HIGHER ORDER MODES IN THE NEW 100 MHZ AND 500 MHZ CAVITIES AT MAXLAB

Å. Andersson, M. Bergqvist, M. Brandin, M. Eriksson, L. Malmgren, H. Tarawneh*.
MAX-Lab, Lund University, Box 118, SE-22100, Lund, Sweden.

Abstract
The MAX-II electron storage ring operates exclusively in multi-bunch mode with all buckets filled. Damping of the longitudinal coupled bunch (LCB) instabilities driven by the higher order modes (HOM) has successfully been provided by passive third harmonic 1.5 GHz cavities. With a new RF system employing three 100 MHz capacity loaded cavities and a fifth harmonic Landau cavity installed, a study of the HOM impedances, and related threshold instability currents, is necessary. Measurements and calculations so far, are being presented.

INTRODUCTION

The MAX-II storage ring is a third generation synchrotron light source [1]. The ring is injected at an energy of 500 MeV and ramped to 1.5 GeV.
The present 500 MHz RF system of MAX-II is not sufficient to provide a Touschek life time that matches the gas lifetime. Also the power delivered to the beam is raised from 35 kW to 45 kW at 250mA, when the two superconducting wigglers are engaged. The available power from the present RF system then becomes marginal [2].
In order to solve both problems, we have chosen to lower the RF frequency to 100 MHz. Three cavities of capacity-loaded type will be installed together with one FM transmitter to each. In this way the bucket height will increase even with a reduction of the RF voltage. Introducing a passive 500 MHz Landau cavity will further increase the Touschek lifetime roughly a factor of 3.
With this scheme of lowering the radio frequency in a 3rd generation light source in order to relatively cheaply 'buy' bucket height, it is of highest interest to study how troublesome the HOM driven LCB instabilities will be.

LONGITUDINAL CB INSTABILITY

The beam-cavity interaction due to parasitic modes of the RF cavity can lead to strong instabilities by the coupling of the beam with the HOMs. If the ring is filled with M uniform equally spaced bunches, i.e. identical current in every bunches, the motion of each bunch can be coupled together in M different modes of oscillations (rigid bunch oscillation) [3]

$$\omega_{\mu,p} = pM\omega_{rev} + (\mu\omega_{rev} + \omega_s)$$

ω_{rev} is the angular revolution frequency, p is an integer $-\infty < p < +\infty$, the number of beam turns, μ is an integer which represents the mode number of the coupled bunch oscillation, $0<\mu<M-1$, and ω_s is the synchrotron angular frequency.
Due to the high quality factor and the shunt impedance, the HOM of the RF cavity can cause instabilities when $\omega_{HOM} \cong \omega_{\mu,p}$ that is when the sharp peaks of the HOM longitudinal impedance have the same resonant frequencies at the beam spectrum lines. There are $\pm M/2$ possible coupled bunch modes, μ, with a phase-shift of $2\pi\mu/M$ between bunches.

INSTABILITY GROWTH RATE

1- 100 MHz Cavity HOM's

This summer we will insert three 100 MHz cavities, Fig. 1, into the MAX-II ring [2]. The HOM's below 1.5 GHz for the 100 MHz cavities have been measured by a network analyzer using one probe and one excitation loop situated at the right hand side endplate. The measurements were performed up to 1.5 GHz since the form factor is sufficiently low above. Two damping antennas at different radii were situated at the same endplate, both were terminated with 50 Ω loads to drain out the HOM's. This endplate is convenient to use for damping antennas since the fundamental mode is not affected while the HOM's have E-field maxima there. Fig.2 shows the effect of the damping antenna on the quality factors of the longitudinal HOM's. *Table 1* presents the measured values from one cavity for the HOM's when the two damping antenna and the input power coupling loop are connected and terminated with 50Ω. The measured resonant frequencies of the same HOM are slightly different for each cavity since they are not identical.

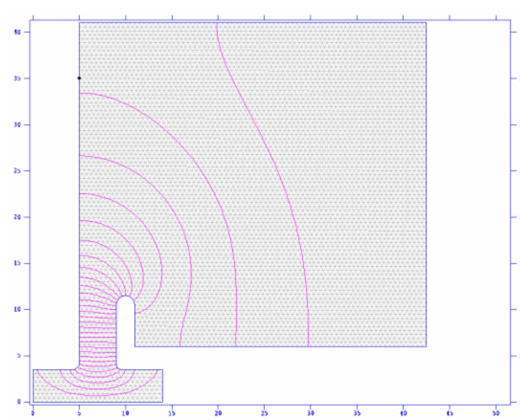

Figure 1: 100 MHz cavity profile with fundamental mode E-field lines.

The HOM's damped Q-values have been measured with the transmission line 50 Ω terminated. We are not certain over how the FM transmitter behaves when connected. It might be that we have to add a filter to the transmission line to make it 50Ω terminated at frequencies higher than say 400 MHz. To perform this we are preparing for online measurements of the HOM's, i.e. the FM transmitter connected and running.

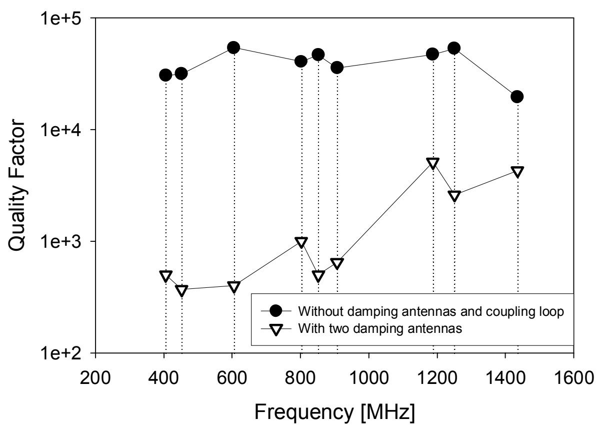

Figure.2: Measured Q-values of the longitudinal HOM's. Lower curve with 50Ω termination on the coupling loop.

Table. 1. Measured HOM's of the 100 MHz cavity.

Measured *f* [MHz]	Measured *Q*
406.26	<300
451.99	320
605.79	<300
801.77	1250
847.01	5750
907.2	700
1187.53	3880
1251.66	1400
1435.89	4860

2- 500 MHz Landau Cavity HOM's

The Landau cavity is of a pill box type. The cavity body length 110 mm was chosen instead of the half wave length mainly to reduce the R/Q- value and to raise some of the longitudinal HOM frequencies [2] which have the effect of minimizing the rise time of LCB instability. The two longitudinal HOM's below 1.5 GHz are shown in Table 2. No damping antennas are used for the 500 MHz Landau cavity.

Table 2. Measured HOM's of the 500 MHz cavity.

Measured *f* [MHz]	Measured Q
TM_{020} 1154.832	35300
TM_{011} 1453.863	22000

3- Growth Rate

The growth rate $1/\tau_L$ of the longitudinal coupled bunch mode number μ excited by a cavity HOM's for a beam current I_b is given by [3]. :

$$\frac{1}{\tau_L} = -\frac{\alpha I_b}{4\pi Q_s (E/e)} \omega_{\mu,p} . \mathrm{Re}\{Z_L(\omega_{\mu,p})\} . e^{-\left[\frac{\omega_{\mu,p}\sigma_l}{\omega_{rev} R}\right]^2}$$

where Q_s is the synchrotron tune, E is the beam energy in eV, α is the momentum compaction factor, R the ring radius and σ_l is the bunch length.

The narrow band impedance Z_L of the cavity longitudinal HOMs is given by

$$Z_L(\omega) = \sum_{m=1}^{M} \frac{R^m}{1 + iQ^m\left(\omega^m/\omega - \omega/\omega^m\right)}$$

Where M indicates the HOMs, Q^m and R^m are the quality factor and shunt impedance of the excited mode and ω^m is the resonant frequency. The HOM's shunt impedances were scaled down from the theoretical value with the same ratios as of the measured Q-values with and without damping antennas.

If we take into account only the natural damping given by the emission of synchrotron radiation, the stability condition for a certain coupled bunch mode is defined by

$$\frac{1}{\tau_L} < \frac{1}{\tau_\varepsilon}$$

where $1/\tau_\varepsilon$ is the damping rate of synchrotron oscillations, the threshold current limit at which a certain mode could be excited is defined by

$$I_{th} = \frac{4\pi Q_s (E/e)}{\tau_L \alpha} \frac{1}{\omega_{\mu,p} Z_L(\omega_{\mu,p})}$$

With the designed value of the beam current of 250 mA in a uniform filling pattern of 30 bunches and a bunch length of σ_l= 5.3 cm (bunch lengthening from the Landau cavity of 3.1) and synchrotron tune Q_s= 0.0017, the growth rate of the LCB instability is suppressed and well-below the longitudinal damping rate with a threshold current of 466mA, see Fig.3. The highest growth rate is for mode μ=28 with $1/\tau_L = 223\sec^{-1}$ caused by the HOM 907.2 MHz. The next highest growth rate μ=14 $1/\tau_L = 118\sec^{-1}$ caused by 451.99 MHz and may lead to LCB instability with a frequency shift of +0.96 MHz. The mode μ=4 due to the HOM 1187.53 MHz has a growth rate of $1/\tau_L = 71\sec^{-1}$ and may lead to LCB instability for a frequency shift of -0.53 MHz ($1/\tau_L = 418\sec^{-1}$). This instability can be observed on the beam lifetime.

We should mention that the Landau damping rate obtained from the higher harmonic cavity is not included in the instability estimates. If the Landau damping rate is higher than the synchrotron radiation damping rate, we gain more suppression for LCB instabilities [4].

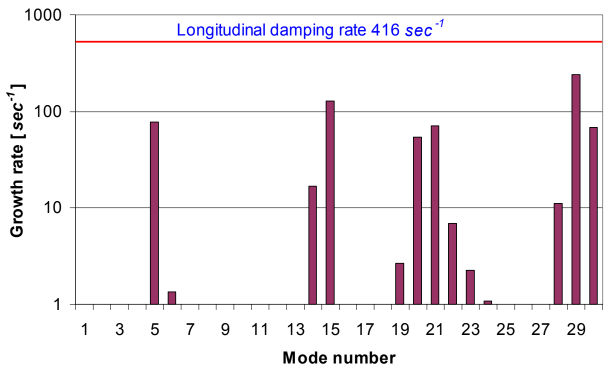

Figure 3: Growth rate of the LCB modes with the measured HOM's frequencies in one cavity and then assuming three identical cavities.

INSTABILITY COMPENSATION

First we have to make sure that this unstable mode is acting longitudinally or a transversely, a possible way to do that is by slightly adjusting the cavity voltage in order to change the synchrotron frequency, this has the effect of reducing the HOM amplitude for the longitudinal CB mode.

The LCB instability for a certain mode can then be suppressed by shifting the HOM frequency into or out of resonance with the beam harmonics by varying the cavity water supply temperature. Measurements have been carried out with different temperatures showing that a frequency shift of the order of 0.5 MHz for most HOM modes is achieved.

When the CBI is acting transversely, a slight change in the chromaticity, horizontally or vertically to identify in which plane it acts, can eliminate this instability by shifting the transverse beam spectrum away from harmful modes. This is as a result of the long bunches obtained by the low RF system where the beam spectrum is not extended to large frequencies[5].

SUMMARY

Measurements of the HOM's frequencies and Q-values in both the 100 MHz and the 500 MHz cavities were presented. Only the 100 MHz cavities are equipped with the damping antennas. Scaling down the theoretical shunt impedances in the 100 MHz cavities with the same amount as the Q-values decrease when the damping antennas are introduced gives us a conservative estimate of the HOM's impedances. Then assuming that a certain HOM is excited in all three cavities simultaneously, the growth rates of the longitudinal coupled bunch instability still do not exceed the synchrotron radiation damping rate. Only after scanning the HOM frequencies, two CB modes are excited and driving CB instability. In that case, the temperature tuning of the RF cavities will allow for significant reduction of this instability by shifting the HOM's frequencies.

In conclusion it seems that the LCB instabilities will be suppressed if our main cavities are equipped with two damping antennas and the transmission line possibly equipped with a filter acting as 50Ω at higher frequencies. This holds even without taking into account the Landau damping rate introduced by the higher harmonic cavity.

REFERENCES

[1] Å. Andersson, et.al. 'The MAX-II Synchrotron Radiation Storage Ring' Nucl. Instr. and Methods, A343 (1994) 644-649.

[2] Å. Andersson, et.al. 'The 100 MHz RF system for MAX-II and MAX-III', Proc. of EPAC02, Paris, France

[3] J. L. Laclare 'bunched beam coherent instabilities' CAS Proceedings, CERN87-03, Vol. I, April 1987.

[4] R. A. Bosch, C. S. Hsue, 'Suppression of longitudinal coupled-bunch instabilities by passive higher harmonic cavity', Proc. of IEEE, PAC1993.

[5] B. Zotter, F. Sacherer, 'Transverse instabilities of relativistic particle beams in accelerator and storage ring ' CERN 77-13, July 1977, p175-218.