268), 1979.

[5] E. Keil, LEP Note 268, Oct. 1980.

[6] R. Littauer and M. Placidi, LEP Note 555, Feb. 1986.

[7] A. Hofmann and J.-P. Koutchouk, ISR Performance Report, Jan. 1981.