THE Q-LOOP : A FUNCTION DRIVEN FEEDBACK SYSTEM FOR THE BETATRON TUNES DURING THE LEP ENERGY RAMP

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Abstract

In normal operation LEP is ramped from injection energy, typically 22 GeV, to energies of over 90 GeV where physics data taking takes place. Effective control of the betatron tunes during the ramp is essential to ensure good transmission of stored current.

The LEP Q-loop is a feedback system used to control the betatron tunes during the energy ramp. By following a preprogrammed tune function it provides a means of avoiding dangerous resonances and thus beam loss. The basic components of the Q-loop will be described, and operational results presented. Emphasis will be given to the problems encountered and the solutions found.

1 Q-LOOP BASICS

The working principles of the Q-loop are quite simple, if not trivial : **measure** the betatron tune with a Phase-Locked-Loop (PLL) technique, **compare** with a reference value, **correct** the difference.This simple procedure is carried out all along the energy ramp.

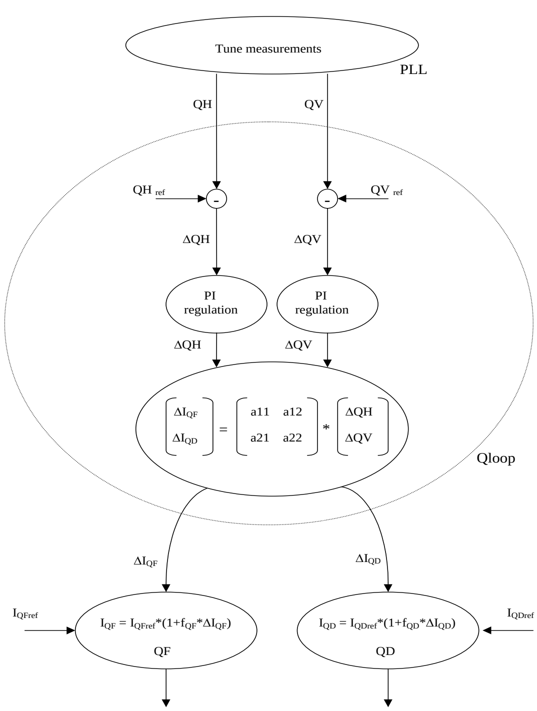

Figure 1: The PLL, Q-loop and Power Converters

2 THE Q-LOOP FUNCTIONS DURING THE RAMP

The Q-loop system enables the User to define a tune function to be followed during the ramp. At LEP, the energy ramp duration is discretized in small uniform time intervals called ”vectors”. All the equipments (magnets, RF,...) whose behavior should follow the ramp are preprogrammed, so that each of them know what to do at any given vector. In the Q-loop tune function, the User usually specifies a desired tune value for a small number of vectors. A linear interpolation will then assign values to all the other vectors.

The User has two ways of specifying a tune value : either he uses a number (ex. .245), or he can use a simple expression containing the symbol ”REF”. Making use of this latter format enables the Q-loop to easily adapt to the tune values before the ramp, which may slightly change from fill to fill. In fact the ”REF” values can be easily set from the Qmeter Q-loop Interface just before starting the ramp. It should be noted the the symbol ”REF” optionally could be followed by an offset (ex. REF + 0.002)

Vector	Qh	Qv
0	REF	REF
80	.245	
100	.265	
136		REF
146		.175
220	.265	
385		.175
420		.185
460	.265	.185
541	.265	.185

Table 1: The tune functions used for the 102/90 Optics in 1998

If the Q-loop is armed, whenever the Qmeter receives the ”Start of Ramp” Timing Event, it starts incrementing the vector number (by following an internal clock), and will try to reproduce the tune functions defined by the User. When a ”Stop Ramp” Event is received, the vector number is not incremented anymore, and the value corresponding to the last vector reached is used as reference until either the ramp is resumed or the Q-loop is stopped.

3 OPERATING THE Q-LOOP

Here is the sequence of operations needed to get the Q-loop ready for the Ramp.

- **Start** the PLL (once target current is almost reached)

- **Check** PLL locks and that lock quality is good (optional, but strongly recommended)

- Once bunch current target is reached and stable working point is found i.e. lifetime is not too low:
Set Reference tune values to current ones.

- **Load** the Q-loop Tune Functions. In 1998 we have worked with initial tunes Qh and Qv close to 0.24 and 0.17 respectively.

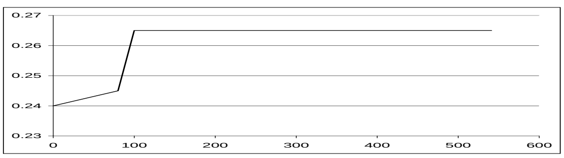

Figure 2: The Qh demanded function

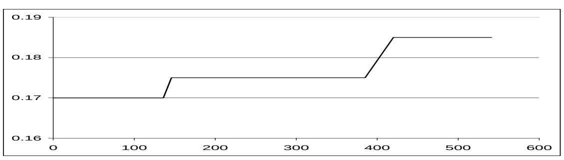

Figure 3: The Qv demanded function

- **Arm** the Q-loop

Now the Q-loop starts regulating the tunes using the Reference values; as soon as the ramp is started, the Q-loop will follow the Tune Function, correcting the tunes toward the values programmed for the current vector number.

4 IMPORTANT TECHNICAL POINTS

A complete presentation of the Q-loop can be found in [1]. Here we focus on a few features that were necessary to make the system working.

- The Amplitude Regulator for the Qmeter PLL Exciter. This feedback system internal to the Qmeter is vital in helping the Qmeter Exciter to produce and mantain a beam oscillation at a constant amplitude, large enough to be unambiguously detected, but not so large to become dangerous for the beam itself. A typical amplitude value of 300 μm is used to allow the PLL to follow the tune during the ramp.
The beam oscillation amplitudes are now computed only on the locking frequency (rather than on the full spectra).

- A slow bandwidth for the PLL(7Hz). It was found that such a modification makes the locking mechanism more robust, even if less sensitive to fast tune oscillations.

- An "anti" wind-up algorithm, minimizing the time needed to unfreeze the corrections after they had reached saturation.

- Freezing[1] of the corrections when lock is lost. Any of three criteria can make the corrections freeze: a) a low beam oscillation amplitude, b) the ratio of beam oscillation amplitude too high compared with the excitation, or c) the difference between demanded and observed tune stays too large for a given time.

5 RESULTS

The usage of the Q-loop has introduced more predictability in the ramp, and more adaptability to different initial conditions. Towards the end of the 1997 run a beam surviving the first dangerous vectors was constantly reaching the target energy without substantial losses.
In fig. 4, the evolution of the tunes during a typical successful ramp for the 102/90 Optics is shown. This corresponds to the functions used in 1997. The interval between two points is 200 milliseconds. Notice the sharp transient at the beginning of the ramp, and the subsequent large tune jumps, to rapidly cross dangerous areas. In fig. 5 we show, for the same ramp, the amplitudes of the PLL signal (top graphs) and the strength of the Qmeter Excitation needed to make the beam producing the signal (bottom graphs).

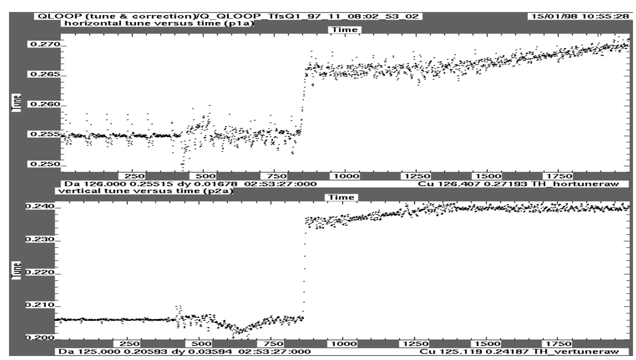

Figure 4: Horizontal and vertical tunes during the ramp

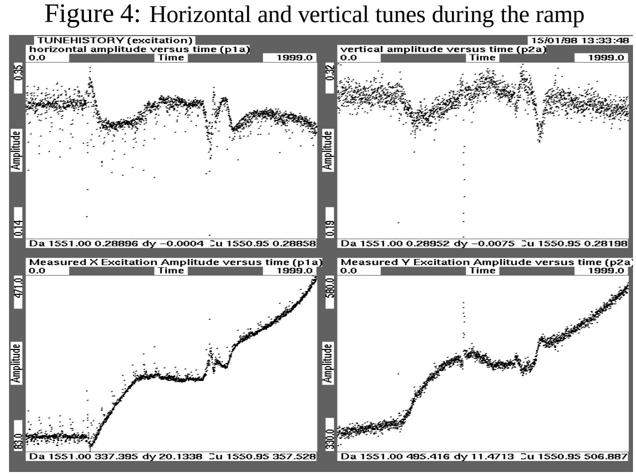

Figure 5: Beam oscillation and Qmeter excitation amplitudes

[1]A programmable parameter determines if the corrections are frozen or set to zero

6 PROBLEMS

Here follows a list of problems we encountered, how we dealt with them, their importance and their current state.

-POTENTIAL INCOMPATIBILITY WITH THE TRANSVERSE FEEDBACK

The Transverse Feedback (TFB) tries to kill all transverse beam oscillations, and it had to be modified to ignore the Q-looop PLL-generated excitation. It was given a non-linear gain, low for beam oscillations up to 0.3 mm, and progressively increasing for bigger oscillations. In this way, the small oscillations driven by the PLL mechanism are allowed to survive. Dangerously large oscillations, due to instabilities, would still be controlled by the Transverse Feedback. It should be noted the the PLL can lock exactly on the tune in fig. 7 even though the spectrum is very wide.

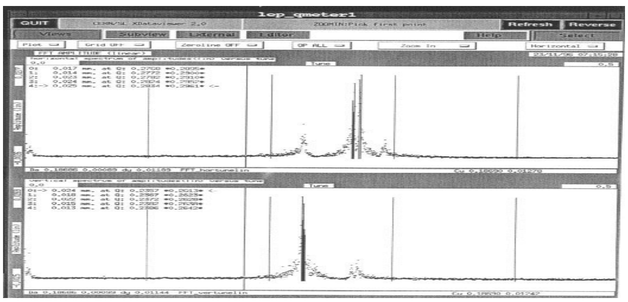

Figure 6: Spectrum at 45 GeV. TFB off.

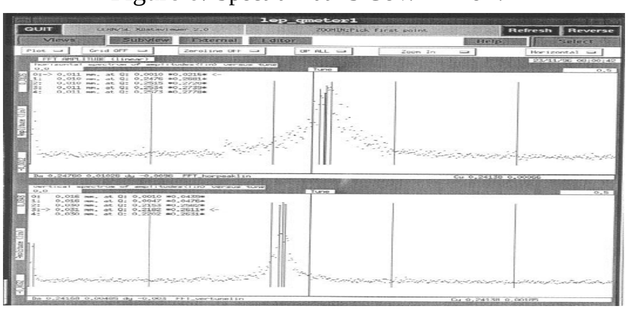

Figure 7: Spectrum at 22 GeV. TBF on.

-THE PROBLEM WITH THE 2Qs SIGNAL

An unforeseen problem made things more difficult for the Q-loop in 1997: the appearance in the tune spectra of a strong peak corresponding to 2Qs (twice the Synchrotron Frequency). Unfortunately this peak ($\approx$ .23) sat very close to the typical Qh value before the ramp ($\simeq$ 0.24, 0.25) and it could easily confuse the PLL algorithm, with lethal consequences for the beam. The amplitude of the 2Qs signal is in some way related to oscillations of the RF cavities, and its strength can be reduced by switching some specific cavities off, as shown in fig.8 . In 1998 this problem appears to be less important, because LEP runs now with a higher value of Qs ($\simeq$ 0.13) at injection, and 2Qs is therefore far away from both Qh($\simeq$ 0.24) and Qv($\simeq$ 0.17). Qh stays well below 2Qs until an energy where is safer to cross (rapidly) this resonance, to reach its final value of 0.265 .

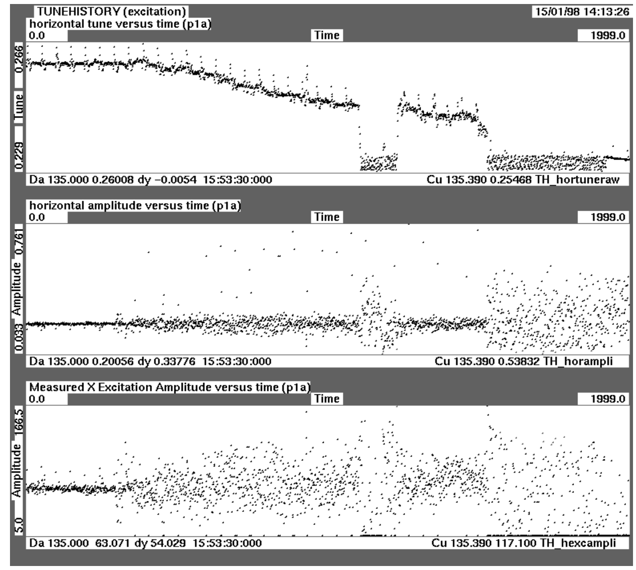

Figure 8: Switching on,off,on,off a oscillating cavity (originally off)

-LOSS OF ELECTRONS IN THE MIDDLE OF THE RAMP

Sometimes around 10% of the electrons were lost while the positrons went through without problems. A possible explanation is that the tune of the electrons is different from the one of the positrons (”tunesplit”). We have to take into account this difference to avoid driving the electrons tune too close to a resonance, while controlling the positrons tune. Generally we can solve this problem by steering the tunes away from any resonances with the help of the tune functions.

-LOSSES AT THE THE START OF THE RAMP

During LEP Operation in 1997 most of the losses occurred at the very first vector of the ramp due to very fast jumps in the tunes (too fast for the Q-loop to correct them). This problem was cured in 1998 by introducing a more gradual start of the ramp.

7 ACKNOWLEDGEMENTS

The experience and the patience of many LEP EICs has been very helpful during the commissioning period. We would like to thank Mike Lamont in particular, whose expertise in setting up the tune functions was essential to the fast startup of LEP this year.

8 CONCLUSIONS

The Q-loop opens the way for LEP to reliably accelerate higher currents and improve its luminosity production. The commissioning of the Q-loop took around three days in 1998 and contributed to the fastest ever startup of LEP !

9 REFERENCES

[1] Karl-Dietmar Lohmann, “Will the Q-loop work with high intensities ? ”, Proc. of the 7th LEP Performance Workshop, Chamonix 1997, CERN-SL/97-06