IMPROVED METHODS OF MEASURING AND CURING MULTIBUNCH INSTABILITIES IN ELETTRA

M. Svandrlik, A. Fabris, C. Pasotti, Sincrotrone Trieste, Trieste, Italy

ABSTRACT

Coupled Bunch Instabilities (CBI) are cured in ELETTRA by high precision temperature tuning of the RF cavities. The growth rates of the longitudinal CBIs are computed as a function of the cavity temperature in order to identify intervals where the growth rates of all modes are below the radiation damping rate. The computed stability intervals can easily be verified on the machine thanks to an automatic measuring system of the coupled bunch mode spectrum. Different oscillation amplitudes can be selected on the machine just by setting different cavity temperatures. A complete suppression of the longitudinal CBI has been obtained with greater ease after the installation of a Higher Order Mode Frequency Shifter (HOMFS) which provides an additional degree of freedom for the optimization procedure. Once longitudinal CBIs are compensated, transverse effects may be observed, which then require further optimizations.

1 INTRODUCTION

CBIs have been cured in ELETTRA since the beginning of operation by temperature tuning of the 500 MHz cavities [1]. The growth rates of all Coupled Bunch Modes (CBM) which may drive a cavity Higher Order Mode (HOM) are computed as a function of the cavity temperatures. The temperatures of the four RF cavities of the storage ring are then set to a value where all CBM are stable. The available tuning range is 40-70 °C.

In the users' operation mode a beam current of 250 mA is stored in ELETTRA at the injection energy of 1.0 GeV and then ramped to 2.0 GeV. 80% of the 432 buckets are filled in a contiguous way. Longitudinal CBI can be easily observed if the cavity temperatures are not properly set. They are not destructive, but, if they drive a strong impedance, they can lead to low frequency oscillations [2] with an increase in energy spread and consequently a deterioration of the light quality [3]. However temperature tuning allows to select the CB oscillation amplitudes, which allows operate the machine under controlled CBI conditions, satisfying the users' demand for high lifetime with minor effects on the light quality.

CBI are generated in ELETTRA by interaction with the coupling impedances of those parasitic cavity modes resonating below the cut-off frequency of the cavity beam tubes. In the longitudinal case cavity HOMs L1, L3, L5, and L9 have been observed as the most harmful.

It may happen that a cavity doesn't have any stable temperature in the tuning range or that the stable interval is too narrow. This was the case for storage ring cavity S3. The HOM L1 was unstable over almost the whole tuning range [1]. To overcome this problem a HOMFS has been installed on this cavity. Stable intervals for a total width of 7 °C could then be found on cavity S3.

When longitudinal stability is achieved, by interaction with the transverse coupling impedance of the cavity transverse instabilities are excited, demonstrating in this way the need for a HOMFS also on the other cavities.

2 LONGITUDINAL INSTABILITIES

2.1 Growth rate computation

The formula used to compute growth rates of longitudinal CBM as a function of cavity temperature has been presented elsewhere [1]. A typical result of this computation is shown in fig. 1 for cavity S9. The growth rates are calculated for the first nine HOMs for 250 mA, 2.0 GeV. The temperature axis crosses the growth rate axis at 126 s^{-1}, which corresponds to the longitudinal radiation damping rate. By tuning the cavity temperature so that the growth rate of all CBM stays below the radiation damping limit, longitudinal stability is achieved. Stability intervals in cavity S9 range from 50.5 to 52 °C and from 57 to 59 °C. The contribution of the coupling impedances of the other three cavities, S2, S3, S8 is also taken into account in the rates calculated in fig. 1. At the temperatures chosen for them in this calculation, 66.0, 66.0, 44.0 °C, no CBM is excited by a parasitic cavity mode above the radiation damping limit (otherwise lines parallel to the temperature axis would appear in fig. 1, not depending on TS9).

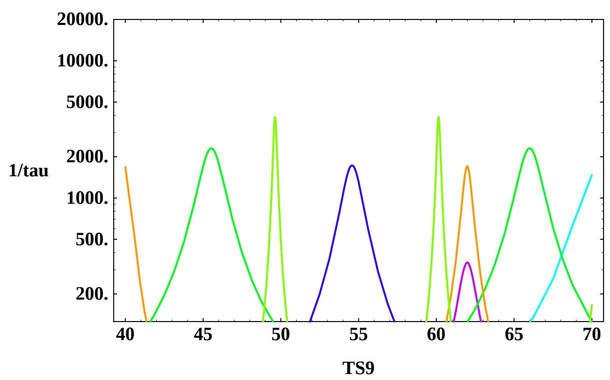

Figure 1: Longitudinal growth rates vs. cavity S9 temperature

In fig. 1 CBM 86 is driven from 42 to 50 °C by the coupling impedance of cavity HOM L5 at 1598.5 MHz. The narrow band peak around 50 °C is CBM 104 driven by HOM L9 at 2118.9 MHz. The temperature coefficient τ for HOM L9 is 110 kHz/°C, therefore the peak is very narrow in temperature. Due to the large τ the interaction with the next CBM, number 103 (shifted by f_0 = 1.1566 MHz in frequency), is very close in temperature, at 60 °C. Thus the mode with the largest τ, L9, defines the maximum possible width of a stable interval. For 250 mA, 2.0 GeV it is about 10 °C. From 52 to 57 °C CBM 363 is excited above the stability limit by cavity HOM L3 at 1419.2 MHz. Finally from 62 to 70 °C we find the next CBM driven by mode L5, number 85.

2.2 The fixed HOMFS

Caused by the final mechanical tolerances, the HOM spectrum is different from cavity to cavity. It may happen that there are no stable intervals within the temperature tuning range of a specific cavity. Particularly critical is the position of the first longitudinal mode L1 (TM-011 like, at 950 MHz). It has the strongest shunt impedance and the lowest temperature coefficient, τ = 12 kHz/°C. Thus the corresponding CBM is unstable over a wide range, 20-40°C. Interaction with the next CBM happens roughly 100 °C away in temperature. For cavity S3 the peak of CBM 389 was at 55.0 °C, exactly in the middle of the 30 °C tuning range, the only stable window at 41.0 °C was very small (less than 1.0 °C at 250 mA, 2.0 GeV).

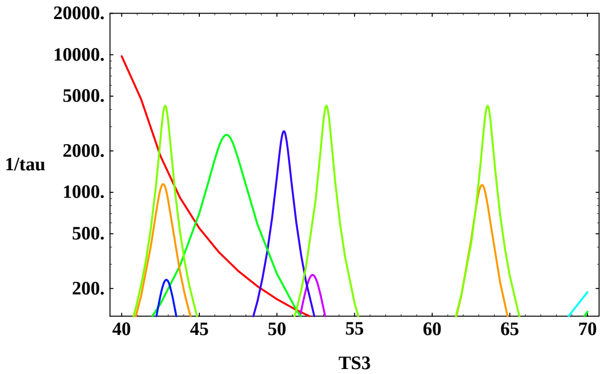

Figure 2: Longitudinal growth rates vs. cavity S3 temperature after installing the HOMFS

The solution to this problem was the installation of a fixed cylindrical plunger on one of the equatorial ports of the cavity. This causes a frequency increase on the accelerating mode L_0 of more than 300 kHz. After tuning L_0 back to 499.654 MHz, by compressing the cavity on the axis with the tuning cage, all HOMs, even those with low field in the equatorial region, show a consistent frequency shift. L1 is shifted by ~300 kHz, i.e. ~25 °C, and the width of the stable windows is improved (fig. 2).

2.3 Measurements on the Machine

The temperature tuning method allows to select many different levels of CBI excitation. A different number of HOMs can be driven by the beam at different impedance strengths, from the peak down to stability. Frequent and rapid acquisition of the longitudinal beam spectrum is then required. The beam signal is picked-up from an annular electrode and measured with a spectrum analyzer in the 500-750 MHz aliased frequency range. The amplitude of the phase oscillation is thus available for all 432 CBM. The acquisition process is fully automatic via a PC. The beam spectrum in fig. 3 is measured at 2.0 GeV, 250 mA at following cavity temperatures:
S2=66.0 °C; S3=66.0 °C; S8=44.0 °C; S9=53.0 °C.

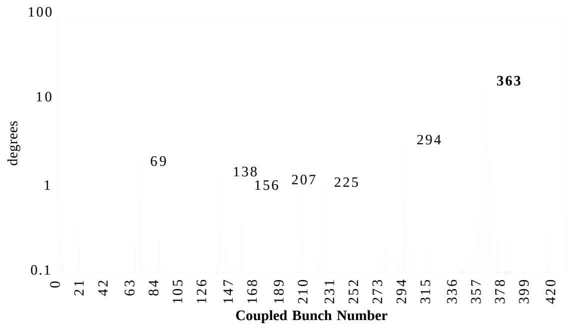

Figure 3: Longitudinal beam spectrum as measured on the machine at 250 mA, 2.0 GeV. TS9 is 53.0 °C

The temperatures of cavities S2, S3, S8 are the same as in fig. 1. Thus if the temperature of cavity S9 is 53.0 °C only the CBM 363 should be excited. This is in excellent agreement with the measurement in fig. 3. The other CBM showing a significant oscillation amplitude are the complementary ones: 69, 138, 207, 276, etc. and 363, 294, 225, 156, etc. (M=432)

In the region 53-57 °C various effects on machine operation can be observed, for example increased bunch length and energy spread leading to an increase in lifetime, and also low frequency oscillations (LFO's) [2,3]. Furthermore at 53.0 °C we do not observe any transverse instability. When TS9 is decreased to 52.0 °C, the coupling impedance of HOM L3 is reduced and the blown up beam recovers the coherent motion. Still we do not see any transverse motion. Below 52.0 °C the CBM 363 stabilizes, which means that longitudinal stability is reached, but the horizontal CBM 318 is strongly excited.

3 TRANSVERSE INSTABILITIES

The frequency lines for the transverse CBM p,n are at ω_{pn} = (pM+n+mQ_s+kQ)ω_0 (in the following m=0, k=1) for M uniform spaced bunches. Following the Sacherer formalism, if the CBM p,n is driven by the narrow band coupling impedance $Z_k^{\perp}(\omega_{pn})$ of the k-th deflecting (dipole) mode in an RF cavity, the instability growth rate for beam current I_b can be approximated by

$$1/\tau_\perp = \frac{\beta_\perp I_b \omega_0}{4\pi c(E/e)} Re(Z_k^\perp(\omega_{pn}))\, e^{-\left(\frac{\omega_{pn}}{\omega_0}\frac{\sigma}{R}\right)^2} \quad , \quad (1)$$

where $\beta_\perp$ is the betatron function at the cavity location, E the energy, c the speed of light, ω_0 the revolution frequency, R the machine radius, σ the bunch length. The real part of the transverse impedance $Z_k^\perp$ in (1) is

$$R_k^\perp(\omega_{pn}) = \frac{\omega_k^2}{\omega_{pn}} \frac{\left(\frac{R}{Q}\right)_{\perp k} \cdot Q_k}{1 + Q_k^2\left(\omega_{pn}/\omega_k - \omega_k/\omega_{pn}\right)^2} \quad (2)$$

In the present case $(R/Q)_\perp$ values are calculated using URMEL-T [4]. As in the longitudinal case [1], the resonant frequency ω_k of the cavity HOM can be computed at any temperature T, RF frequency ω_{RF} and beam loading Δf_{BL}, from the frequency ω_{k0} measured on the cavity at temperature T_0 and ω_{RF0}

$$\omega_k = \tau_k(T-T_0) + \varphi_k\left[(\omega_{RF} - \omega_{RF0}) - \Delta f_{BL}\right] + \omega_{k0}\ . \quad (3)$$

The temperature coefficient τ_k, in kHz/°C, and the HOM frequency change for unit accelerating mode frequency change, φ_k, are measured. By substituting ω_k in (2) by relation (3), the growth rate (1) for the transverse CBM p,n becomes a function of the cavity temperature, for given RF frequency and beam loading parameter.

The strongest coupling impedance belongs to the third parasitic cavity dipole mode, T3 at 1114 MHz [4]. Using formula (1), the growth rate for the driven Horizontal CBM, HCBM 318, as a function of cavity S3 temperature is plotted in fig. 4 (150 mA, 2.0 GeV). The vertical axis origin is the horizontal radiation damping rate, of 96 s^{-1}.

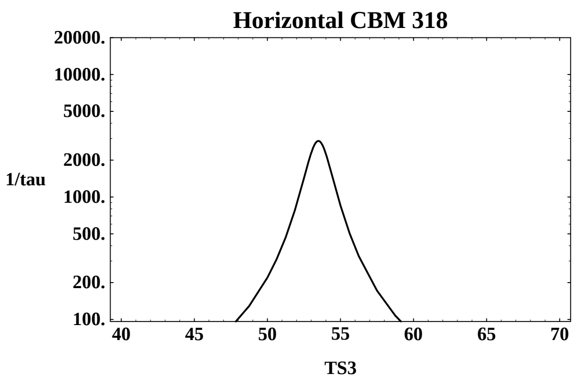

Fig. 4: HCBM 318 growth rate vs. TS3 as computed.

We have checked the calculation by picking up the transverse beam spectrum from one of the stripline electrodes. The amplitude of the lower betatron sideband at 615 MHz, belonging to the frequency spectrum of the HCBM 318, has been measured on the spectrum analyzer. The result is shown in fig. 5 for 150 mA at 2.0 GeV.

When TS3 is 50-52 °C strong longitudinal LFO's are observed due to the intense driving force (fig. 2) and transverse effects are absent, even if the calculation for the nominal bunch density in fig. 5 predicts them.

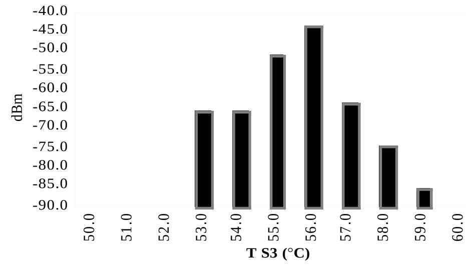

Figure 5: HCBM 318 amplitude as measured vs. TS3.

At 53-54 °C the longitudinal driving force is reduced and the HCBM 318 appears. Longitudinal stability is achieved from 55 to 59 °C where the HCBM 318 amplitude reaches its maximum and decreases in good agreement with the curve in fig. 4. When TS3 is 53-59 °C, 250 mA of beam current cannot be stored. If we store 250 mA for TS3 at 52 °C and then change the temperature to 53 °C the beam current drops down to typically 130-150 mA. The rest of the scan shown in fig. 5 can then be performed without loosing more beam current. Large horizontal oscillations can be observed on the synchrotron radiation profile monitor. Thus the large longitudinal stable interval on cavity S3 shrinks to a narrow window at 66.0-68.0 °C due to the transverse coupling impedance of HOM T3.

Transverse effects are caused also by cavity S9. In fact, the beam is driven by the transverse coupling impedance of the parasitic modes T3 and T5 in cavity S9 close to the longitudinal stable windows shown in fig. 1. Cavities S2 and S8 are very quiet with large stability windows.

As for the HOM L1 the parasitic cavity mode T3 is rather large in temperature (fig. 4) but well spaced from one CBM to the other (τ = 15 kHz/°C, Q ~36000). To achieve stability it must be shifted outside the temperature tuning range. An adjustable HOMFS has thus been designed, to increase the shifting range for the HOM frequencies. It will be installed in the near future on both cavities S3 and S9. Measurements on a spare cavity and simulations [4] show that the transverse coupled bunch oscillations should be eventually stabilized.

REFERENCES

[1] M. Svandrlik et al., "The cure of MBI in ELETTRA", in *Proceedings of the 1995 Particle Accelerator Conference*, Dallas, Tx, USA, May 1995.

[2] R. Nagaoka, A. Wrulich, "Modelling of Low Frequency Longitudinal Coupled Bunch Oscillation", this conference.

[3] A. Wrulich et al., "Observation of Multibunch Instabilities in ELETTRA", this conference.

[4] M. Svandrlik et al., "Simulation and Measurements of HOM of the ELETTRA Cavities in view of CBI Compensation by Temperature Variation", this conf.