OBSERVATION OF COUPLED BUNCH INSTABILITIES IN ELETTRA

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Abstract

Coupled bunch instabilities (CBI) are the most harmful instabilities in ELETTRA. Longitudinal excitations generate an increase in effective momentum spread which has a particularly adverse effect on the higher harmonics of the light spectrum. Their intensity is reduced and their width is increased. The excitation level of CBIs can be controlled by tuning the temperature of the cavities. We can differ between three different regimes. For a medium and high excitation level, a relaxation oscillation is observed. Due to the strong driving term of the longitudinal CBI the oscillation amplitude increases very quickly until it reaches the regime of Landau damping, where the motion decoheres. The blown up bunch is then damped down in dimension by radiation damping, until the process starts again from the beginning. For a small excitation level an extension of the phase space dimensions occurs and a coherent longitudinal oscillation is observed. Only in the regime of complete or nearly complete compensation of longitudinal CBIs, are transverse effects observed. These are again compensated by temperature tuning of the cavities, as well as tune and chromaticity adjustment. In addition a higher order mode shifter is used to shift dangerous parasitic cavity modes away from the operating region of the cavity.

1 INTRODUCTION

ELETTRA has now entered the regime of routine operation for experimental use [1]. The compensation of CBIs by means of cavity temperature tuning is in the meantime a well established operation procedure [2].

For nominal operation at 2 GeV, an initial beam current with 80% filling of the maxium bunch number of 432 is accumulated in the storage ring. The high number of bunches gives rise to CBIs by interaction with the higher order cavity modes (HOM).

The coupling of the sharp, high Q resonances of the cavities to the beam harmonics can be avoided by a proper setting of the cavity temperatures. In addition, remote controlled mechanical HOM-tuners have been tested which allow a precalculated shift of dangerous cavity modes away from coupled bunch modes [3]. Different loading conditions of the cavities, for changes in current and energy (during ramping from 1 GeV to 2 GeV as part of the injection procedure) can be tuned in this way very easily.

2 OBSERVATIONS

The CBI excitation level can be verified by measuring the coupled bunch mode amplitudes. An automatic procedure has been developed which constantly measures the oscillation amplitudes and displays them in a graph as shown in figure 1.

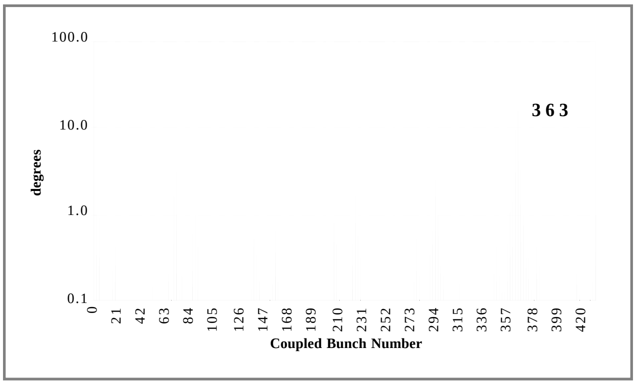


Figure 1: Coupled bunch mode (CBM) amplitudes for a medium excitation (250 mA, 2 GeV). Excited is CBM 363 by the mode L3 [4] of cavity S9 at 53°C.

The horizontal axis labels the various 432 coupled bunch modes, whereas the vertical one indicates the longitudinal extension in degrees.

According to the different qualitative behaviour of the beam, we can distinguish between three different regimes concerning the MBI excitations.

2.1 Landau Damping Regime

In this case the growth rate of CBI excitation is above the radiation damping rate. For strong excitations, as for instance for the lowest longitudinal cavity mode, the amplitude increases very quickly and enters in a strongly nonlinear regime where the motion then very rapidly decoheres. The oscillation has the typical form of a sawtooth, as demonstrated in figure 2 where, the signal of one Beam Position Monitor (BPM) button is shown.

The variation of the signal amplitude is caused by the sensitivity of the signal on the longitudinal bunch dimensions, which means the zero order Bessel function $J_0(2\pi\lambda_{RF}/\sigma_s)$ of the 500 MHz component of the beam current spectrum (this is not strictly true, since the distribution function is not Gaussian anymore).

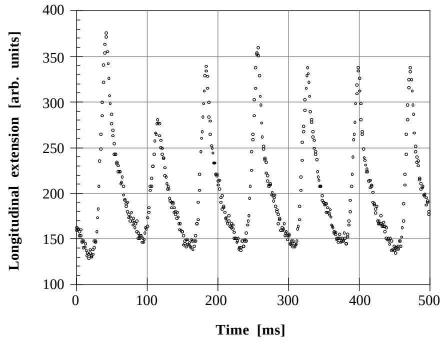


Figure 2: BPM button signal during the relaxation oscillation.

The effect was first observed on a low frequency spectrum analyzer, as a larger frequency peak and its harmonics, which corresponds to the average time interval between two processes, as shown in figure 2, and a broadening of the spectrum in the frequency range close to the radiation damping frequency (figure 3).

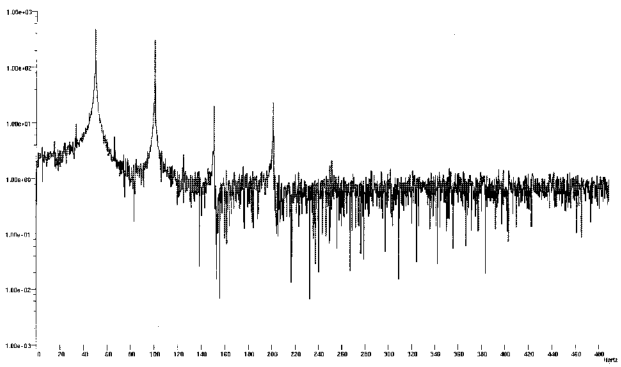


Figure 3: Low frequency oscillations observed during the relaxation oscillation.

Another indication for CBI excitation is the use of the orbit displacement signal measured in ELETTRA, which was initially a puzzle to interpret. From the beginning a variation of the orbit signal taken from any BPM could be observed under certain beam conditions. Eventually the variation could be related to particular sampling characteristics of the BPM signal. The four buttons are read consecutively by the same detector sampling with a rate of 1 KHz. In the case of a sawtooth excitation, the signal was (for most of the time) sampled at the slow decaying slope of figure 2, corresponding to different bunch lengths. This introduced an error which simulated an orbit displacement, and therefore an oscillation of the orbit displacement around a central value. The rms-value of the distribution is a measure for the excitation level of the longitudinal CBIs. At the beginning an averaging of the BPM readings was used in order to get stable conditions. A more rigorous solution of this problem was then achieved by changing the sampling rate to 20 KHz.

For smaller CBI driving terms, i.e. smaller growth rates, the amplitude does not immediately sample the nonlinear regime, as shown in figure 4.

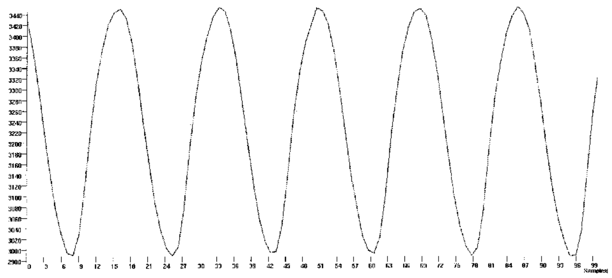
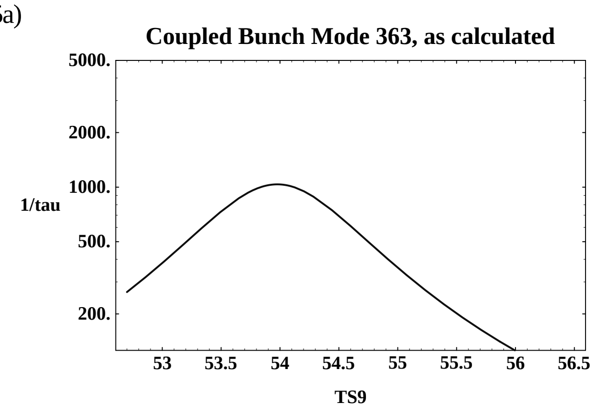


Figure 4: BPM button signal for medium CBI excitation.

Due to the difference in slope, the beam starts to decohere in the weakly nonlinear regime. The once started decoherence reduces the driving term of the coupled bunch instability and therefore the growth diminishes. After having reached full decoherence, radiation damping brings down the beam to the original size where the process starts from the beginning. The Fourier analysis of this motions is dominated by a frequency peak which corresponds to the inverse of the time interval between two subsequent events. Going to even smaller excitation levels, the saturation is reached earlier, the time interval is decreased and consequently the frequency shifted to higher values, as shown in figure 5.

5a)



5b)

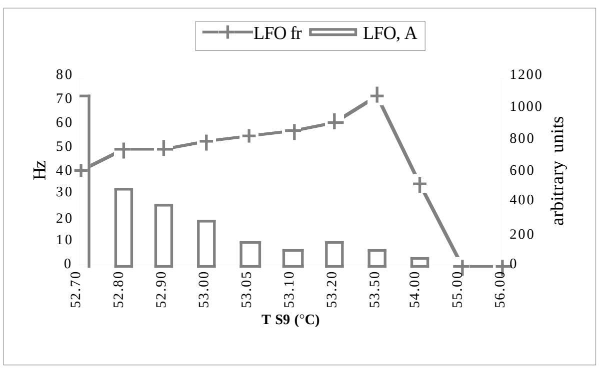
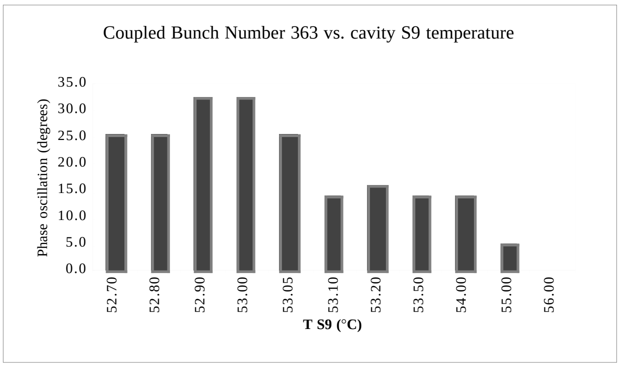


Figure 5: Growth rate of Coupled Bunch Mode 363 (for 150 mA at 2 GeV) as a function of cavity temperature (a) and the corresponding change in frequency and amplitude of the relaxation oscillation (b). In figure (b) also the lifetime is reported.

A similar correlation to the growth rate of the cavity mode can be observed for the amplitude of the coupled bunch oscillation and the rms value of the orbit fluctuation measured by the BPMs (figure 6).

6a)



6b)

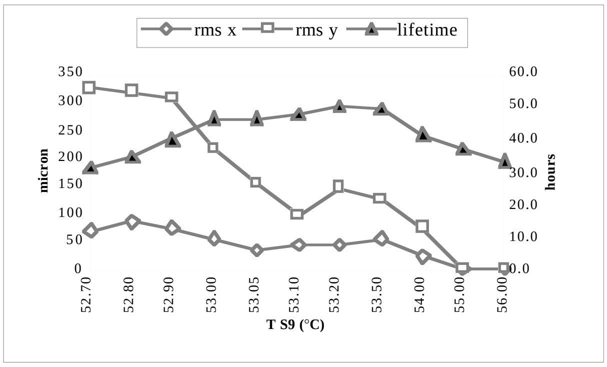


Figure 6: Amplitude (measured) of mode 363 (a) and fluctions of the orbit reading (b) as a function of cavity temperature.

A theoretical and quantitative description of this regime is given in [4].

2.2 Radiation Damping Regime

For small CBI driving terms, the rate of radiation damping is sufficient to combat the longitudinal CBI growth, and the amplitude does not reach the regime of decoherence. No low frequency oscillations are observed.

In this case the bunch extends in phase space and performs some residual coherent oscillations at its coupled bunch mode frequency. In figures 5 and 6 this regime starts from a cavity temperature of 55 °C.

Usually ELETTRA is on purpose operating in the radiation damping regime, in order to reduce the particle density and consequently to increase the Touschek lifetime from 9 hours (for full compensation at 2 GeV with 250 mA) to 24 hours.

2.3 Compensation Regime

Only in the state of full longitudinal compensation (or sufficiently small excitation), transverse CBIs become visible. They can be partly corrected by chromaticity and tune variation.

A satisfactory compensation can again be achieved by tuning the cavity temperature and using the HOM-shifters of the cavities to displace dangerous transverse modes.

3 CONCLUSIONS

Observations of Coupled Bunch Instabilities in ELETTRA have been reported. One can distinguish between three different regimes for the longitudinal excitation, (i) the Landau damping regime where a relaxation oscillation is observed, (ii) the radiation damping regime for weak excitations where the longitudinal phase space occupied by the beam is increased and a coherent oscillation is observed and (iii) the regime of full longitudinal compensation, where transverse effects become visible.

Coupled Bunch instabilities in ELETTRA may be avoided by carefully choosing the temperature of the rf-cavities.

REFERENCES

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