DAΦNE TECHNICAL NOTE

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Note: **BM-10**

Report on DAΦNE longitudinal quadrupole measurements done on 9-12 November 2002

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Introduction

Since 2001 longitudinal quadrupole motion limiting the maximum multibunch beam current was observed in DAΦNE, mainly in electron ring [1]. The applied cure was based on a special setup of the longitudinal feedback, putting an offset in the front end and a small delay offset (150 psec) in the backend timing. During 2002 summer shifts, it was found fruitful to apply same cure to the positron ring too, to maintain low roundness at high current.

This note describes measurements of the longitudinal quadrupole oscillations made on the 9th and the 12th of November 2002.

Quadrupole feedback fundamentals

In order to have quadrupole feedback the processing channel must meet three requirements:

a) Detect quadrupole oscillations in the front-end;
b) Generate feedback correction signal in the DSP channel at the right frequency and phase;
c) Apply quadrupole kick to the bunch.

The above requirements must be met in addition to the dipole feedback ones.
We use existing LFB as a frequency-multiplexed system to do both dipole and quadrupole feedback.

Front-end setup

Feedback input signal for bunch k is given by

$$x_k(t) = i_b(1 + a_q \sin\omega_q t)(\phi_{dc} + a_d \sin\omega_d t)$$

where i_b is the bunch current, a_q and ω_q are the quadrupole oscillation amplitude and frequency respectively, ϕ_{dc} is the dc phase offset, a_d and ω_d are the dipole amplitude and frequency (synchrotron frequency) respectively.

There *must* be a phase offset in the front-end to produce quadrupole gain. The offset sign affects the sign of the quadrupole feedback. A gap transient will change the gain along the turn by varying ϕ_{dc} from bunch to bunch. The peak-to-peak amplitude of the gap transient must be less than $\frac{1}{2}$of the full ADC range, otherwise quadrupole feedback will be negative for some bunches and positive for others.

Filter design options

Since the dipole and quadrupole motions are well separated in frequency, it is conceptually possible to design a control filter with independent gain and phase responses for the two frequencies. The basic idea consists of two filters in parallel, adjusting each of them for proper gain and phase response. These coefficient vectors are summed to form a parallel connection of the two filters.

For measuring quadrupole growth rates, a filter has been designed with a notch at the quadrupole frequency and a normal dipole response.

Kicker and timing requirements

To get a quadrupole kick, we need a differential kick effect between head and tail of bunch (as noted in the past by the DAΦNE team). This is implemented via a shift in kicker timing off the maximum crest. This shift in kicker timing reduces the system gain on the dipole mode, so there is a need to balance the operating point to have adequate margins for both control paths.

Producing quadrupole kick in the back-end

The longitudinal feedback kick signal at DAΦNE is centered around $\frac{13}{4} f_{RF}$ QPSK carrier. At the optimal dipole timing there is no quadrupole kick, though shifting the bunch timing produces both dipole and quadrupole kick components as shown in Fig. 1.

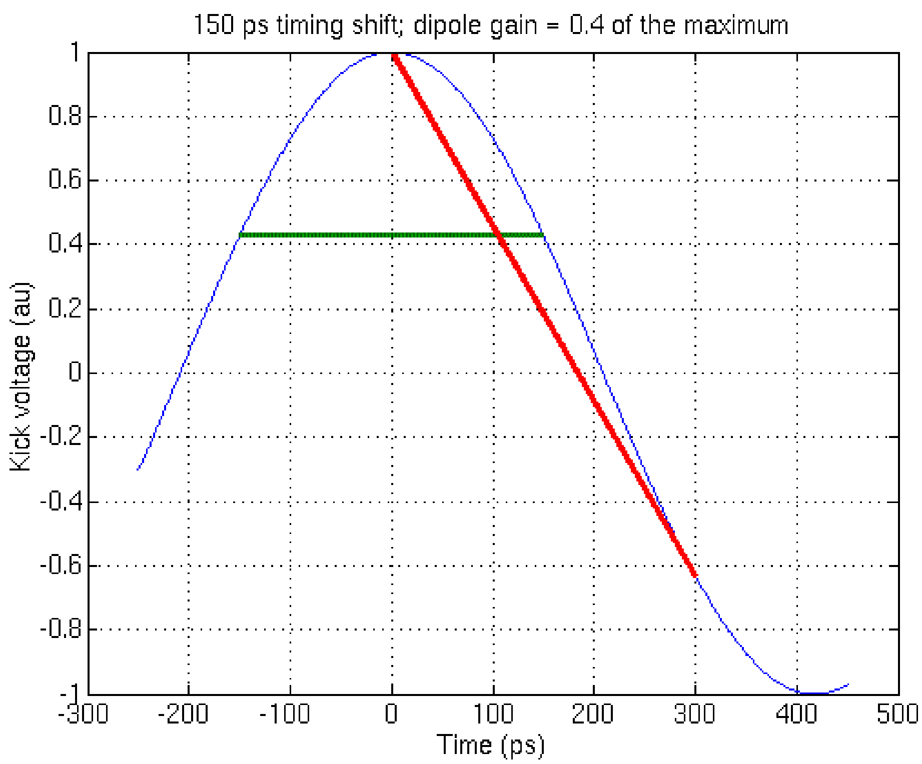

FIGURE 1. Kick voltage versus backend timing

Results for the e^- ring

The first test was to load a quadrupole open-loop filter (with the dipole control operating). A filter with a notch response at the quadrupole frequency was used to confirm that the observed quadrupole motion is **not** excited due to the response of the LFB control filter.

Large quadrupole motion was clearly seen in the spectrum of the BPM signal while running a peak/notch filter with the response shown in Fig. 2. With such a filter the longitudinal feedback system does not affect the quadrupole motion. Thus we concluded that the observed oscillation was due to the external driving terms such as high-frequency longitudinal impedances.

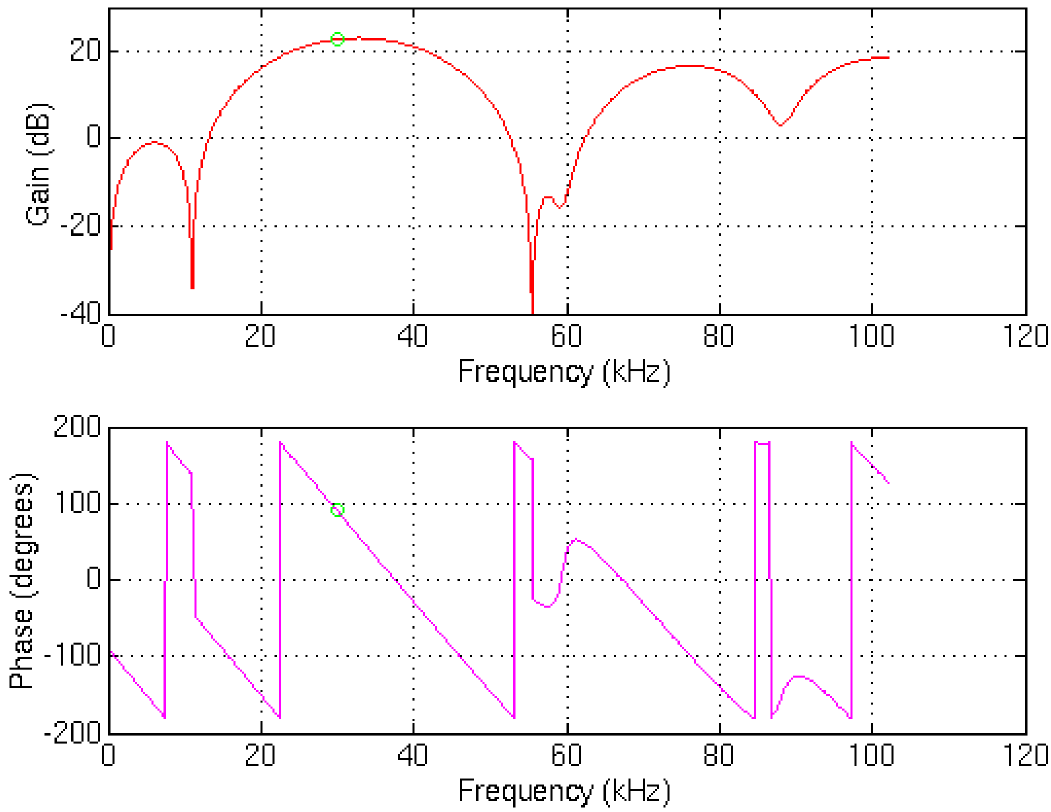

FIGURE 2. Frequency response of the quadrupole open-loop filter with a peak at 30 kHz and a quadrupole notch at 56 kHz.

Next we optimized the phase response of the dual peak filter to obtain maximum damping at the quadrupole frequency while keeping the gain constant. The baseline kicker timing established by the DAΦNE team in the past was used in all of the closed-loop quadrupole experiments. Frequency response of the resulting closed-loop filter providing control of both dipole and quadrupole instabilities is shown in Fig. 3. Note that the phase response of the filter is 90 degrees for the dipole signals and –90 for the quadrupole ones. Phasing sign (90 or –90 degrees) depends on the signs of the input offsets and the back-end timing offset.

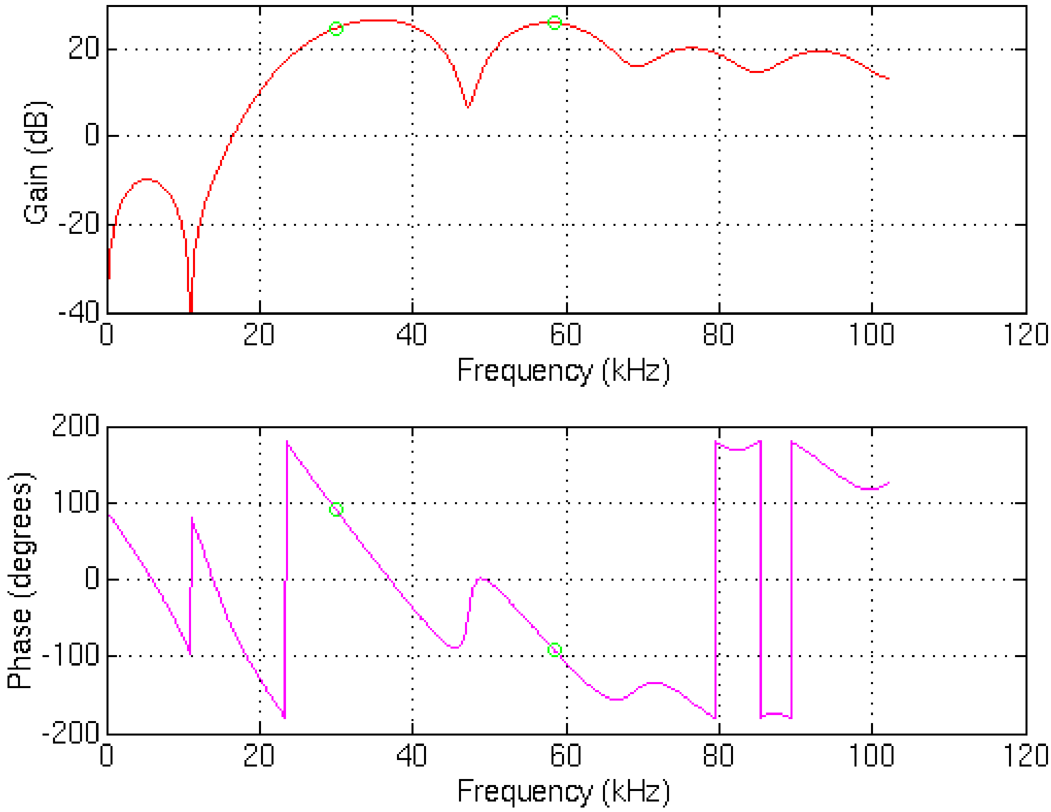

FIGURE 3. Dual-peak filter response with a notch at the mode zero frequency

In course of the high-current measurements we observed some excitation of the dipole mode 0 by the longitudinal feedback. To minimize this effect a notch was added to both filters at 11 kHz. Both filters shown in Figures 2 and 3 both include such a notch.

Using two filters described above we performed quadrupole grow/damp measurements as follows. Feedback system was configured initially with the dual peak filter to control all longitudinal instabilities. Upon a software trigger filter coefficients were switched to those of the quadrupole open-loop filter shown in Fig. 2. Without feedback control quadrupole oscillations grew due to the noise excitation. After an adjustable open-loop period of 5-10 ms the coefficients of the dual peak filter were restored thus activating the quadrupole feedback and damping the beam motion.

Figures 4 and 5 illustrate the beam behavior during a quadrupole grow/damp. Figs. 4 and 5 show the amplitudes of longitudinal oscillation filtered around dipole and quadrupole frequencies respectively. The raw data was recorded by the LFB system during a grow/damp. Note that quadrupole oscillation grows and damps reaching 1.25 units of amplitude. During the same period the dipole motion is controlled by the feedback and remains at the system steady-state noise floor.

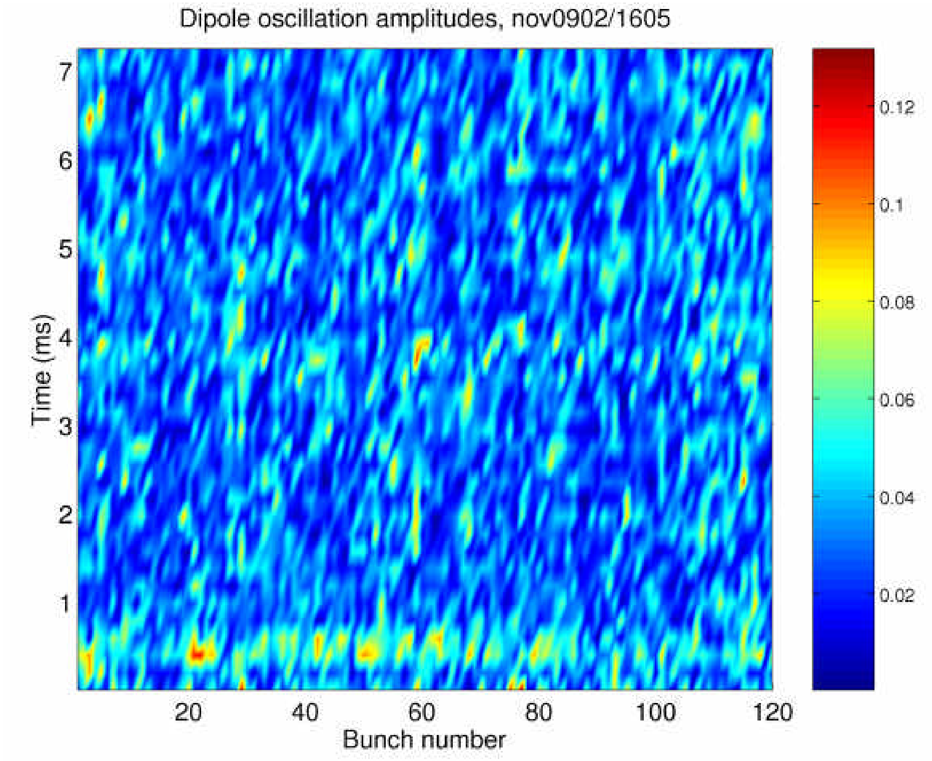

FIGURE 4. Bunch oscillation amplitudes filtered around synchrotron frequency

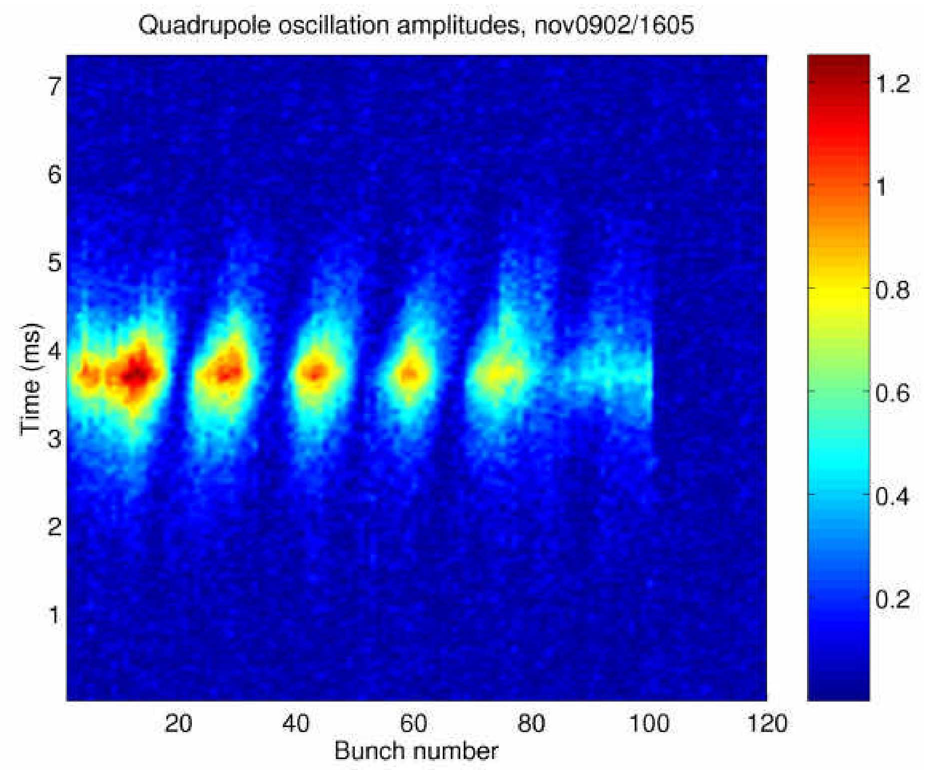

FIGURE 5. Bunch oscillation amplitudes (quadrupole)

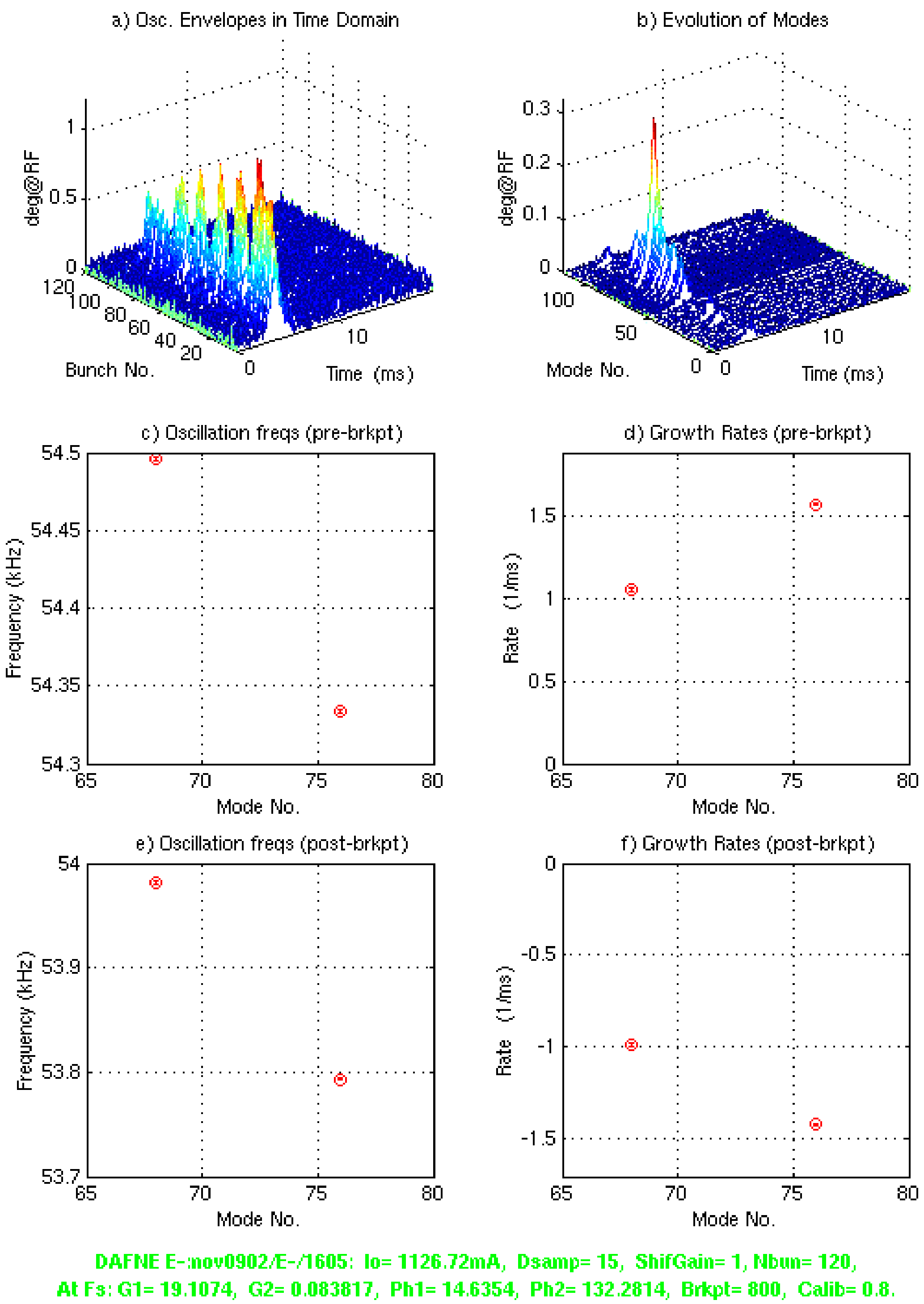

FIGURE 6. Modal analysis showing open (growth) and closed (damping) -loop exponential rates and oscillation frequencies for a quadrupole grow/damp

Note in Fig. 5 that bunch amplitudes during a grow/damp period show an interference pattern with 7 or 8 peaks over a revolution (several peaks are smeared or missing due to the gap). Such a pattern indicates two excited eigenmodes of comparable amplitudes separated by 7 or 8 revolution harmonics. The slope in the time evolution of the peaks is proportional to the oscillation frequency difference between the two eigenmodes.

These predictions are verified by the modal analysis of this dataset shown in Fig. 6. Here the bunch motion has been filtered around the quadrupole oscillation frequency and projected onto the even-fill eigenmode basis. Due to the gap in the fill pattern this projection does not provide a true eigenmode representation. Nevertheless we observe two strongly excited modes: 68 and 76. By fitting complex exponentials to the growth and damping parts of the transient we extract the open and closed-loop eigenvalues for these two modes. The eigenvalues show 160 Hz frequency shift between the two modes. Note that the feedback system affects two modes differently producing 2 ms^{-1} eigenvalue shift for mode 68 and 3 ms^{-1} for mode 76. It is unclear what is causing this difference, but one possible source is bunch-to-bunch coupling in the front or back-end of the feedback system. Such coupling modifies the frequency response of the feedback channel and results in mode-to-mode loop gain and phase variations.

Results for the e^+ ring

We have made a preliminary study which indicated that the dual-peak control filter was also applicable in the positron ring. Additional machine development time will be necessary to fully commission such a filter.

References

[1] A. Drago et al., “Longitudinal Quadrupole Instability in DAΦNE Electron Ring”, EPAC’02, Paris, 3-7 June 2002.