The evolution of the Impedance at ELETTRA and related Instabilities

E. Karantzoulis, Sincrotrone Trieste

[1]

The stored current performance of a machine greatly reflects its impedance status and ELETTRA is a typical example. The commissioning of the SR started October the 4th 1993 and by October 17th 216 mA were stored. Single bunch was tried in 1994 and more than 60 mA were stored on May 7th whereas at the same day were obtained 530 mA in 80% multibunch filling; the maximum reached was 700 mA (3 years later) and no injection saturation effects were observed! All that show that special care was taken to have the impedance of the machine as low as possible. With the exception of the rf-cavities, the vacuum chamber (shape and material) with its connections, holes, steps etc. is the other important contributor of impedance. The vacuum chamber was made of stainless steel with dimensions 82x53 mm while at insertions had 76x20 mm (full horizontalXvertical). The cavities are four copper single cells of a smooth bell shape.

Impedance budget calculations using mostly analytic formulae estimated that the broad band longitudinal impedance should be 0.7 Ω while the corresponding transverse 200 k Ω /m with an estimated cut-off frequency of about 2.3 GHz. The predictions worked quite well since single bunch measurements have shown that the longitudinal broad band impedance should be ~ 0.5 Ω and the transverse 130 k Ω /m. These values confirm also the theoretically predicted high current thresholds of ELETTRA. Thus budget analysis can be quite reliable as long as it is used with caution.

The instability situation in 1994 was thus as follows:

1) Resistive wall, was not observed. The closest unstable frequency due to the machine tune of 0.2 is 0.8 f_0 = 0.92528 MHz. At this frequency the pessimistic (i.e. assuming all machine with the chamber dimensions as in the straight sections) impedance is 800 kΩ /m and for 300 mA at 2 GeV the resistive wall growth rate is ~3 ms corresponding to a coherent frequency shift of ~300 Hz. For this to be Landau damped the incoherent betatron frequency spread must be at least 600 Hz which is well inside the measured (multibunch) spread of 1 kHz.

---

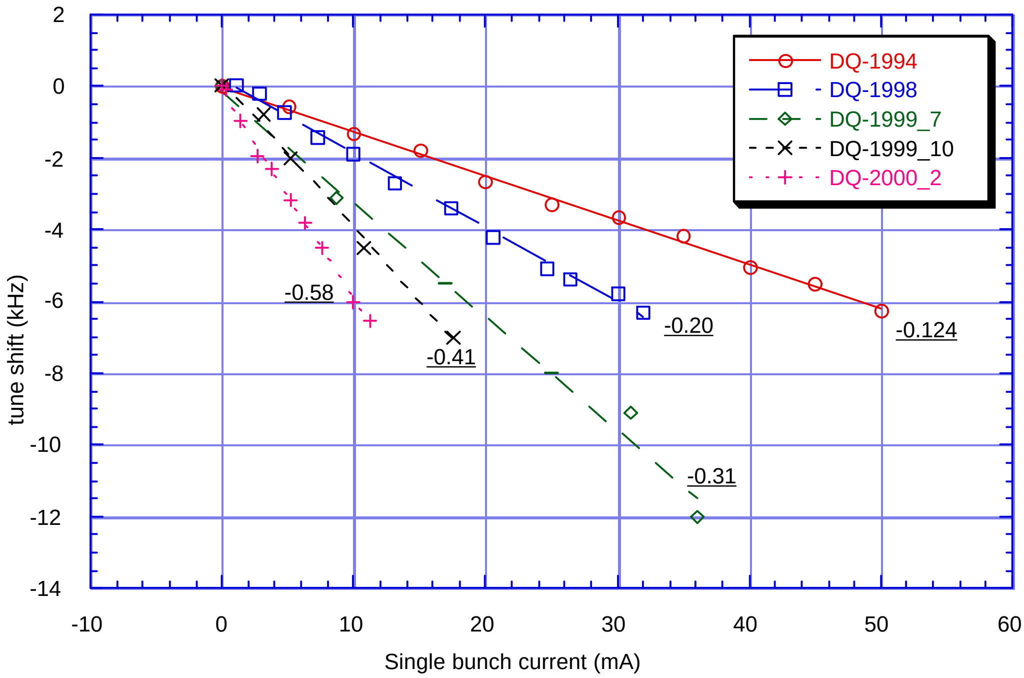
[1] **talk given at: beam Instability Workshop – ESRF, Grenoble 13-15 March 2000**

2) Mutibunch instabilities existed as predicted and are generated by the HOMs of the rf cavities. Careful tuning of the cavity volume (via temperature control) shifts the HOMs from the beam harmonics. A complete instability free condition at 150 mA was achieved while above the 150 mA it is still possible but more difficult (for more on this, M. Svandrlik)
3) Mode coupling. Threshold predicted at 40 mA/bunch but not seen. Simple threshold estimations with the actual impedance set the threshold at 58 mA (1 GeV) but 65 mA were injected without saturation. However above 50 mA the beam was blown up and throbbing.
4) Head-tail instabilites. The m=0 mode for small (0.1) positive chromaticity was stable. At much higher currents 35 mA the m = -1,1 were also seen but no mode merging occurred. With slightly negative chromaticity the m = 0 threshold was found at ~22 mA above which the beam blew up vertically and oscillated. This threshold was quite expected since using the impedance data the necessary Landau damping frequency (ω_L) should have been at about 200 Hz whereas the “natural” tune spread available $\Delta Q/Q$ is ~6. 10^{-6} (i.e ω_Q = 357 Hz)

Due to scarce interest of users in single bunch, lack of special instrumentation, low impedance and no serious instability problems, no beam excitation measurements (to probe the real part of the impedance) or other additional measurements were performed. In any case our impedance model had worked well from the beginning. ELETTRA however, never stopped evolving and since 1997 ID straight section chambers have been replaced with low gap (14 mm) ones as well as some bending magnet vacuum chambers (Udl) ones made of Aluminium with a modified internal aperture for photon extraction, as seen in the next table.

Date	Section – length m	Material
Sept 97	**ID 4 4.0**	Stainless steel
Oct 98	**ID 9 4.8**	Aluminum
Oct 98	Udl 9.2	Aluminum
Aug 99	**ID1 4.8**	Aluminum
Aug 99	Udl 1.2	Aluminum
Sept 99	Udl 1.1	Aluminum
Jan 00	**ID2 4.8**	Aluminum

The detuning of the coherent vertical betatron oscillation with single bunch current for m=0 was measured after each ID chamber installation. The results are summarised in the following graph:

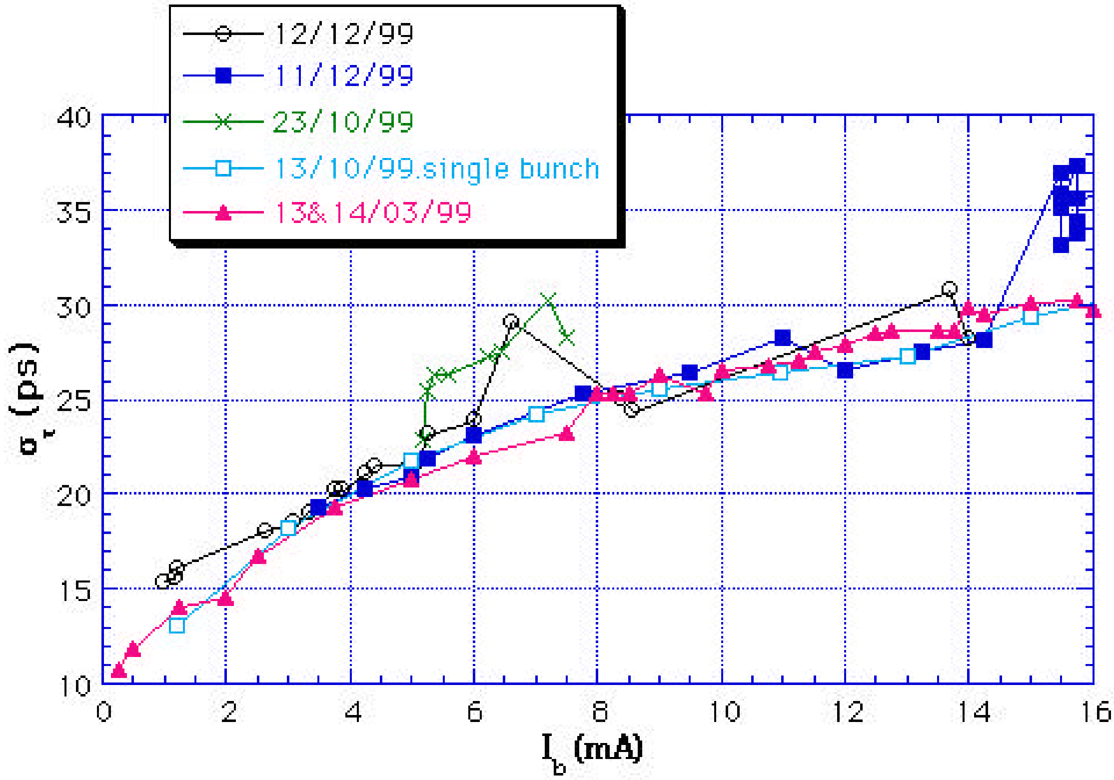


It is quite interesting to observe that the vertical effective impedance increases proportionally with the number of low gap chambers, i.e. each chamber adds about ~0.1 kHz/mA to the original r1= 0.12kHz/mA. Since:

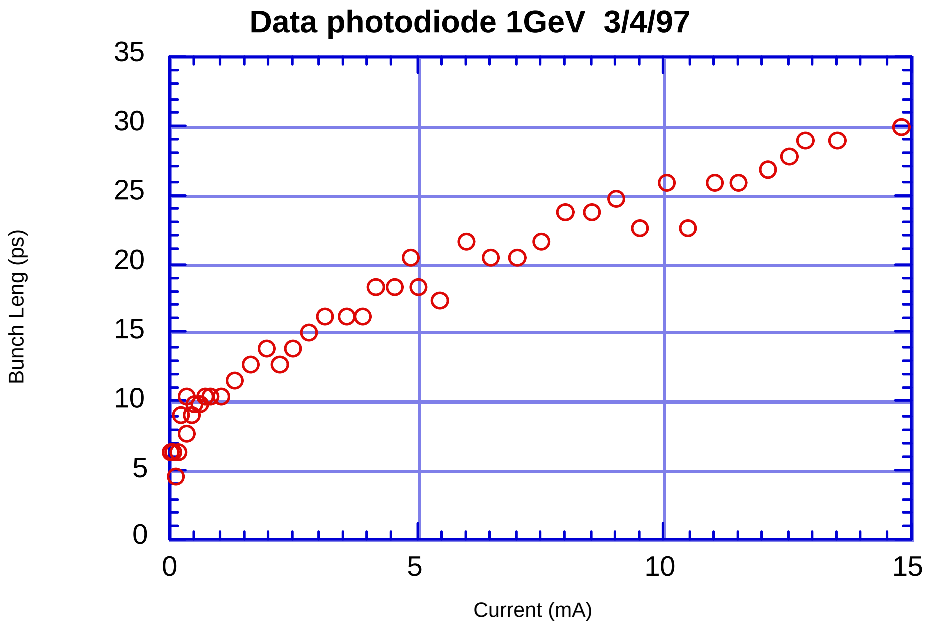
$$\frac{r_1}{r_2} = \frac{Z^{eff}{}_{V1}}{Z^{eff}{}_{V2}}$$

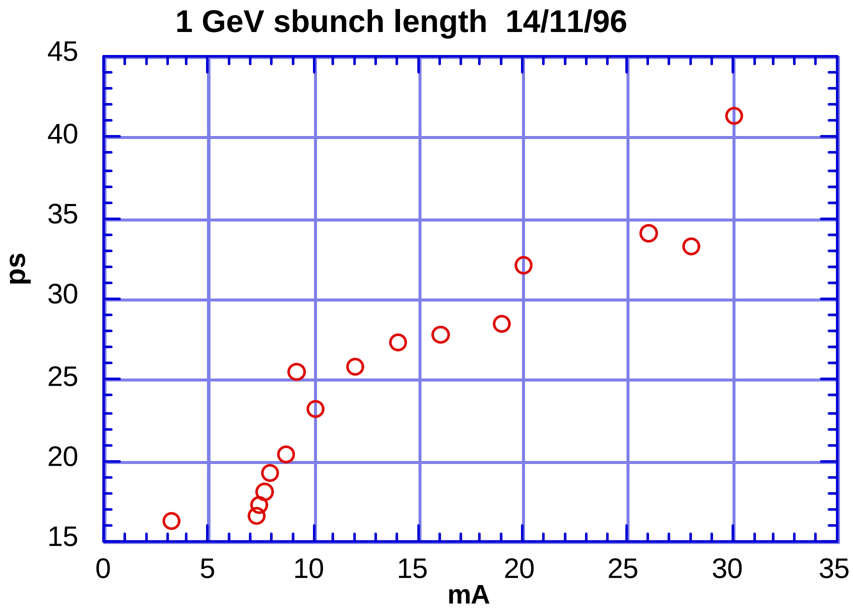
the vertical effective impedance is now 4.6 times larger. Again as in the past, no horizontal tune shift was seen.

At the same time bunch length measurements performed do not indicate clear changes in bunch length. Taking as a worst case a 25% change in bunch length (maximum observed including measurement uncertainty) the longitudinal effective impedance could have increased at most by a factor of two. Single bunch length measurements versus current at 1 GeV, 1.76 MV are presented below:

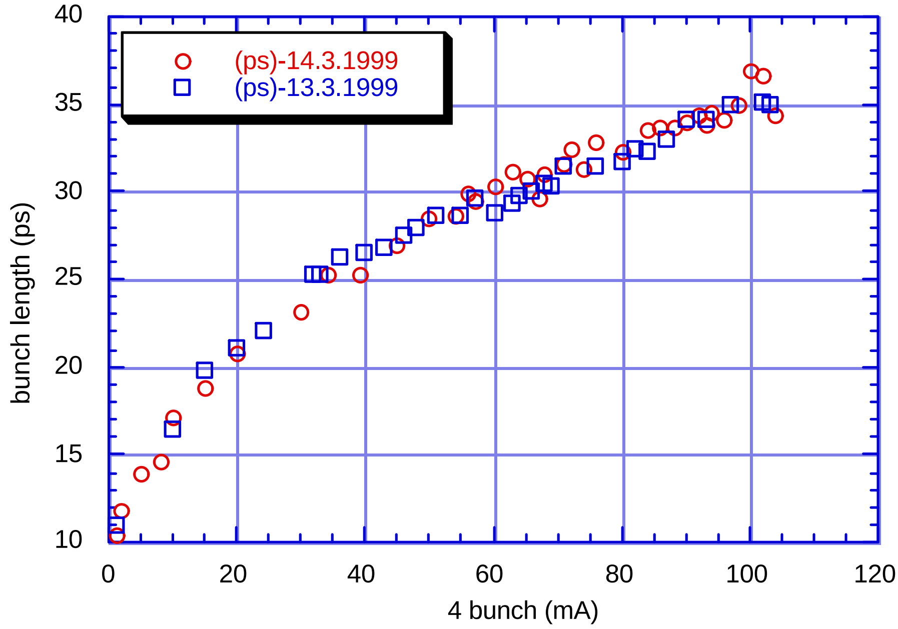


To be compared with:



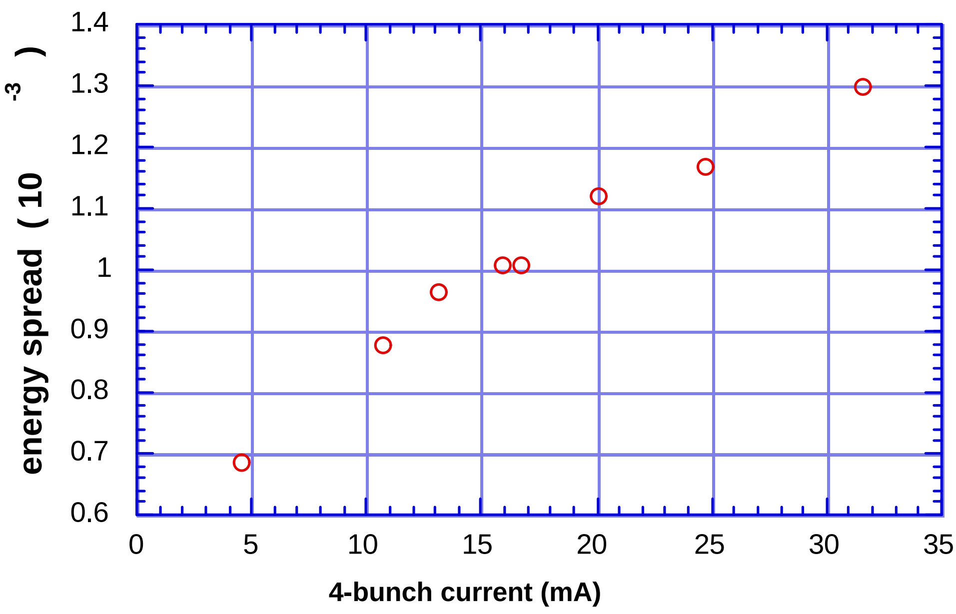


Measurements were also performed with 4-bunch needed for the SR-FEL of ELETTRA. The Figure below shows measurements in the 4 bunch mode in a multibunch instability free setting:



(The FEL lased first time in the night of 28.2.200 at 350 nm with 35 mA in 4 bunches. The beam was very stable and no other beam stabilisation means was needed.)

Some preliminary measurements of energy spread performed during the 4-bunch operation using the FEL spectra, agree with expectations:

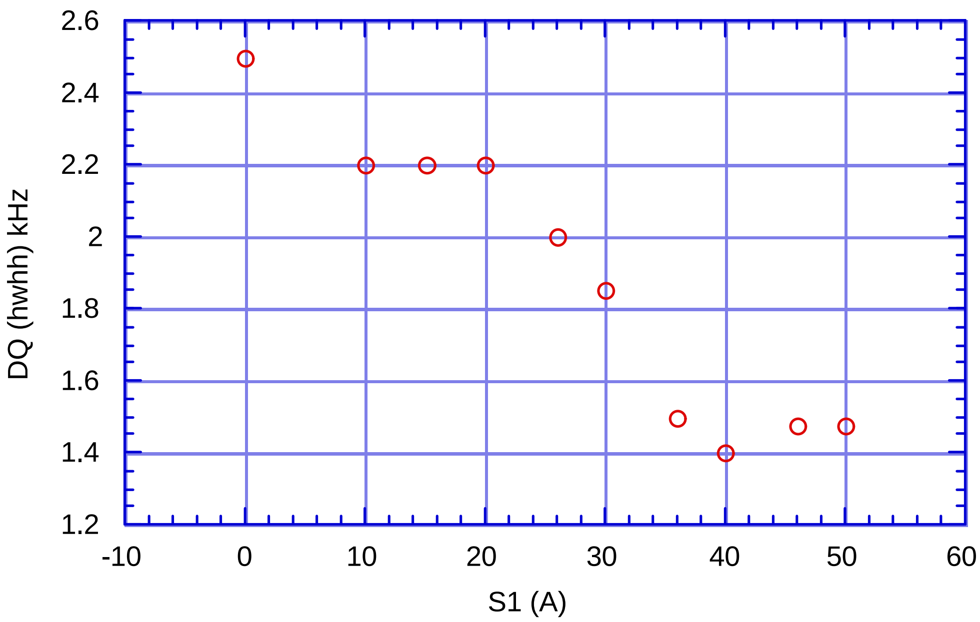


In any case all data indicate that the low frequency broad band longitudinal impedance is still in the range of 0.7 Ω. However assuming an increase of the effective longitudinal impedance by a factor of 2 and by means of the PW theorem and using the approximations for short bunches the transverse shunt impedance should have been doubled since 1994 amounting now to 0.250MΩ/m and with an average βv ~ 4 m gives R_T βv~1 MΩ. It is then conceivable to consider the increase of the effective transverse impedance as the combined result of the increase of both, transverse shunt impedance and cut-off frequency .

Assuming the ring has still a circular chamber geometry (only the 7% of the ring is flat) the combined data can be better understood when using the BBR model, if one assumes that the resonating frequency (usually chamber's cut-off) increases with the number of new flat sections. The present value of the cut-off frequency that fits better is about 3.5 GHz.

With these new developments we now examine the present instability situation:

1) Resistive wall; still not clearly observed. After the first installation of the stainless steel low gap chamber resistive wall-like signals were noticed but could not clearly identified as such. At that time we had also set the multibunch excitation at a minimum (high brilliance mode). What we have seen were excitations of the betatron side bands around the 500 MHz (SR driving frequency ; thus aliased to 0). However the excitations were not always there and not stronger at frequencies closer to 500 MHz but rather had a random pattern. Dependence on the filling pattern was measured and for a 30% filling the side bands disappear. A certain correlation with the orbit was also seen, not excluding thus the probably that the beam is probing some transverse impedance. A small detuning of the harmonic sextupole gave the



necessary damping and the effect is cancelled. In the graph above the tune incoherent frequency spread measured as a function of the S1 harmonic sextupole current for the multibunch case is shown. The optimum (for dynamic aperture) setting was 45 A whereas to damp, a 30 A setting was used. Possibly the the rate of the “instability” could be ~2π kHz for currents in the range of 200-300 mA. Adding all other chambers the situation did not change, furthermore it has been noticed that during the vacuum conditioning of the new chambers those lines appear pronounced indicating the possibility of fast ion effects. This subject will be studied in detail in the near future. The resistive wall impedance at 0.8 f_0 (= 0.93 MHz) assuming an equivalent chamber radius of 10 mm for the whole ring made of aluminium is 1.3 MΩ/m. Adding the 0.8 MΩ/m found previously, it is safe to assume a total maximum impedance of 2 MΩ/m which will give for 300 mA at 2 GeV a minimum growth time of ~1.4 ms corresponding to a coherent frequency shift of ~700 Hz. For that to be Landau damped the incoherent betatron frequency spread must be at least 1.4 kHz.

2) Mutibunch instabilities did not change behaviour. In fact for the last 2 years almost the same cavity temperature setting is used
3) Mode coupling. The mode m= 0 and m= -1 merging at 40 mA/bunch was seen with nearly zero chromaticities. (ESRF - ELETTRA collaboration, P. Kernel, R. Nagaoka, J.L.Revol and L. Tosi)
4) Head-tail instabilites: with slightly negative chromaticity no more than 12 mA can be stored.

Conclusions

As ELETTRA is diverging from the “perfect” machine (i.e. no users) so its impedance increases. At present the machine’s cut-off frequency is about 3.5 GHz and the transverse shunt impedance was doubled, being ~0.25 MΩ/m

Two more flat chambers will be installed and from the above data one expects the effective transverse impedance to further grow maybe up to 7 times that of 1994. Having a $\Delta fq/\Delta I$= 0.8 kHz/mA still gives a margin of up to some 20 mA/bunch before ELETTRA has to increase the chromaticity.