COLLECTIVE EFFECTS AT ELETTRA

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Abstract

Observation and analysis of various collective effects at ELETTRA are presented including transverse effects while in multibunch mode and in the absence of longitudinal instabilities, few bunch mode cancellation and ion trapping. Results of recent measurements of the ring impedance are shown and a comparison is made with earlier measurements.

1 INTRODUCTION

ELETTRA has entered its fourth year of routine operation for experimental use. For nominal operation an initial electron beam current of 320 mA with 90% filling of the maximum bunch number of 432 is injected at 1 GeV and subsequently ramped in energy to 2 GeV, the nominal operation energy for users. The large number of bunches and the high currents in the machine give rise to coupled bunch instabilities that however due to the large machine acceptance and damping mechanisms only seldom lead to a beam loss. In the majority of cases there is a deterioration of the photon beam quality accompanied by an increase of the lifetime.

ELETTRA can provide any number of bunches starting from single bunch. Up to now no user has been interested in single bunch operation, however lately many users have shown interest in the so called few bunch mode whereby from 4 up to 24 bunches are stored symmetrically in the machine. Due to the low impedance of the machine (longitudinally less than 0.7 Ω and transversely less that 200 kΩ/m) relatively high currents per bunch can be stored before single bunch effects strongly manifest themselves. It is interesting to notice that except for the usual bunch lengthening no other single bunch effects such as head tail and/or mode coupling are observed for single bunch currents up to 40 mA. Since users usually need currents below 20 mA per bunch, single bunch instabilities are not at present our main concern.

In the few bunch operational mode the machine in principle can suffer from multibunch instabilities. It has been shown during machine experiments that if the number of bunches is less or equal to 18 self cancellation of dangerous cavity high order modes (HOMs) can be achieved rendering the beam very stable. This mechanism fails in case of a larger number of bunches.

Other collective effects like ion trapping were never clearly observed under normal operating conditions due to the ultrahigh vacuum of ELETTRA. Evidence of ion trapping was confirmed only when during machine physics experiments heavy gases such as Ar were locally injected into the storage ring increasing the local pressure by at least two orders of magnitude.

2 ION TRAPPING

The ultrahigh vacuum of ELETTRA being of the order of 0.1 (without beam) to 1.5 nTorr (2 GeV, 320 mA) is a poor medium for ion trapping and effects were seen only during the commissioning (1993) when the vacuum was low. In order to study the machine and beam behaviour under high localised pressures from various gases, ranging from H to Ar, tests were made with a gas infusion system in one of ELETTRA's straight sections[1]. To study ion trapping we have locally injected Ar with lateral pumping to create a pressure bump of the order of 75 nTorr. Observation of beam characteristics such as beam size and lifetime were carried out for various beam fillings, currents and energies. The Figures 1, 2 below show some preliminary results especially on the increase of beam size as a function of filling and current.

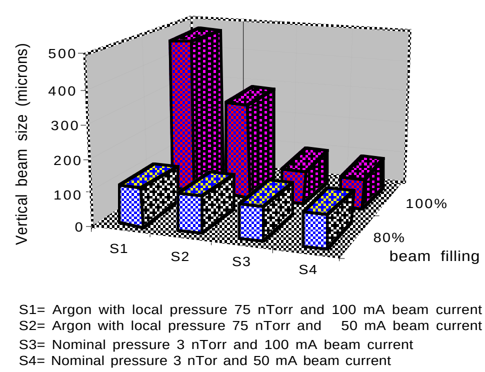


Figure 1: Vertical beam size as a function of current, filling and local gas pressure at 1 GeV.

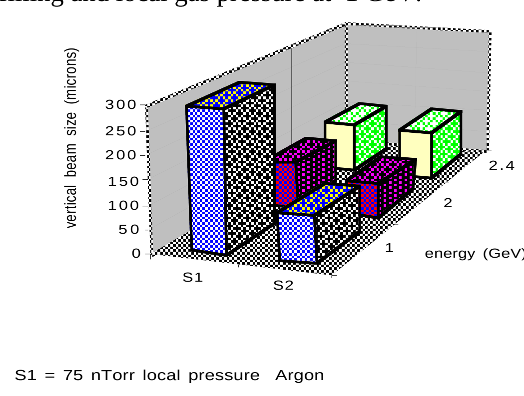


Figure 2: Vertical beam size as a function of current, energy and local gas pressure for 100% filling.

The increase in vertical beam size with beam current that occurs only with high local pressure and 100% filling and which is large at low energy, is evidence of ion trapping. No change in the beam spectra neither any particular low frequency beam oscillations were observed. While injecting we encountered a temporary saturation at about 100 mA in 100% filling but no sudden total or partial beam losses.

3 TRANSVERSE MULTIBUNCH INSTABILITIES

The control of multibunch instabilities via temperature tuning at ELETTRA has been described in [2, 3]. Although it cannot fully compete with feedback systems that are to be built [4] the cavity temperature control has given very good results. In general we can temperature tune the cavities to a setting where almost no longitudinal excitation exists for a certain current range.

In the complete absence of longitudinal instabilities, achieved at 2 GeV and for beam currents of the order of less than 150 mA, transverse instabilities may manifest themselves due to the lack of Landau damping. In the majority of cases the machine suffers a deterioration of beam quality rather than a beam loss. These transverse instabilities are either generated by transverse higher order modes of the cavities (TCBI) or are resistive-wall like that cannot be cured by temperature tuning. In case of TCBIs cavity temperature tuning can also be used to control the excitation since total TCBI elimination is possible with the present settings though with very narrow margins. To additionally minimise transverse effects a betatron tune shift is induced [5] and up to 150 mA the machine is instability free.

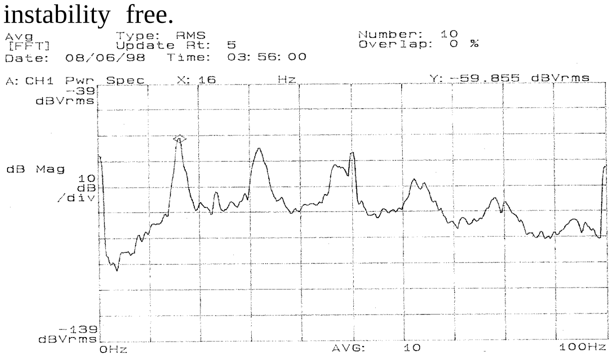


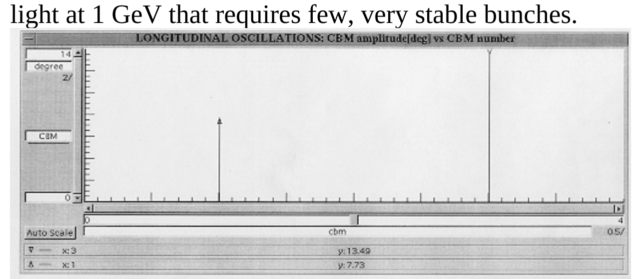
Figure 3: Low frequency beam spectrum in the absence of longitudinal but in the presence of strong TCBI excitation at 2 GeV and 130 mA.

Studying the beam dynamics in the presence of only transverse instabilities, preliminary measurements are made with only the transverse mode n=318 excited. An interesting observation from these measurements is the first evidence of low frequency oscillations of 16 Hz and -60 dB in the absence of longitudinal excitation and in the presence of only the n=318 transverse HOM (Figure 3). Spectra taken after the mode was shifted/damped confirmed the fact that the n=318 was generating the oscillations. More studies will follow to better understand this effect.

4 FEW BUNCH INSTABILITIES

ELETTRA can be filled to any combination of bunch number including strange fillings such as half ring continuous filled accompanied with a single or few bunch in the empty other half. Such a filling is currently under study.

Users lately became interested in the few equidistant bunch operation. With a small number of bunches fewer coupled bunch modes are involved. As the number of the bunches decreases it may well occur that some mode cancellation occurs rendering the beam very stable even at 1 GeV. Beam stability at 1 GeV is not our main concern, but this is relevent for the SR FEL[4] project for coherent light at 1 GeV that requires few, very stable bunches.



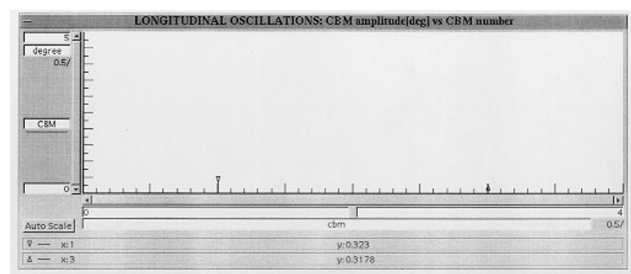


Figure 4: Upper picture (4a) shows the longitudinal spectrum where the coupled bunch modes 1 (8°) and 3 (13.5°) excited by HOMs. Lower picture (4b) shows the same modes when mode cancellation occurs (both modes below 0.5°) with 4 bunches at 1 GeV.

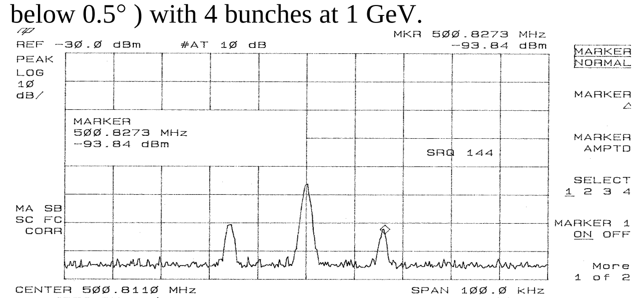


Figure 5: Mode cancellation for four bunches at 1 GeV (sideband at -94 dBm).

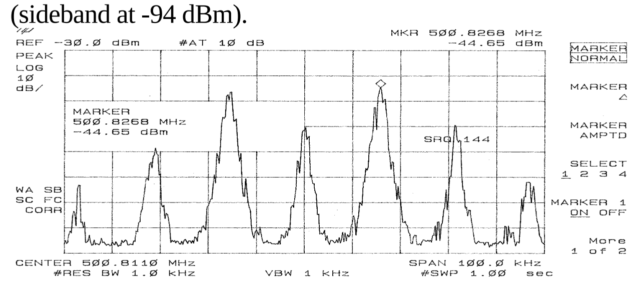


Figure 6: Mode cancellation breaks for a different filling pattern (6 bunches) (side band at -45 dBm).

The probability of CBM (coupled bunch mode) cancellation is higher when fewer bunches are stored. This happens when a coupled bunch mode n samples the HOMs of the cavities in such way that the sum of the growth rates over all HOMs becomes negative or zero. After careful tuning of the temperature of the cavities longitudinal mode cancellation has been observed for 6 and 18 bunches at 2 GeV, but most important for 4 equidistant bunch operation at 1 GeV with a total current of 100 mA, as shown in Figures 4 and 5. In Figure 6 the break down of the cancellation is shown when 6 bunches with the same total current were injected.

5 SINGLE BUNCH MEASUREMENTS

The transverse impedance can be extracted from measurements of the betatron frequency shifts with current. Measurements for 2.52 MV peak accelerating voltage at 3 different energies are shown in Figure 7.

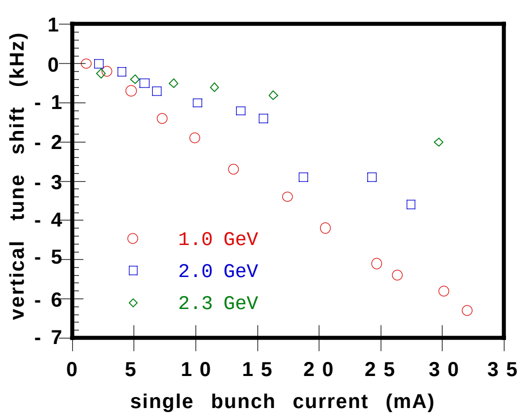


Figure 7: Variation of vertical tune with single bunch current at 3 different energies; 1 , 2 , 2.3 GeV

From the initial slope of a quadratic fit (Figure 7), the effective transverse impedance can be derived using the relation:

$$\left(\frac{df_\beta}{dI}\right) = \frac{f_0\, R\, \beta}{2\pi\, \sigma\, E/e}\, Z_{T\,eff}$$

At short bunch lengths the impedance is reduced due to the incomplete overlapping of the beam spectrum with the impedance curve. For a gaussian distribution the reduction is given by the relation $|Z_v|_{T\ eff} = 2(\omega_r\, \sigma_\tau\,)^2\, |Z_v|_T$ where ω_r is the resonance frequency of the Q=1 resonator model and σ_τ is the bunch length. For the measured bunch length at small currents, i.e. σ_τ=18.5 ps at 1 GeV and using the theoretical values for the other energies the transverse broad band impedance is found:

$|Z_v|_{T\ \mathrm{from\ 1.0GeV\ data}}$ = 150 kΩ/m

$|Z_v|_{T\ \mathrm{from\ 2.0GeV\ data}}$ = 176 kΩ/m

$|Z_v|_{T\ \mathrm{from\ 2.3GeV\ data}}$ = 180 kΩ/m

to be compared with $|Z_v|_T$ =130 kΩ/m [6], the value found during the early days of ELETTRA commissioning.

In the mean time six out of twelve straight sections have been replaced by a low gap vacuum chamber thus increasing the chambers' cut off frequency from 2.2 GHz (corresponding to an effective radius b =23 mm) to 2.6 GHz (corresponding to an effective radius b =18 mm). Using the approximation $|Z|_T = (2R/b^2)\ |Z/n|_0$ for a circular geometry the broad band longitudinal impedance found is < 0.70 Ω. Measurements of bunch length in 1997 revealed a broad band longitudinal impedance of 0.6 Ω while the measurements of 1994 [6] gave an impedance of 0.75 Ω. As previously, no significant variation of the horizontal and synchrotron tune with current could be observed.

6 CONCLUSIONS

Multibunch instabilities at ELETTRA can be controlled to a satisfactory level by simple temperature tuning of the rf cavities. Temperature tuning can also be used to almost completely eliminate longitudinal instabilities (in fact for currents below 150 mA complete elimination has been achieved) and/or to selectively excite a transverse mode. In the presence of only transverse excitation preliminary evidence of low frequency oscillations have been observed. In the few bunch mode by carefully tuning the cavities mode cancellation and thus stability even at 1 GeV has been achieved.

Ion trapping was observed by creating a pressure bump in a straight section. Filled with Argon the local pressure was as high as 75 nTorr. Further use of the experimental set up [1] will help in better understanding the beam and machine behaviour under locally elevated pressures of various gases.

Measurements indicate that the transverse impedance of the ring has increased by ~30% since first commissioning. Such an increase may be attributed to the installation of many low gap vacuum chambers.

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