DAΦNE TECHNICAL NOTE
INFN - LNF, Accelerator Division

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Note: **G-67**

Analysis of Mechanisms Driving the Horizontal Instability in the DAΦNE Positron Ring

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Introduction

The horizontal instability has been limiting the maximum achievable positron current since the beginning of regular DAΦNE operations for physics experiments. However, it became particularly disturbing the collider performance only after the long shut down in 2003, when the instability threshold dropped by about a factor of 2-3.

During the last years many different measurements aimed at studying the instability have been carried out:

1) Instability threshold, rise time and modal analysis.
2) Betatron tune shifts as a function of beam current.
3) Instability dependence on the RF frequency, bunch length, beam pattern etc.
4) Comparison of vacuum behavior in electron and positron rings.
5) Study of solenoid effects on the vacuum pressure.
6) Local orbits bumps along the positron ring.
7) Others.

Many of the measurements were repeated and some of them were performed for different DAΦNE configurations.

In this Note we would like to give an analysis of possible mechanisms driving the instability answering questions that we are often aksed during Accelerators Division meetings, dedicated Workshops and Conferences:

1) Why do we think that the instability is driven by an electron cloud?
2) Why is it difficult to perform a systematic study of the instability?
3) Why do we think that the resistive wall also contributes to the instability?
4) Why do we consider that the instability has a beam break up nature?

5) What are the indications that scrubbing takes place in the positron ring?
6) Why did we start a dedicated study of the instability only after the shut down of 2003?
7) What are the particular changes that could lead to the instability reinforcement after the shut down of 2003?
8) Why do we consider that the e-cloud in the wiggler gives rise to the instability?

Respective data of the measurements can be found in the DAΦNE log-books [1], several presentations [2-5] and in a few papers published so far [6-14]. Most relevant pictures are attached at the end of the Note.

Analysis

1. Why do we think that the instability is driven by an electron cloud?

    a) There is a large positive tune shift in the horizontal plane, much higher than in the electron ring.
    b) Anomalous pressure rise has been observed in the positron ring.
    c) The dynamic pressure rise with positron beam current in the straight sections is lower when solenoids are on.
    d) The instability is so fast that its growth rate can not be explained by the conventional instabilities due to the HOMs or resistive walls. Instead, it is in agreement with Frank Zimmermann's predictions for the e-cloud instability in DAΦNE (made in 1997, 15 μs for 120 bunches).
    e) Besides, the instability does not scale with the total beam current as it is in case of the conventional instabilities. The threshold rather scales with bunch current for short gaps between bunches (no gap, by 1, by 2.), for intermediate gap length the growth rate even increases with the beam current, and for longer gaps the beam gets stable.
    f) There is some evidence of beam scrubbing, see 5.

2. Why is it difficult to perform a systematic study of the instability?

    a) More than one physics mechanizms contribute to the instability. The two dominating ones, in our opinion, are: electron cloud and resistive wall impedance.
    b) Instability parametric dependences evolve in time. We attribute this fact to the scrubbing effect, see 5.

3. Why do we think that the resistive wall also contributes to the instability?

   a) Both the quadrupolar resistive wall wakes and e-cloud contribute to the positive tune shift in the horizontal plane. (The resisve wall contribution is in a very good agreement with Sam Heifets's formula and respective small positive tune shifts is also observed in the electron ring).

   b) Grow-damp analysis has revealed that the mode –1 is unstable corresponding to the most unstable mode in case of the resistive wall instability. In some way the resistive walls might impose corresponding phase relation between bunches. However, it should be noticed, that the unstable mode –1 in the horizontal plane was observed also at KEKB. Accroding to Ohmi's simulations it is purely e-cloud multibunch mode (We have his .ppt presentation).

4. Why do we consider that the instability has a beam break up nature?

   a) Growing dipole oscillations towards bunch train end.

   b) The growth rate (< 10 μs) is faster that the synchrotron period (> 30 μs).

   c) Beam stability is very much sensitive to injection conditions. Indeed, beam is more stable with a more flat bunch pattern after the injection kickers pulse reduction and injection closed bump adjustment.

   d) Theoretically (see Zimmerman's paper) the beam break up instability growth rate scales linearly with the beam emittance. Namely the emittance was reduced after the 2003 shut down and this could be one of possible explanations why the instability is faster now.

5. What are the indications that scrubbing takes place in the positron ring?

   According to last year experience of DAΦNE running:

   a) The instability threshold was getting higher in time, especially at the beginning of the run. Besides, usually after few days without beams the threshold was getting somewhat lower, but the situation was recovering in a short time (typical scrubbing behaviour).

   b) We also observed some correlation between the instability threshold and improving dinamic vacuum at some points of the vaccuum chamber (multipacting?)

   c) The dependence of the instability threshold on bunch patterns changed (favorably for operations; one can compare results of the grow-damp measurements made recently and about one year ago)

   d) The dependence of the instability threshold on the RF frequency (orbit variation) that was found in the beginning of the run now has dissapeared.

6. Why did we start a dedicated study of the instability only after the shut down of 2003?

   The instability was not limiting DAΦNE performance before the shut down of 2003:

   a) The threshold was definitely higher. With 45 bunches separated by 1 empty bucket we managed to put in collision 1.3 A of positrons. Immediately soon after the shut down in the same conditions (45 bunches) we could not store more that 450 mA. After one year the maximum storable current has increase to about 800 mA (scrubbing), still much lower than before.
   b) The instability was detected as growing dipole oscillations without bunch size increase. Once the instability damped by the feedback, we were not observing any reduction of the luminosity.
   c) Since before the shut down we were colliding by a factor of two less bunches the main limiting factor was the beam-beam effect (higher bunch current for equal beam currents).

7. What are the particular changes that could lead to the instability reinforcement after the shut down of 2003?

   There are the following hypothesis under considerarion:

   a) The wiggler poles has been modified in order to decrease the wiggler nonlinearities. This could lead either to Landau damping loss (this hardly can be the case since the instability is too fast) or to change in dynamics of the e-cloud creation (Cristina Vaccarezza and Frank Zimmermann are performing simulations).
   b) Lattice variations: average horizontal beta functions in wigglers are somewhat higher and the emittance is by a factor of two smaller (see 4 d)).

8. Why do we consider that the e-cloud in the wiggler gives rise to the instability?

   a) At the beginning of the run we found the instability thrshold dependence on RF frequency (almost a factor of 2 by varying 10 kHz). The frequency variation gives orbit changes that are biggest inside wigglers where the dispersion is high.
   b) We wired solenoids on all accesible straight sections. This reduced dynamic vacuum, but did not change the threshold at all. This means that there is an e-cloud in the straight sections, but it is not dominating.
   c) The wiggler modification is one of the major DAΦNE modification during the 2003 shut down.

References

[1] DAΦNE Log-books, 2001-2005 years.

[2] http://www.lnf.infn.it/acceleratori/dafne/report/dafne_2005.pdf

[3] http://www.lnf.infn.it/acceleratori/dafne/report/PAC05_Invited_Zobov.pdf

[4] http://www.lnf.infn.it/acceleratori/dafne/report/Teytelman.pdf

[5] http://icfa-ecloud04.web.cern.ch/icfa-ecloud04/talks/Tuesday/SessionD/SessionDTalk5.pdf

[6] C. Vaccarezza et al., "Electron Cloud Build-Up Study for DAΦNE", in Proceedings of PAC05: 779-781, 2005.

[7] C. Vaccarezza et al., "Experimental Determination of E-Cloud Simulation Input Parameters for DAΦNE", in Proceedings of PAC05: 817-819, 2005.

[8] A. Drago, D. Teytelman and M. Zobov, "Recent Observations on a Horizontal Instability in the DAΦNE Positron Ring", in Proceedings of PAC05: 1841-1843, 2005.

[9] M. Zobov et al., " DAΦNE Operations and Plans for DAFNE2", in Proceedings of PAC05: 112-116, 2005.

[10] F. Zimmermann et al., " Electron Cloud in Wigglers", CLIC-Note-650, EUROTEV-REPORT-2006-002, Jan. 2006, 39 pp.

[11] C. Vaccarezza et al., "Experimental Observation and e-Cloud Simulations for DAΦNE", in Proceedings of 31st ICFA Beam Dynamics Workshop: Electron Cloud Effects (ECLOUD 04), Napa, California, 2004, 6 pp.

[12] A. Drago, "Horizon5al Instability and Feedback Performance in DAΦNE e+ Ring", in Proceedings of EPAC04: 2610-2612, 2004.

[13] D. Alesini et al., "Report on DAΦNE MD on 17-18/03/2004" , DAΦNE Technical Note BM-14, 20 May, 2004.

[14] D. Alesini et al. , " Report on DAΦNE MD on 14/01/2004", DAΦNE BM-11, January 14, 2004.

Most relevant pictures

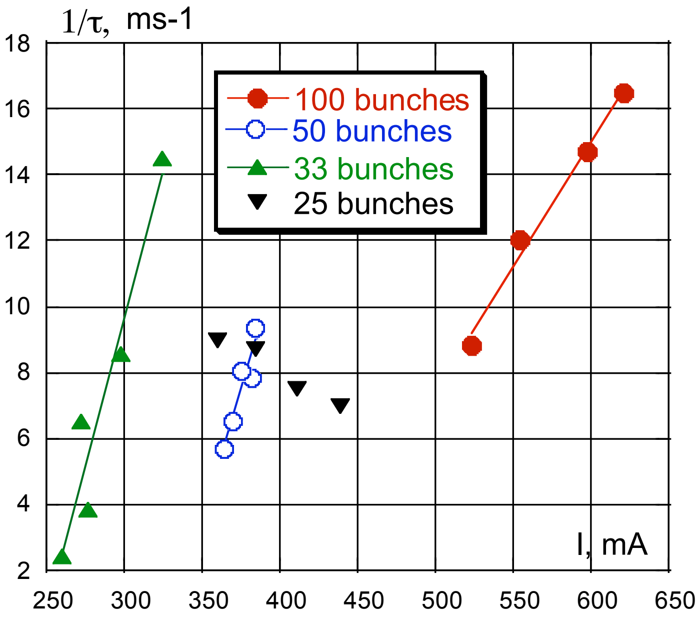
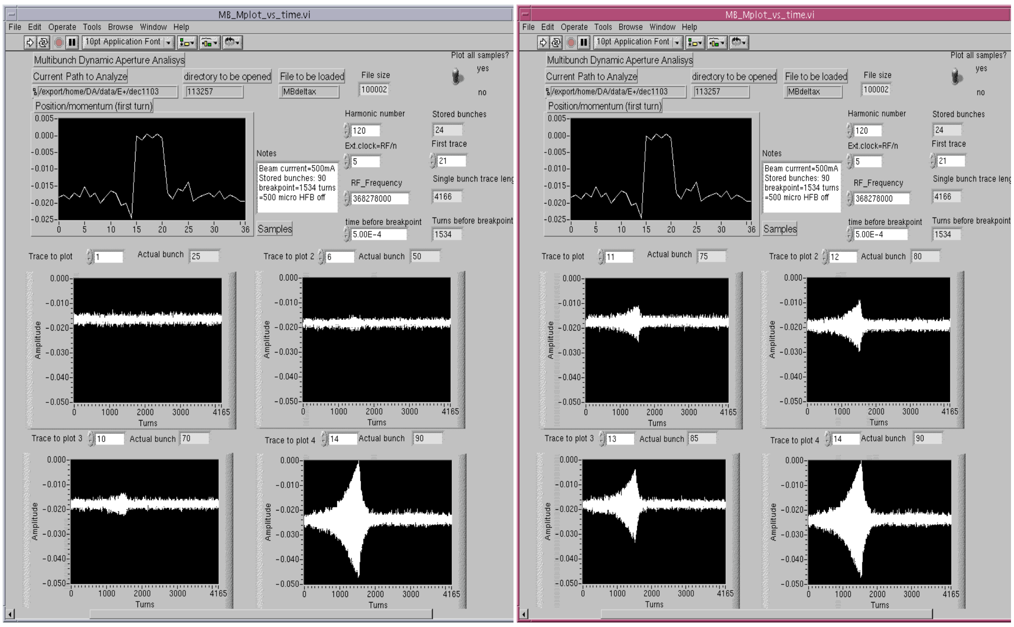


Figure 1: Growth rate of the instability as a function of positron beam current for different bunch patterns.



Current Path to Analyze: /export/home/DA/data/E+/dec1103
directory to be opened: 113257
File to be loaded: MBdeltax
File size: 100002
Harmonic number: 120
Stored bunches: 24
Ext.clock=RF/n: 5
First trace: 21
RF_Frequency: 368278000
Single bunch trace leng: 4166
time before breakpoint: 5.00E-4
Turns before breakpoint: 1534

Notes:
Beam currrent=500mA
Stored bunches: 90
breakpoint=1534 turns
=500 micro HFB off

Left window:
Trace to plot: 1 Actual bunch: 25
Trace to plot 2: 6 Actual bunch: 50
Trace to plot 3: 10 Actual bunch: 70
Trace to plot 4: 14 Actual bunch: 90

Right window:
Trace to plot: 11 Actual bunch: 75
Trace to plot 2: 12 Actual bunch: 80
Trace to plot 3: 13 Actual bunch: 85
Trace to plot 4: 14 Actual bunch: 90

Figure 2: Horizontal grow-damp measurements for bunches 25, 50,70,90 (left figure) along the bunch train and for bunches 75, 80, 85 and 90 at the bunch train tail . Shown is the turn-by-turn horizontal position offset. The horizontal feedback is switched off during 500 μs.

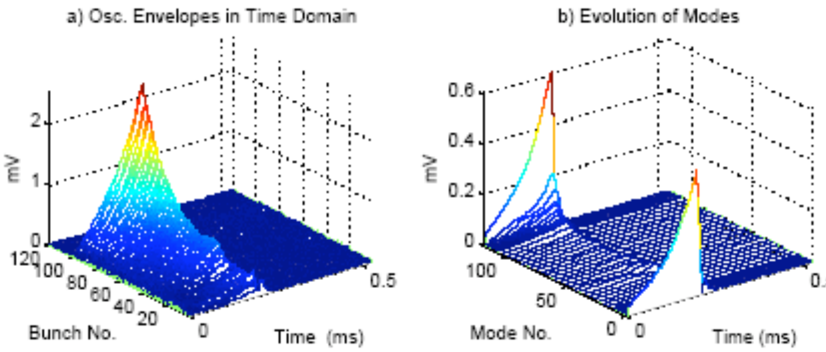


Figure 3: Modal analysis of the horizontal grow-damp measurements. Mode –1 is unstable (Courtesy D. Teytelman, SLAC).

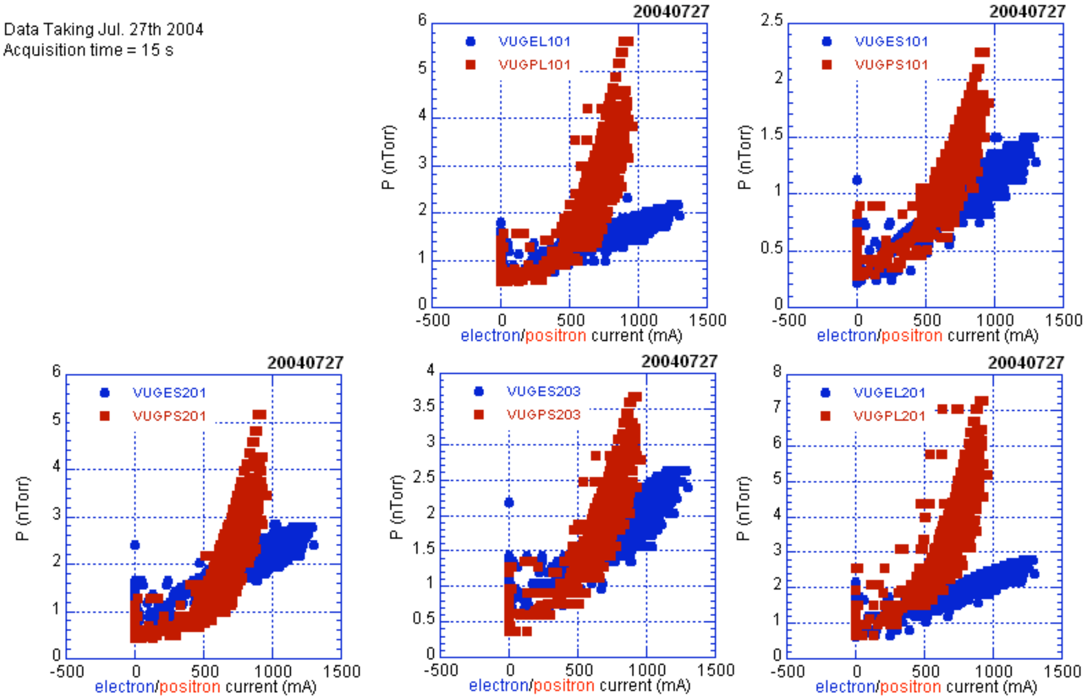


Figure 4: Vacuum pressure read-out versus total beam current as recorded by vacuumeters placed in similar locations in the electron (blue dots) and positron (red dots) rings.

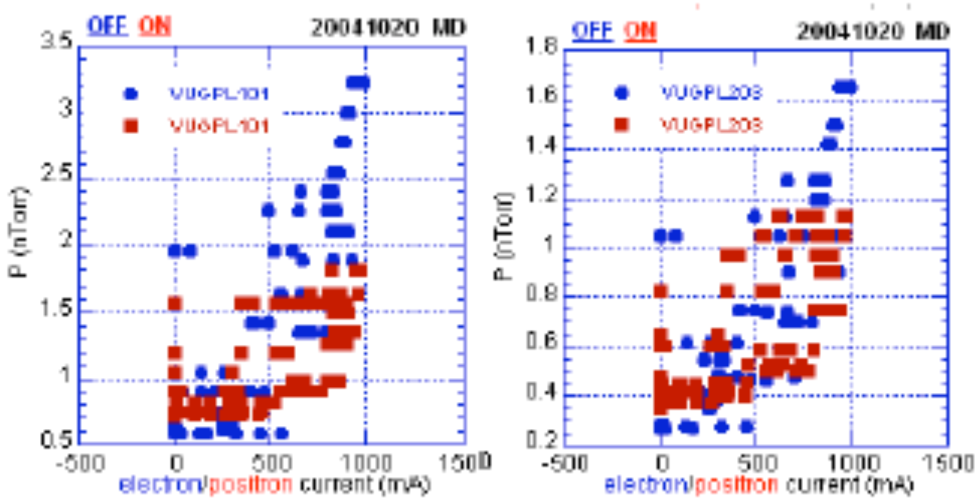


Figure 5: Vacuum pressare read-out versus total current as recorded in 2 straight section locations of the positron ring where a 50 Gauss solenoidal was turned on (red dots) and off (blue dots).

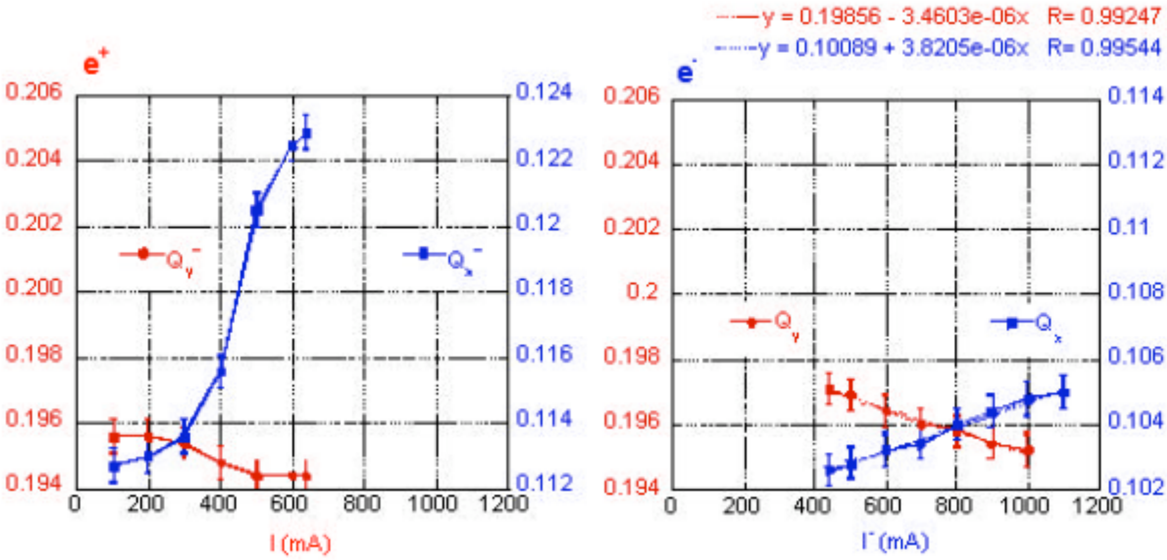


Figure 6: Vertical (red) and horizontal (blue) tune shifts measured as a function of the total beam current in the positron ring (left picture) and in the electron one (right picture).