LONGITUDINAL QUADRUPOLE INSTABILITY IN DAΦNE ELECTRON RING

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Abstract

A longitudinal quadrupole (q-pole) instability was limiting the maximum stable current in the DAΦNE e- ring at ~800mA. The instability threshold dependence on various machine parameters as radiofrequency voltage (Vrf) and momentum compaction has been measured. An unexpected interaction with the longitudinal feedback system has been found and the understanding of a damping mechanism has allowed increasing the threshold. The maximum stable beam total current has now reached more then 1.85A, no longer limited by the quadrupole instability.

1 INTRODUCTION

DAΦNE is a Φ–factory, e+/e- collider in operation for physics experiments since 1999 with gradually increasing peak and integrated luminosities [1]. In order to reach the high required luminosity, in the $10^{32}cm^{-2}sec^{-1}$ range, multibunch beams with currents of several Amperes have to stored in both rings of the collider. The design current per single bunch of 44mA has been successfully exceeded in both rings. About 200mA have been stored in a single bunch without destroying instabilities. In the multibunch operation, a longitudinal quadrupole (q-pole) instability was limiting the maximum stable current in DAΦNE e- ring to ~800mA. The experimental study of the instability has allowed to find measures to damp or avoid it and to store stable e- beam with more then 1.85A. Below we discuss the instability phenomenology, its threshold dependence on different machine parameters, describe the cure and propose possible directions for further study of the instability mechanism.

2 QUADRUPOLE INSTABILITY

Considering the longitudinal dynamics in DAΦNE, strong, coupled bunch synchrotron oscillations make active damping systems necessary.

In each main ring, a broadband bunch-by-bunch longitudinal feedback (LFB) is operating since 1998. This system has been developed in collaboration with PEP-II/SLAC and ALS/Berkeley [2]. A zero-mode feedback, acting around the RF cavity is also operating.

These systems work fairly well, but last year an unexpected longitudinal quadrupole instability was limiting the total current to ~800mA in the e- ring. This trouble appeared usually above 600mA, producing harmful effects for the beam-beam interaction.

2.1 Phenomenon Description

To introduce the argument, let's consider, as an example, a rather usual case of 45 stored e- bunch, each followed by one empty bucket, with less than 300mA of total beam current, Vrf = 120kV. With longitudinal feedback on, no sidebands are visible around the n-th revolution harmonic, see Fig. 1.

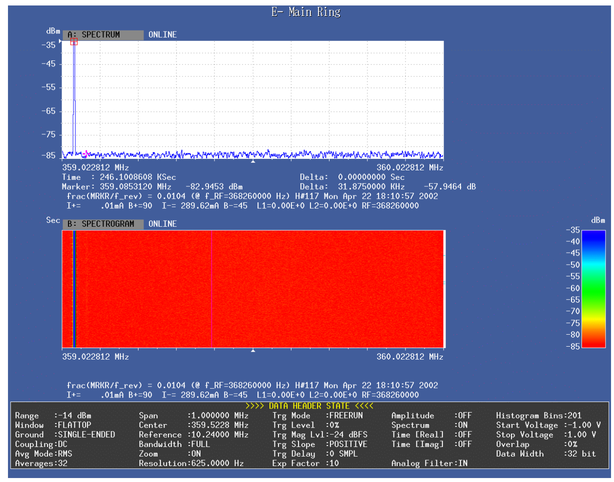

Figure 1: Multibunch beam spectrum with LFB on.

Considering now the same case with LFB off, it is possible to observe several sidebands indicating large dipolar oscillations (see Fig. 2).

The difference between the first sideband and the revolution harmonic is equal to the synchrotron frequency (dipole), the other satellite oscillations are multiple of the first one.

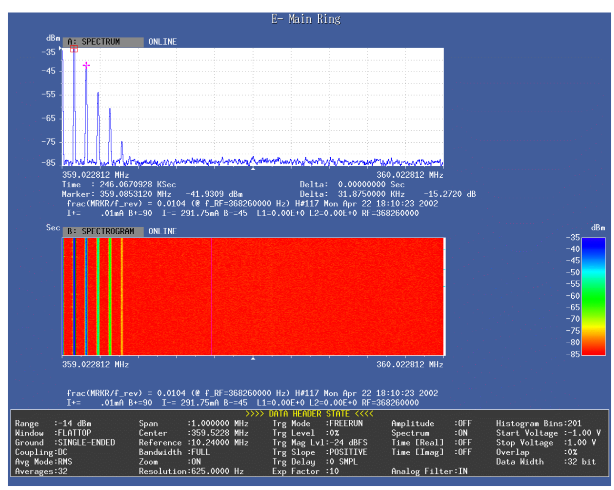

Figure 2: Multibunch beam spectrum with LFB off.

Still, in multibunch mode with LFB on, at high currents (between 600 and 800mA), and only in the electron main ring a quadrupole line (without dipole) appeared, limiting further current injection, as seen in Fig. 3, indicated by the cursor.

The current limit consists of the fact that new injections can produce loss of bunches and/or loss of LFB control with successive large decrease of the total beam current.

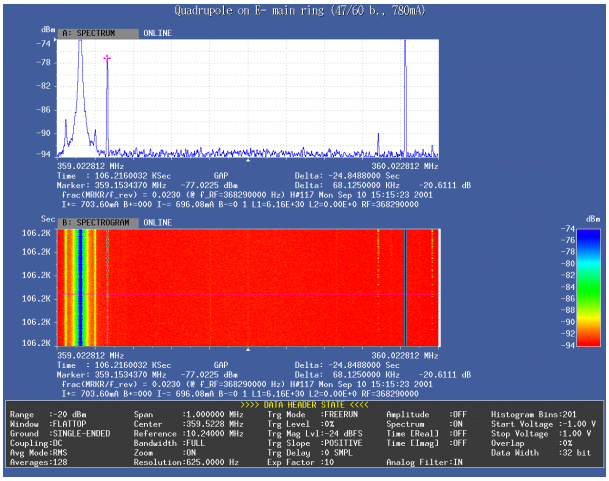

Figure 3: Quadrupole instability in e- ring at ~700mA with LFB on (Vrf=170kV).

The current limit consists of the fact that new injections can produce loss of bunches and/or loss of LFB control with successive large decrease of the total beam current.

Besides, there is another peculiar aspect: considering for example a multibunch case with Vrf=120kV, 770 mA, 45/60 bunches, it is possible to observe the q-pole frequency at 58.75kHz, while the second harmonic of the synchrotron frequency is at 60kHz, with a difference of -1.25kHz from the zero current line.

2.2 Relevant Parameters

In order to overcome the current limit, the q-pole instability threshold has been measured as a function of the following machine parameters:

- Radiofrequency voltage
- Momentum compaction (α_c)
- Orbit (considering the eventuality of a trapped mode)
- Injected patterns and number of bunches
- Bunch length and LFB backend setup.

2.3 First Measurements

A clear variation of the q-pole threshold was observed as function of the RF voltage: with 47 bunches the threshold was ~550mA with Vrf =120kV and ~750mA with Vrf =170kV.

The dependence on momentum compaction has been evaluated. A ~10% increase of the α_c value (from .03 to .033) has allowed to increase the quadrupole threshold by ~ 17% (from ~750 to ~880mA in 47 bunches) (Oct. 2001). However, variations of this parameter have not given a definitive solution for the instability damping.

Afterwards the q-pole threshold has been measured varying number of bunch and fill patterns. It has been found that the threshold increases with the number of bunches, but this is neither conclusive nor sufficient to cancel the current limit.

2.4 Two Different Behaviours

The measurement that has indicated more clearly the way to follow, was that of single bunch q-pole threshold versus RF voltage, with LFB off and on, see Fig.4.

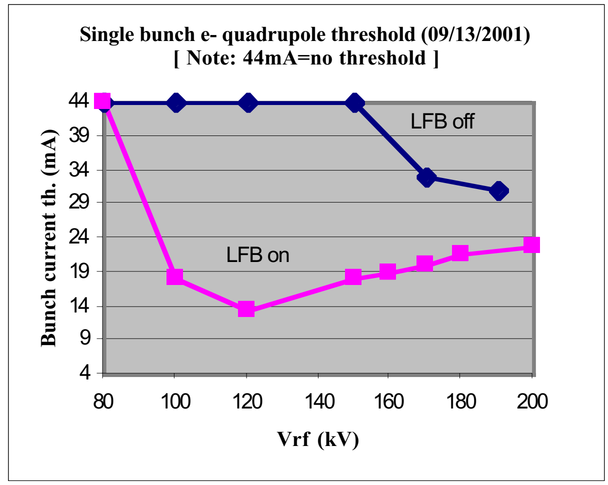

Figure 4: Single Bunch Q-pole Threshold.

Comparison shows that the lowest threshold case with LFB on corresponds to no q-pole evidence with LFB off. In general, the two situations (with and without LFB) have different behaviour as if they were two different types of quadrupole instabilities at all. This persuasion has led to study any possible interaction between LFB and q-pole instability threshold.

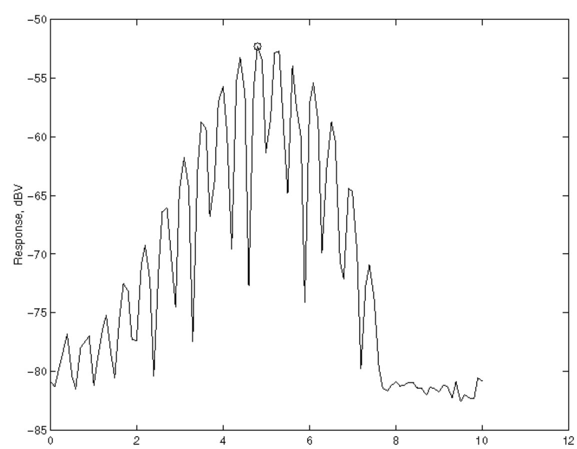

Figure 5: Longitudinal backend response.

2.5 Bunch Length and LFB backend (BE)

Figure 5 shows the single bunch longitudinal backend response as a function of timing in the cavity kicker of the LFB system. The bunch passage should be synchronized with the centre of the highest lobe to exploit the most of the power. The useful period is 418psec and contiguous lobes are in LFB opposite phases.

On the other hand, the measured e- bunch length (FWHM) is <144psec at 1mA and grows up to 300psec at 39mA, with Vrf equal to 120kV [3] (see Fig. 6).

Measuring FWHM versus Vrf, bunch length decreases as the voltage increases.

From these data, it can be supposable that a bunch length comparable to the BE period could drive an interaction between LFB and q-pole instability.

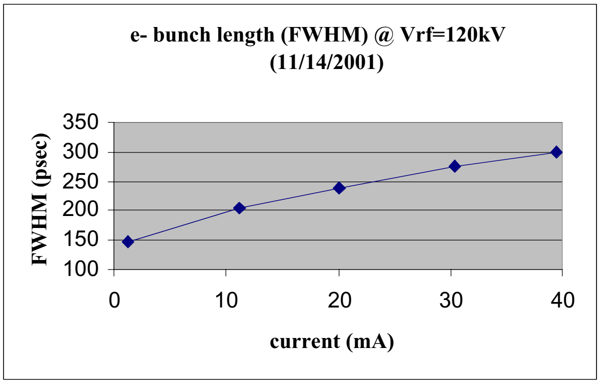

Figure 6: Bunch length versus bunch current.

2.6 Q-pole with LFB off

Now we consider the case of q-pole oscillations with LFB off, in single bunch, with Vrf=190kV: it is a RF voltage higher than the used one and q-pole appears above 24mA. In this case, after turning on LFB, we have observed that the BE delay shift does not show effects. Still, increasing by 256 times the LFB gain, the q-pole sideband is attenuated and shifted. This lets us think that it is truly an effect of the LFB.

3 THE CURE

Measuring the q-pole threshold versus LFB backend delay, we have found that increasing conveniently the BE timing (i.e. kicking the bunch tail) produces higher or no thresholds and decreasing delay (i.e. kicking the bunch head) lowers q-pole threshold.

Still, in single bunch with Vrf=120kV and beam current > 26mA, just decreasing by 150psec the LFB backend delay, it is possible to excite a quadrupole motion (note that this happens also in the e+ ring at higher currents).

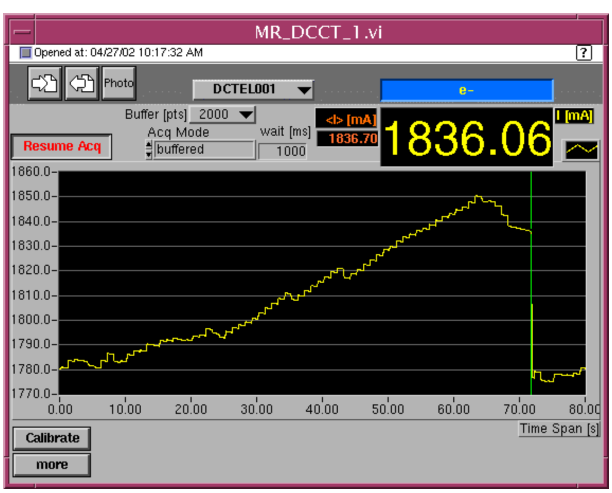

Figure 7: A stable e- beam with 1850mA and 90 bunches.

After this discovery, it has been always possible to adjust the LFB backend delay to avoid q-pole instability for all the typical collision cases and store more then 1850mA of stable electron beam in April 2002 (see Fig. 7).

4 DISCUSSION AND DEVELOPMENTS

Despite the cure found experimentally is very reliable, the underlying mechanism(s) still has to be explained.

In the future, it would be interesting to study more deeply the phenomenon. To do this, some working directions could be outlined:

a) Use a narrower LFB bandpass filter. In fact, e- LFB uses a 40.5kHz centered FIR filter that has a good –90 degree phase response for the dipole. This is enough convenient to damp it and to coexist with the mode zero oscillations, but the filter phase response could be critical at the longitudinal quadrupole frequency and narrower band filters would have lower amplitude responses for the q-pole (purely software solution).

b) Try a lower frequency as LFB BE carrier. If 11/4*RF would be used in place of 13/4*RF the BE period would increase by 80psec (expensive solution in term of hardware and machine time, probably).

c) Develop a LFB setup for the case in par.2.6.

d) Create numerical models and perform simulation of the instability including LFB.

5 CONCLUSIONS

After discovering how to manage q-pole motion, it has been possible to exceed the 800mA limit in collision. To use correctly the LFB, the trade-off between dipole and q-pole responses has to be carefully checked. During 2002, DAΦNE no longer suffered longitudinal q-pole limits. To put in collision 2 Amperes e- beam against a 2 Amperes e+ beam is the possible next development.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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