DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **G-71**

BEAM-BEAM LONGITUDINAL DAMPING

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Abstract

In fall 2009, during the last weeks of DAΦNE runs for the Siddartha experiment, measurements on the positron longitudinal behavior have been done. In particular the longitudinal damping effect induced on the positron beam by the electron one has been characterized and measured with high precision using both a commercial spectrum analyzer and the diagnostic capability of the e+ longitudinal bunch-by-bunch feedback. The results of these measurements are shown in this note.

1. Introduction

In the typical injection scheme of DAΦNE, the electron bunches are stored in the main ring before the positron ones because the electron injection efficiency is higher. Electrons are therefore injected to a rather high current (≈2 A), then the transfer line is switched to positrons, which takes about 1 minute, and then positrons are injected. The electron beam current decays rather rapidly, and finally the two beams collide at approximately the same currents, starting slightly above 1 A.

After electron injection and during the transfer line switching time, there are beam collisions with very high electron currents (between 2A and 1.5A) and relatively low positron ones (between 500 and 200 mA). In this particular situation, a longitudinal damping of the positron beam has been observed even with the longitudinal bunch-by-bunch e^+ feedback turned off. After repeated observations of this behavior, three dedicated machine studies on Sep/30/2009, Nov/04/09 and Nov/05/2009, have been carried out with the goal of precisely measuring characteristics of the damping effect.

The instrumentation tools used to make the measurements in the positron main ring have been the following: a) a commercial Real-time Spectrum Analyzer RSA3303A by Tektronix, working from DC to 3 Ghz, and connected to a high bandwidth pickup; b) the longitudinal bunch-by-bunch feedback with its beam diagnostic capability both in real time and off-line that can be used in closed and open loop.

2. Measurements description

Fig. 1 shows a plot from RSA 3303A of the 118-th revolution harmonics (highest peak, at 362.484 MHz) of the positron beam together with the synchrotron sidebands placed at 35±1 kHz of distance. The e+ longitudinal feedback is off (i.e. open loop) and the total beam current is I^+ = ~130mA in 103 bunches. In the following Fig. 2 the electron beam with a total current of ~1700 mA and all its feedbacks on (closed loop) collides with e^+ beam. The result is clearly shown in the plot: the e+ synchrotron sidebands are almost completely damped, again with the e+ longitudinal feedback turned off (open loop).

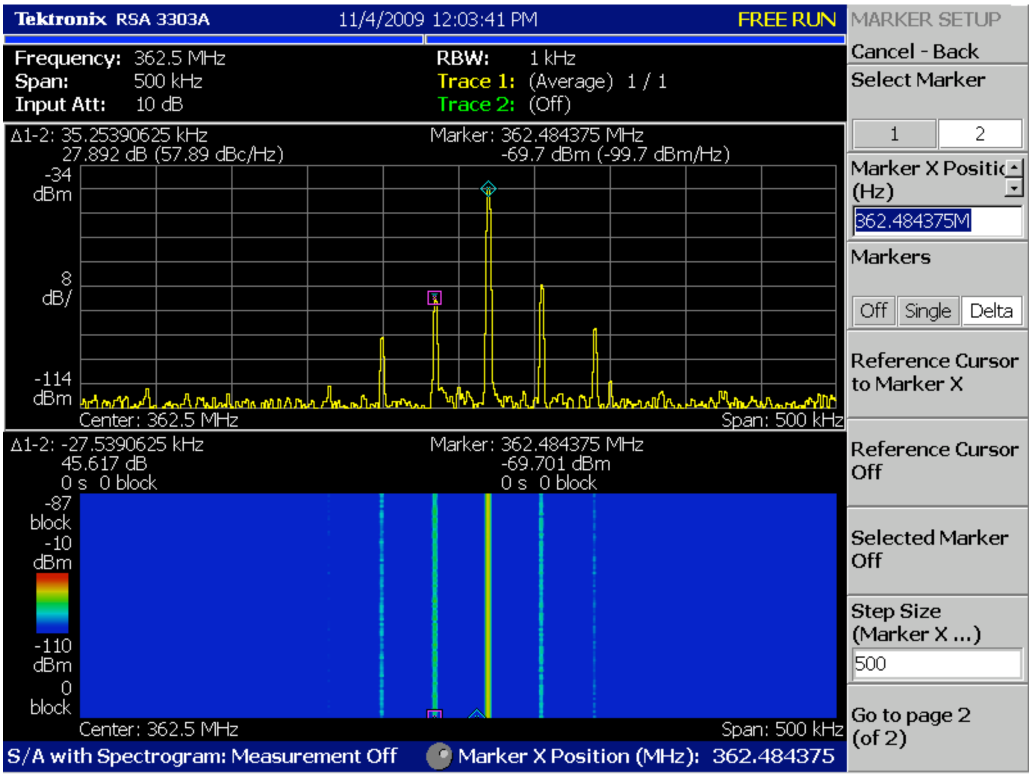

Fig. 1 – Positron 118-th RF harmonic with synchrotron sidebands.

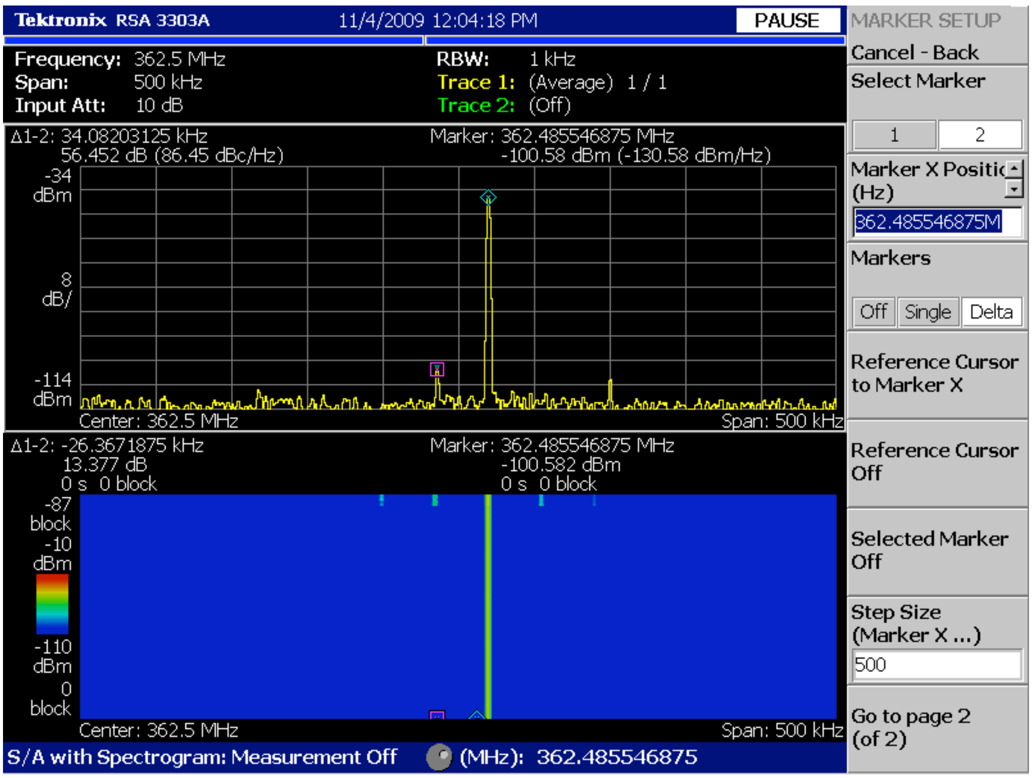

Fig. 2 – Synchrotron sidebands damped by beam-beam collisions.

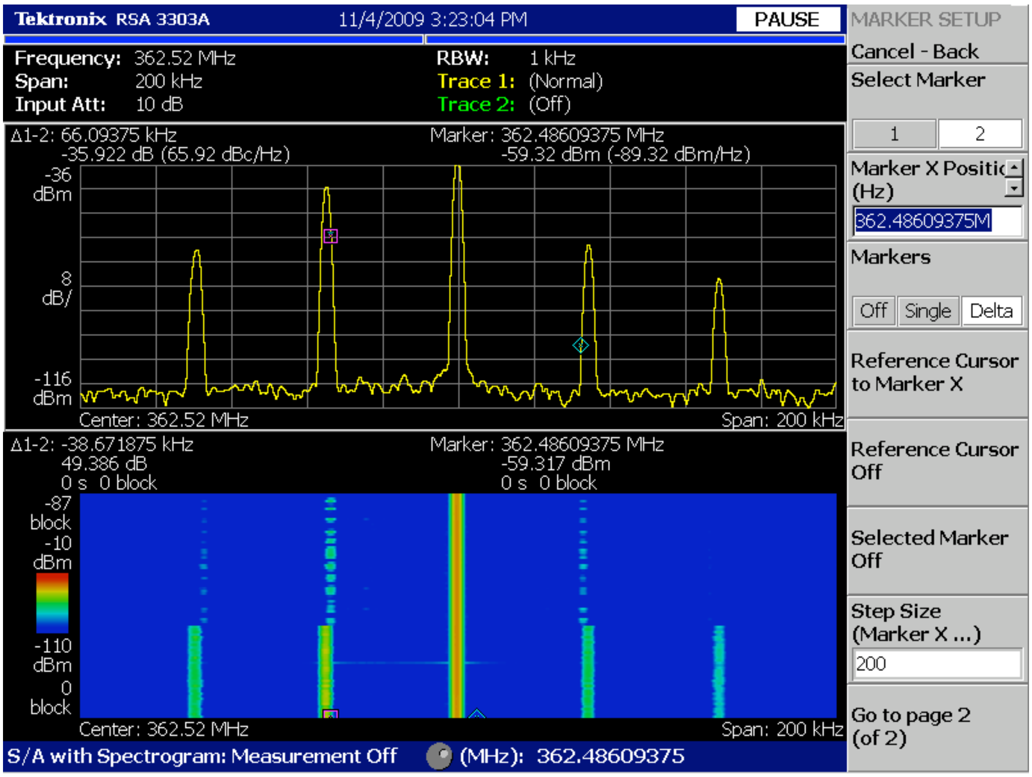

Fig. 3 – Positron beam longitudinal behavior shows “in collision – out of collision” case.

Fig. 3 shows the case “in collision – out of collision” with the same setup as the previous ones, that is with the e^+ longitudinal feedback turned off and all the others on. A frequency shift of the order of <-1 kHz in the sidebands is clearly visible but the resolution of the instrument is not accurate enough to be exactly measured. It is evident that the damping effect induced by the beam-beam collisions makes the synchrotron frequency on both sidebands lower. In the case of Fig. 3 the total currents are 1550 mA for the electrons and 390 mA for the positrons.

It is possible to download from RSA 3303A the traces also under text form. Downloading these data to the MATLAB environment (Fig. 4), and zooming, the following Figs. 5 and 6 have been created. Data have been recorded on September 30-th 2009; in this case the positron longitudinal feedback is turned on (as well as all the other feedback systems). The beam currents are similar to the case of November 4-th. Data coming from the spectrum analyzer are elaborated by MATLAB: the highest peak is the e^+ 118-th harmonic; the red trace shows positron spectrum without collision, the blue one the same with colliding beams. The vertical scale is in dBm, the horizontal one shows the number of bin (proportional to frequency). This case is interesting because it shows a situation in which the e^+ feedback has a too low gain and the electron (stronger) beam damps longitudinally and shifts in frequency the positron synchrotron oscillation. In Fig. 5 it is also possible to see that the beam collisions produce also a horizontal tune shift (increasing the frequency). Fig. 6 is a zoom of the previous figure in the area of the longitudinal sidebands and similarly Fig. 7 a zoom of another data record on the same day: in this case the damping effect seems stronger while the frequency shift is not so evident.

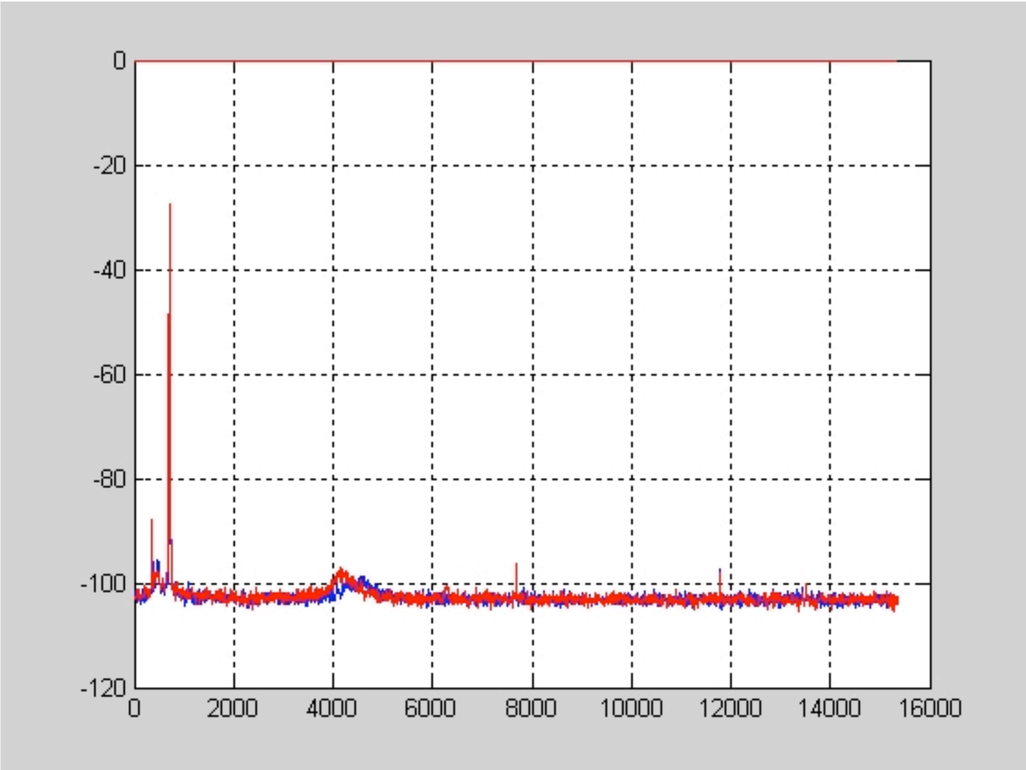

Fig. 4 – Data from the spectrum analyzer (the highest peak is the e^+ 118-th harmonic) elaborated by MATLAB: in red beams out of collision, in blue beams in collision. The vertical scale is in dBm, the horizontal scale shows the number of bin (frequency).

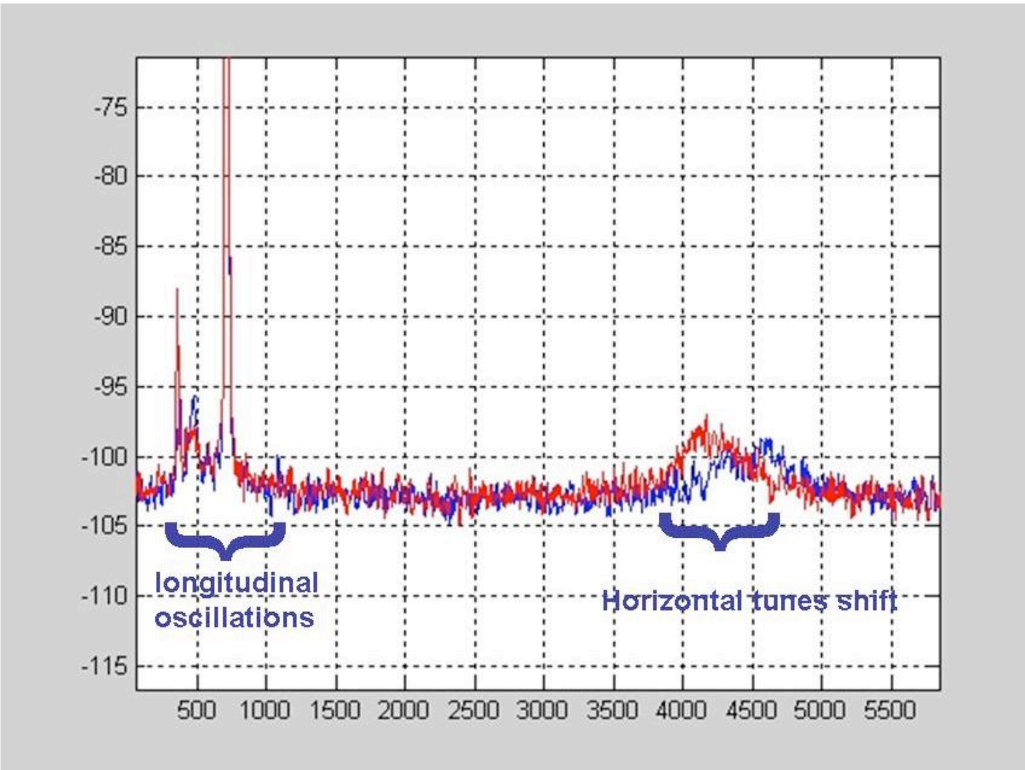

Fig. 5 – Zoom of the previous figure, showing the longitudinal and horizontal tunes.

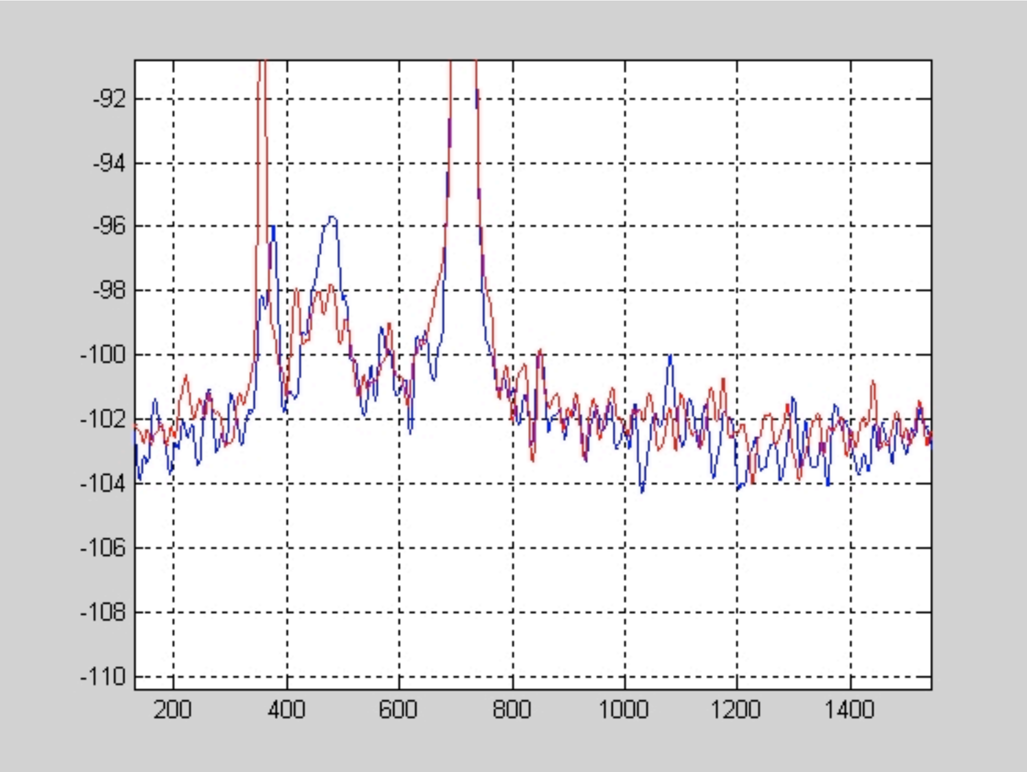

Fig. 6 – Zoom of the previous figure, particular of the longitudinal sidebands.

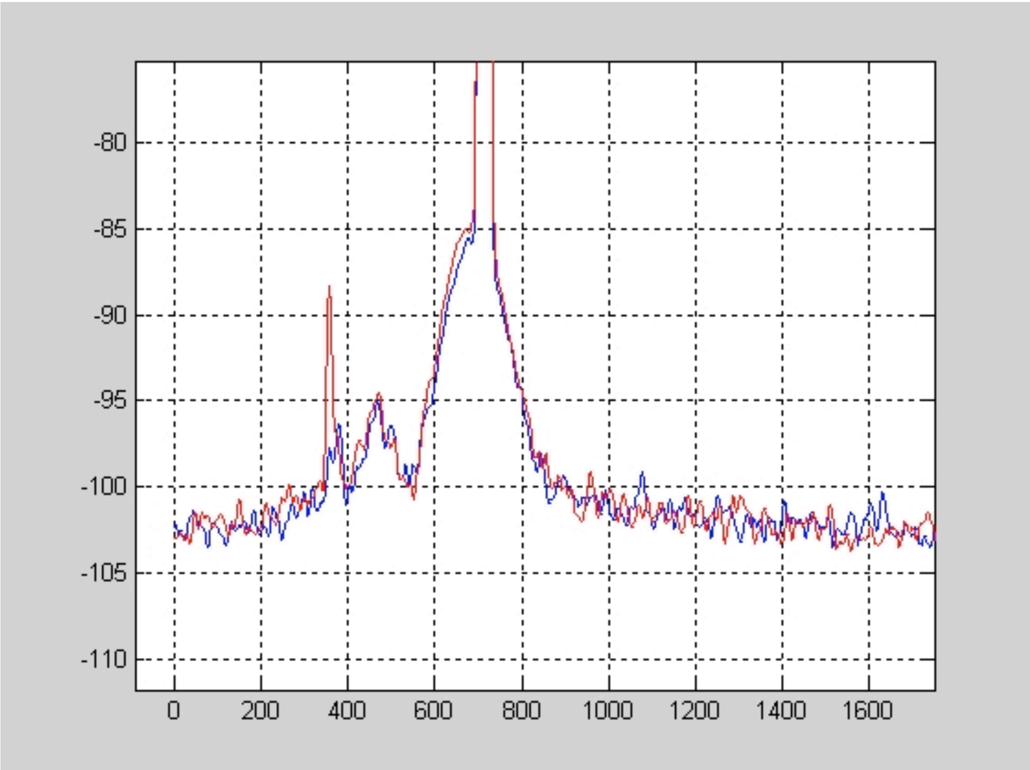

Fig. 7 – Another case similar to the previous figure, particular of the longitudinal sidebands.

With the goal to confirm the measurements done with the spectrum analyzer and to more precise evaluate the effects, the beam diagnostic tools of the DAΦNE longitudinal feedback have been used. With this system it is possible to record longitudinal data separately for each bunch. Data can be recorded both in closed and in open loop, that is with the feedback working or not.

Fig. 8 and 9 show two frequency spectra of the positron longitudinal motion. The first one is taken without beam-beam collision, the second with collision. In both cases the e^+ longitudinal feedback is off. In fig. 8 (no collisions), the synchrotron motion (at 35 kHz) is so large that both its first (at 70 kHz) and second (at 105 kHz) harmonics are clearly visible. In the following fig. 9 the beam-beam effect damps partially the longitudinal motion and, as a consequence, the first and second harmonics are missing.

The following Figures 10 and 11 show the modal growth rate analysis for the cases respectively without and with collisions, turning off for a short time the bunch by bunch feedback. In both cases mode 19 is the strongest unstable longitudinal mode but while out of collisions it has a growth rate, in inverse units, of 1.99 ms^{-1}, (corresponding to 502 microseconds), in collision the growth rate is halved, 1.04 ms^{-1}, corresponding to 961 microseconds.

The synchrotron frequency shift induced on the positron beam by the beam-beam collisions with the e^+ longitudinal feedback turned off is shown in Fig. 12, where the synchrotron frequency (out of collisions) is 34.86 kHz, and in Fig. 13, where the synchrotron frequency (in collisions) is 34.23 kHz. The frequency shift induced by the beam-beam collisions is therefore 630 Hz at the current of 320 mA (out) and 250 mA (in) for the positrons, with the electron beam at 520 mA (out) and 476 mA (in) respectively.

3. Conclusion

The damping effect of a strong electron beam on a weak positron one has been observed in DAΦNE for the first time during collisions with the crab waist scheme. Our explanation is that beam collisions with a large crossing angle produce a longitudinal tune shift and a longitudinal tune spread, providing Landau damping of synchrotron oscillations.

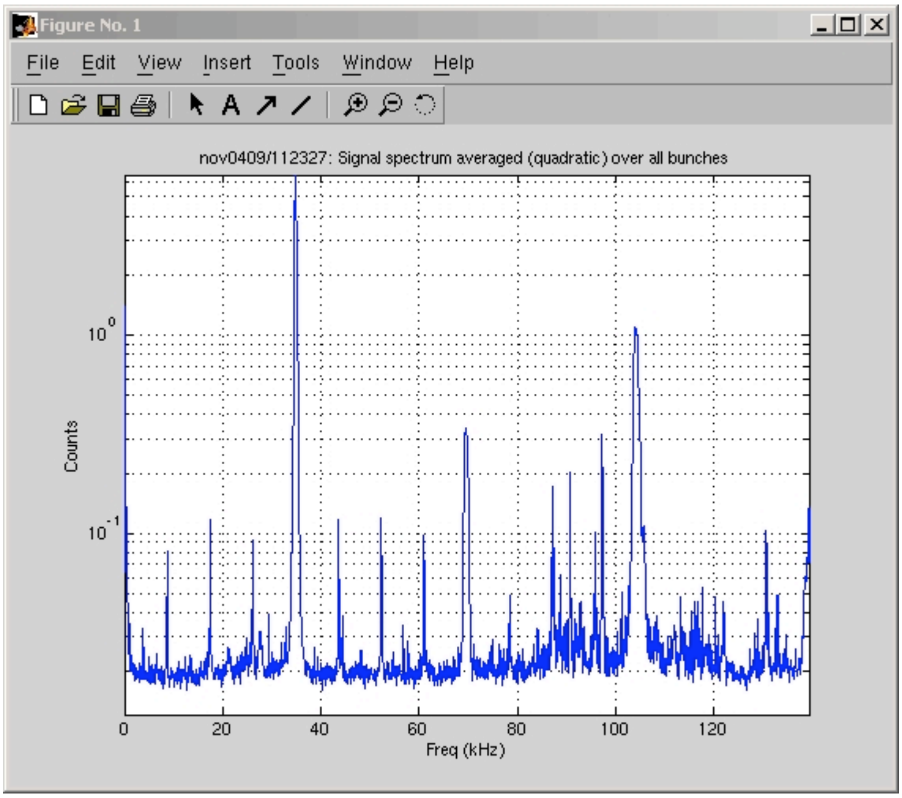

Fig. 8 – Feedback diagnostics: beam frequency spectrum, out of collision, feedback off.

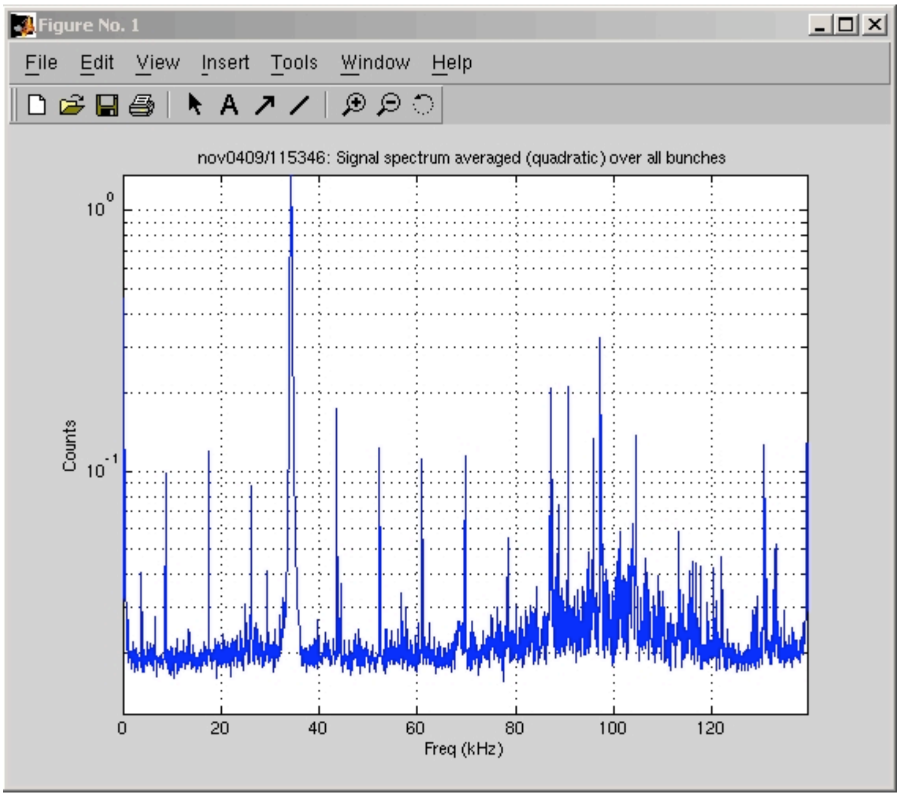

Fig. 9 – Feedback diagnostics: beam frequency spectrum, in collision, feedback off.

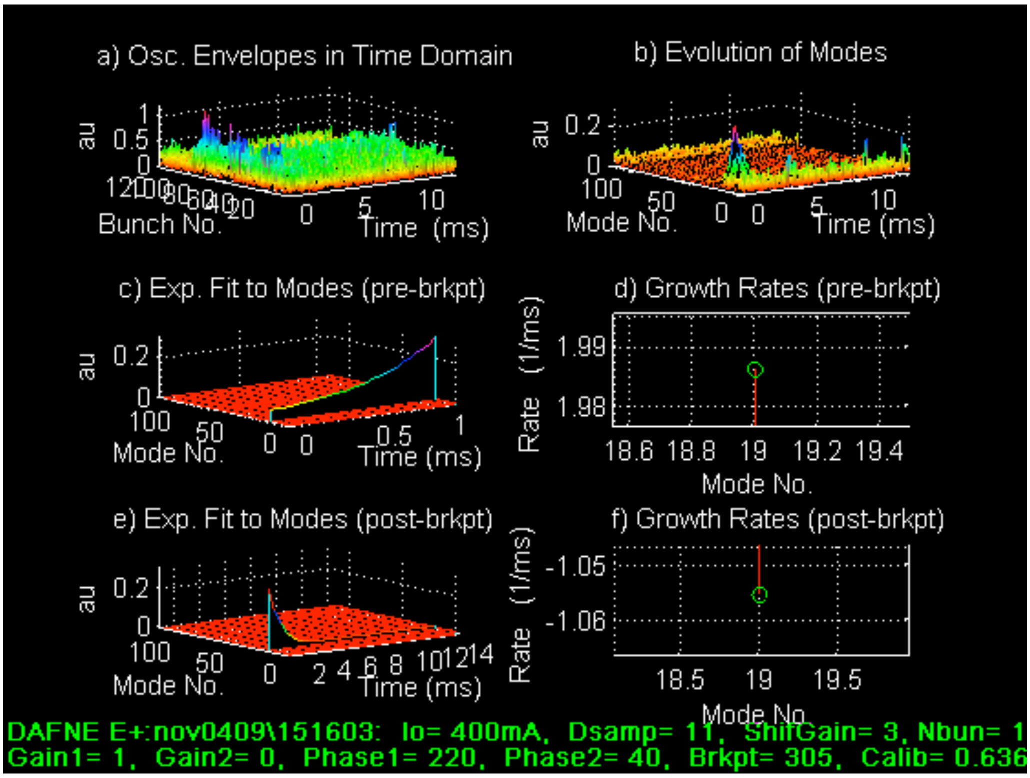

Fig. 10 – The Modal growth rate out of collision is 1.99 ms^{-1}.

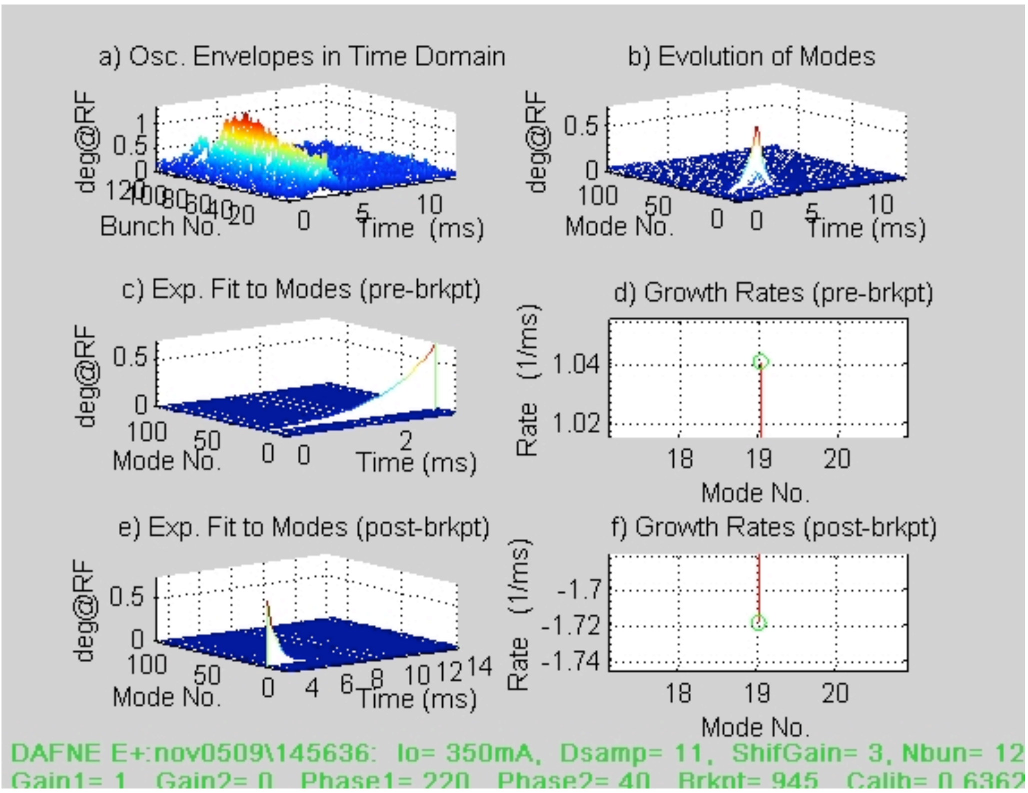

Fig. 11 – The Modal growth rate in collision is 1.04 ms^{-1}.

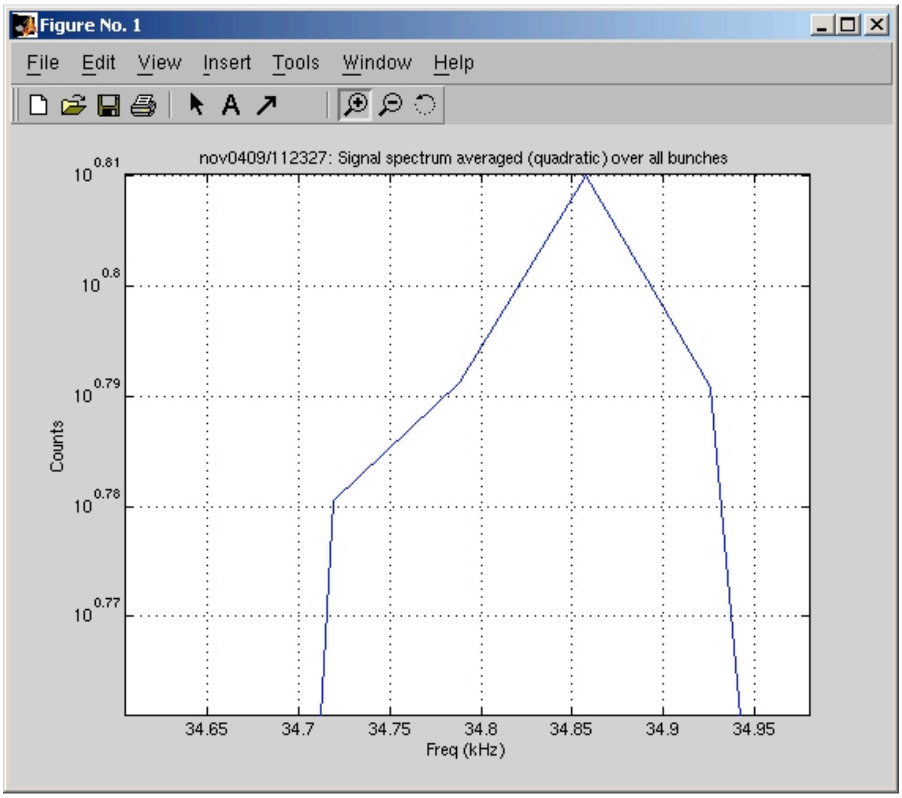

Fig. 12 – The Synchrotron frequency (out of collision) is 34.86 kHz.

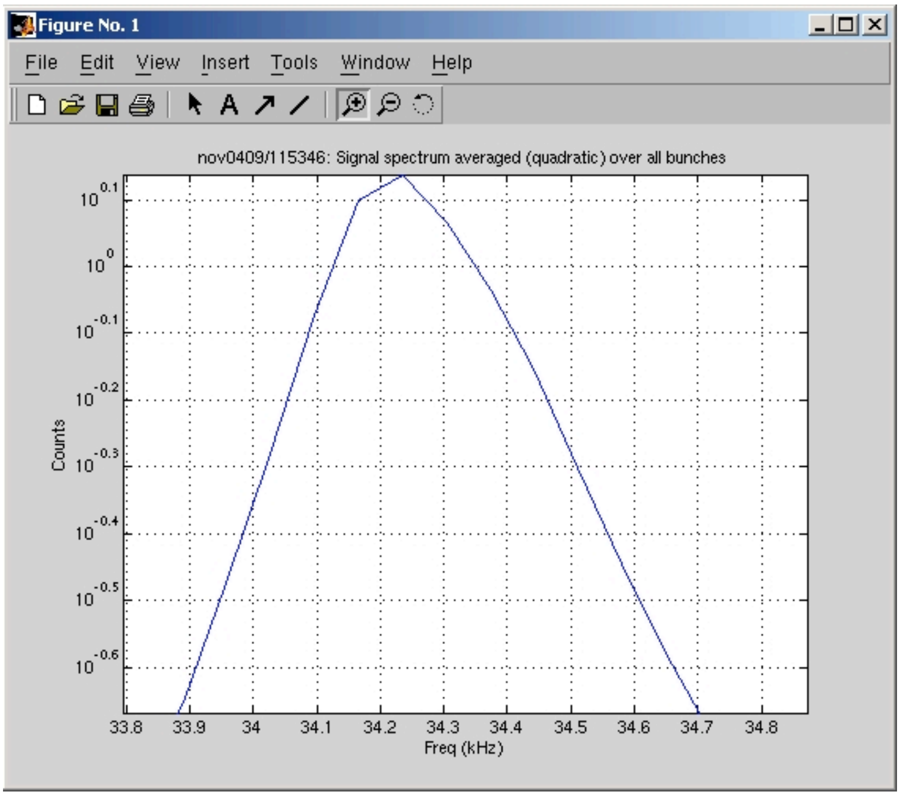

Fig. 13 – The Synchrotron frequency (in collision) is 34.23 kHz.