COUPLED BUNCH INSTABILITY CALCULATIONS FOR THE ANKA STORAGE RING

A. Fabris, C. Pasotti, M. Svandrlik, SINCROTRONE TRIESTE, Trieste, Italy

Abstract

The RF accelerating system for the 2.5 GeV ANKA storage ring will be based on four ELETTRA-type cavities. Coupled Bunch Instabilities (CBI) caused by the interaction between the electron beam and the cavity Higher Order Modes (HOM) will be avoided by the same HOM frequency shifting technique that is used successfully in ELETTRA, by precise cavity temperature tuning together with the movement of a plunger (the HOM Frequency Shifter). Computations are presented here for longitudinal and transverse coupled bunch instabilities. The results show the possibility of storing beam current intensities as large as 400 mA at 2.5 GeV.

1 INTRODUCTION

Four single cell ELETTRA type cavities will be installed on the ANKA storage ring [1]. Beam stability and beam lifetime, along with reliability of operation, will be among the major issues for this source, which is industrial users' oriented. These parameters can be heavily affected by beam instabilities, therefore the cure of the CBI caused by beam-cavity interactions has been one of the main topics in the machine design.

Given the satisfactory results obtained in the cure of this kind of CBI at ELETTRA by applying HOM frequency shifting technique [2], it was decided to follow a similar approach even at ANKA.

Table 1: ANKA parameters

Parameter	Design Value
Energy, E/e	2.5 GeV
Momentum Compaction, α	8.1 10^{-3}
Beam Current, I_b	400 mA
RF frequency, f_{RF}	499.652 MHz
Revolution frequency, f_0	2.7155 MHz
Harmonic number, h	184
Long. Rad. Damp. Time, τ_ε	1.45 ms
Hor. Rad. Damp. Time, τ_x	3.08 ms
Ver. Rad. Damp. Time, τ_y	2.96 ms

Considering the ANKA parameters listed in Table 1 it is quite evident that the HOM frequency shifting technique can be even more successful than it has been at ELETTRA. In fact thanks to the larger energy (2.5 instead of 2.0 GeV) and to the larger revolution frequency (2.72 MHz instead of 1.57 MHz), and the accordingly faster damping times, the available space between two subsequent beam spectrum lines is expected to be larger. An evaluation of the stability probability is however required, together with an analysis for lower energies.

The beam is extracted from the ANKA booster synchrotron at 500 MeV and injected into the storage ring, where it is ramped to 2.5 GeV. At lower energies the damping times are so low that the stability threshold current is expected to be, for almost all HOMs', well below 1 mA. Operational experience at ELETTRA, where beam is injected at 1.0 GeV and ramped to 2.0 GeV, shows the necessity of introducing a Landau damping mechanism to combat the harmful transverse instabilities. Beam storing is possible and current losses during the first part of energy ramping are avoided by properly exciting a longitudinal coupled bunch mode at injection energy.

2 LONGITUDINAL CBI

When curing CBI's by mode frequency shifting techniques, there are two important parameters. The first is the threshold current for a given HOM, which is an indication on how harmful a HOM can be when the beam spectrum hits exactly the HOMs' resonant frequency. The second is the minimum frequency shift which is needed to avoid the unstable interaction region, thus stabilizing the CBI [3].

2.1 Threshold Currents

For N uniform filled and equally spaced bunches the growth rate for the longitudinal Coupled Bunch Mode (CBM) number n, excited by a cavity HOM with shunt impedance $R_{\|}$, is given by

$$\frac{1}{\tau_{\|}} = \frac{\alpha \cdot I_b}{2Q_s\left(E/e\right)} f_{p,n} \cdot R_{\|}\left(f_{p,n}\right) \qquad (1)$$

where $f_{p,n}$ is the frequency of CBM n,

$$f_{p,n} = \left(p \cdot N + n + Q_S\right) \cdot f_0,$$

Q_S the synchrotron tune and p an integer. If we take into account only the natural damping given by the emission of synchrotron radiation, the stability condition for that CBM is defined by

$$\frac{1}{\tau_{\|}} < \frac{1}{\tau_\varepsilon} \qquad (2)$$

where $1/\tau_\varepsilon$ is the growth rate of the synchrotron oscillations. The maximum beam current which can be stored still keeping CBM n stable is then limited by

$$I_b < \frac{1}{\tau_\varepsilon} \cdot \frac{2Q_s\left(E/e\right)}{\alpha} \cdot \frac{1}{f_{p,n} \cdot R_{\|}(f_{p,n})} \qquad (3)$$

If the CBM frequency $f_{p,n}$ is close to the resonance frequency of the cavity HOM f_r, i.e. the frequency difference $\Delta f=(f_{p,n}-f_r)$ is much smaller than f_r, the shunt impedance can be approximated by

$$R_{||}(\Delta f) \cong \frac{\left(R/Q\right) \cdot Q}{1+4Q^2 \cdot \left(\Delta f / f_r\right)^2} \qquad (4)$$

with Q the quality factor and R/Q the shape factor of the considered cavity HOM. For $f_{p,n}=f_r$, $\Delta f=0$ and the HOM impedance seen by the CBM is a maximum. The stability condition (3) then becomes

$$I_b^{max} < K_L \cdot \frac{1}{f_r \cdot \left(R/Q\right) \cdot Q} \qquad (5)$$

where the meaning of K_L is obvious by comparing relations (3) and (5). K_L gives a quantitative indication of the sensitivity of a given storage ring to longitudinal CBI. For example, K_L(ANKA)~0.8*K_L(ELETTRA), which means that, for the same HOM impedance, the threshold current for a CBI is lower in ANKA than in ELETTRA. In fact, at 2.5 GeV, the threshold current for HOM L1, when $f_{p,n}=f_r$, is 5.0 mA in ANKA while it is 6.4 mA in ELETTRA. Since the energy will be ramped in the ANKA storage ring from 500 MeV up to 2.5 GeV, it is essential to verify the behaviour also at lower energies.

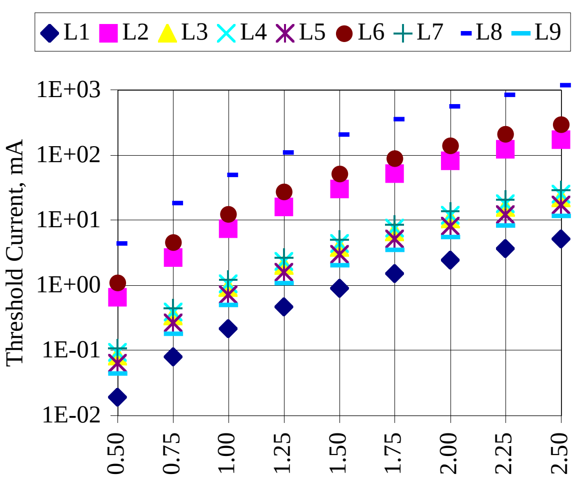

Figure 1: Threshold currents as a function of energy.

In figure 1 the threshold currents are shown as a function of energy for all longitudinal HOMs resonating below the cut-off frequency of the cavity beam tubes. They are shown for the worse case, $\Delta f=0$. At injection energy threshold currents are below 1 mA for almost all HOMs.

2.2 Minimum Frequency Shift

When CBM n is excited by a cavity HOM, the HOM frequency shift which is needed to stabilize the CBI is obtained by substituting expression (4) for $R_{||}$ in relation (3):

$$|\Delta f| > \left| \frac{f_r}{2Q} \cdot \sqrt{I_b^{nom} \cdot \frac{\alpha \cdot \tau_\varepsilon}{2Q_s \left(E/e\right)} \cdot f_{p,n} \cdot \left(R/Q\right) \cdot Q - 1} \right|$$

for the nominal current I_b^{nom}. The argument of the square root is positive for $I_b^{nom} > I_b^{max}$.

Again in the case of ANKA it is interesting to consider this frequency shift as a function of energy for all longitudinal HOMs below cut-off. This is shown in figure 2 for a nominal beam current of 400 mA. The stable interval width in fig. 2 is compared to a revolution frequency, i.e. $\left(1-2 \cdot |\Delta f|/f_0\right)$ is plotted. This is then the probability of setting a stable frequency for that HOM.

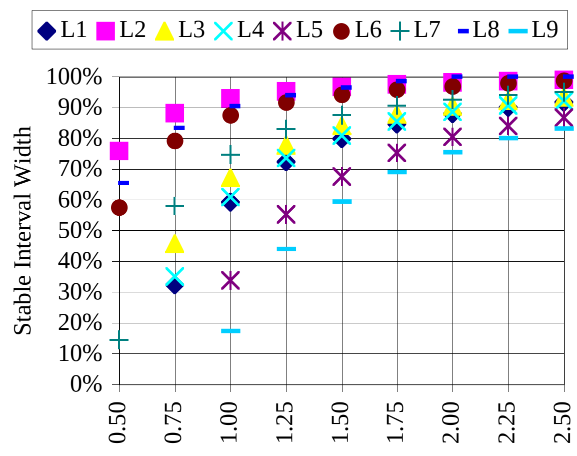

Figure 2: Stable Interval Width for 400 mA.

For HOMs L5 and L9 no stability can be achieved below 1.0 GeV by mode shifting. At 500 MeV also HOM L1 cannot be stabilized. At higher energies harmless HOMs like L2, L6 and L8 approach 100% stability probability. For the most harmful L1, L5 and L9 modes the stable interval width is larger than 80% of a revolution frequency, approaching 90% for L1. In Elettra, at 2.0 GeV, 300 mA, stable conditions can be found even if for L1 this width is less than 80% of f_0, for L5 it is 65% and for L9 it is reduced to well below 60%.

2.3 Simulation of HOM distribution

The analysis presented so far concerns single HOMs. To guarantee stability the beam needs to be free of any interaction with cavity HOM's. To take into account the effect of all HOM's, four HOM frequency distributions have been randomly generated, starting from the typical HOM frequencies of Elettra-type cavities [1]. The beam cavity interaction has then been computed as a function of cavity temperature. The result is shown in figure 3 for one of the random generated cavities. The horizontal axis is the longitudinal radiation damping rate, $1/\tau_\varepsilon = 690$ 1/s. The curves are the growth rates of the CBMs interacting with cavity modes in the temperature regulation interval 40-70 °C. For temperatures where all growth rates are below $1/\tau_\varepsilon$ the CBI's are cured. In fig. 3 this is the case between 40 and 54 °C. For the other random distributions stable interval width range from 10 to 20 °C.

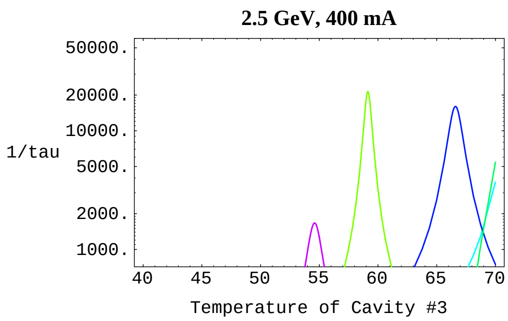

Figure 3: Longitudinal CB growth rates vs. temperature.

3 TRANSVERSE CBI

A similar analysis can be performed for transverse CBI's. The growth rate of the transverse CBM number n at frequency $f_{p,n}$ excited by the cavity HOM with transverse impedance $R_{\perp}(f_{p,n})$ at the CBM's frequency is given by

$$\frac{1}{\tau_{\perp}} = \frac{\beta_{\perp} \cdot I_b \cdot f_0}{2\left(E/e\right)} \cdot R_{\perp}\left(f_{p,n}\right)$$

where $\beta_{\perp}$ is the betatron function at the cavity location. In ANKA there will be three different options for the machine optics: the so called f-optik, h-optik and y-optik, with different working points [4]. The location of cavities can be dispersion-free or dispersive (Dx=0.5). Horizontal CBI are most sensitive to the y-optik with Dx=0, which has a maximum β_x of 20 m. The maximum vertical betatron function at the location of the cavities is β_y=9.4 m for the y-optik with dispersion. In both cases taking the stability condition based only on the radiation damping, $1/\tau_{\perp} < 1/\tau_{x,y}$, for a given HOM when $f_{pn}=f_r$ the maximum stable stored current is lower than in Elettra, being reduced to 23% for the horizontal case and to 66% for the vertical case. If $f_{pn}=f_r$ threshold currents in ANKA at 2.5 GeV are low, below 10 mA for the most harmful T2 and T3 modes. At 500 MeV they are below 1 mA for all modes, both in the horizontal and in the vertical case.

The minimum cavity HOM frequency shift required to stabilize a transverse CBI is given by

$$|\Delta f| > \left| \frac{f_r}{2Q} \cdot \sqrt{I_b^{nom} \cdot \frac{\beta_{\perp} \cdot \tau_{x,y} \cdot f_0}{2\left(E/e\right)} \cdot R_{\perp}(\Delta f = 0) - 1} \right|$$

for the nominal current. |Δf| for horizontal CBI's for the y-optik, Dx=0, 400 mA, are shown in fig. 4. Below 1.25 GeV the stable interval width is lower than half a revolution frequency for almost all transverse HOM's. Based on experience of Elettra, additional Landau damping is thus required. At 2.5 GeV the stable interval width is between 80 and 100% of the revolution frequency for all HOMs, which is equivalent to the situation in Elettra, at 2.0 GeV, 300 mA. By considering all HOM's in four random generated cavities, stable windows are wider than 20°C, as can be seen in the example plotted in figure 5.

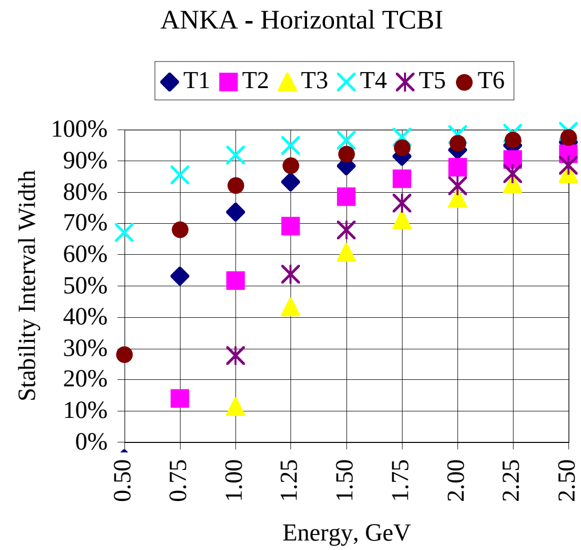

Figure 4: Stable Interval width for 400 mA.

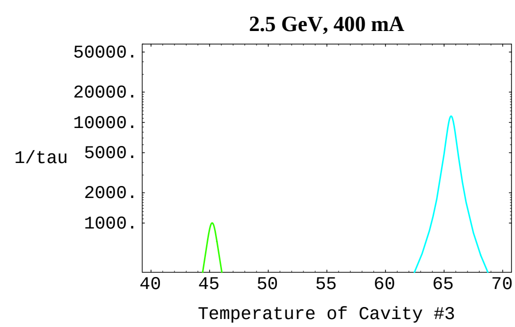

Figure 5: Horizontal CB growth rates vs. temperature.

4 OUTLOOK

- Curing CBI by mode shifting at 2.5 GeV in ANKA will be easier than in ELETTRA. Stable windows exist both for the transverse and longitudinal case.
- ANKA is more sensitive than ELETTRA to CBI if the beam spectrum line hits the HOM frequency.
- At injection energy the beam will be unstable. A proper selection of longitudinal excitation will be needed in order to damp harmful transverse effects.

5 ACKNOWLEDGEMENT

The authors would like to thank D.Einfeld for several useful discussions and F.Perez and S.Voigt for providing the information on the ANKA storage ring.

REFERENCES

[1] M.Svandrlik et al., "The ANKA RF cavities", this conference.

[2] M.Svandrlik et al., "The Cure of MBI in Elettra", Proc. of PAC 95, Dallas, May 95, pp. 2762-2764.

[3] R.Brinkmann, D.Einfeld, J.Schaper, M.Svandrlik, "MBI at the SBLC Damping Ring", Proc. Int. Workshop on MBI in Future Electron and Positron Accelerators, Tsukuba, July 1997, pp 273-300.

[4] S.Voigt, private communication.