HIGHER ORDER MODE (HOM) INDUCED LONGITUDINAL COUPLED BUNCH (LCB) INSTABILITIES AT THE SRS

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Abstract

Experimental studies at the Synchrotron Radiation Source (SRS) have shown that variation of the RF cavity temperature can introduce LCB oscillations, observed on the beamline tungsten vane monitors (TVM). Analysis of the beam spectra under various conditions indicate that a cavity HOM is the cause. Precise control of the temperature of each of the four accelerating cavities is necessary to suppress these oscillations. This paper also outlines the steps taken to minimise HOM interaction and consequently reduce LCB instabilities.

1 INTRODUCTION

If all electron beam bunches are uniformly filled in a storage ring, i.e. identical current in every bunch, and the beam exhibits no coherent oscillation, the beam spectra will contain components n of Bf_{rev}, where B is the number of bunches and f_{rev} is the revolution frequency. Peaks at other frequencies indicate a non-uniform fill or that the beam exhibits some coherent oscillation. Providing the bunches move in a correlated way, the beam spectrum contains components:

$$f_{\mu,n}^{\pm} = nBf_{rev} \pm (\mu f_{rev} + f_s) \qquad (1)$$

where: μ = integer corresponding to the mode number
          of the coupled bunch oscillation

f_s = synchrotron frequency (Hz)

The peaks at frequencies $f\mu,n$ are observed as side-bands of the main nBf_{rev} spectral components. Modulation of the beam with a frequency $\mu f_{rev}+f_s$ gives rise to these side-bands. The modulation component exists if the beam contains a coherent oscillation with frequency f_s (or f_s+mf_{rev} with an integer m)[1]. The coupling between bunches will be due to high Q components within the storage ring, and being the highest contributor of high Q components an RF cavity is the most probable cause.

The growth rates and threshold currents for longitudinal cavity induced instabilities are well defined in accelerator physics literature[2]. The corresponding threshold current limit at which the mode, coinciding with a beam resonance, could be excited is defined as:

$$I_{th//} = \frac{2E_oQ_s}{\tau_{//}\alpha} \frac{1}{F_iR_s} \qquad (2)$$

where: $I_{th//}$ = Threshold average current (A)
          $\tau_{//}$ = Mode damping time (s)
          α = Momentum compaction factor
          F_i = Longitudinal mode frequency (Hz)
          R_s = Longitudinal shunt impedance (Ω)
          Q_s = Synchrotron tune
          E_o = Beam energy (eV)

2 LCB OBSERVATIONS ON THE SRS

The diagnostics used to monitor beam spectra are two pairs of electro-static plates, configured in the horizontal or vertical plane. The bandwidth of these plates limit the frequency range of spectra observable, the cut-off response of the plates being ~800MHz.
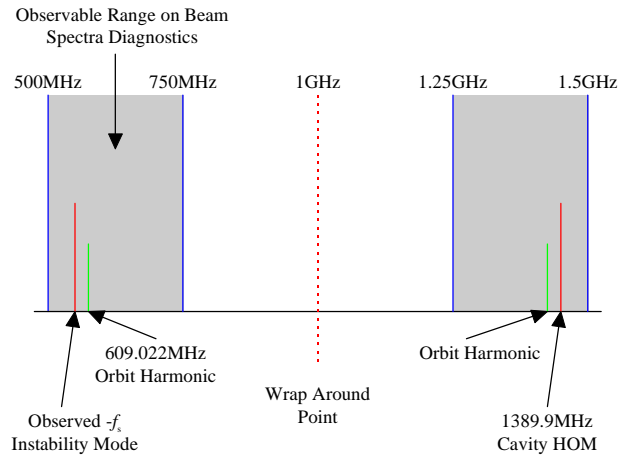

Figure 1: Extrapolation of -f_s Peak about 609.022MHz Orbit Harmonic from 1389.9MHz Cavity HOM

Aliasing is therefore used (see Figure 1) to interpret the base-band information observed using these plates. A clear relationship was observed between the 1390MHz signal on the cavity probe monitor with the -f_s peaks about the orbit harmonics between 500MHz and 750MHz. Wrapping the spectra around the nBf_{rev} break points confirms the existence of the cavity mode at 1390MHz.

Previous observations during both Accelerator Physics and normal user beam conditions have shown that a clear current threshold exists at a total beam current

of 242mA (i.e 1.51mA/bunch), whereby as the beam current naturally decays a 1390MHz cavity resonance[3] disappears from the cavity probe signals and f_s side-bands about the f_{rev} peaks also disappear (see Figure 2).
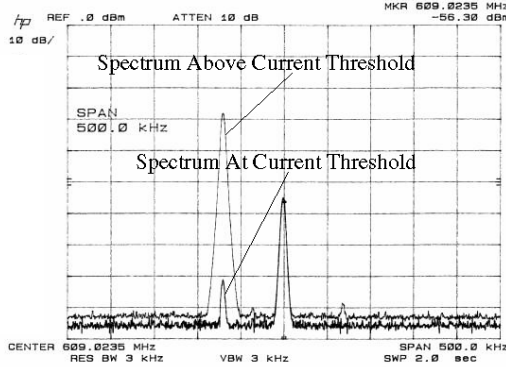

Figure 2: f_s peak about 609.022MHz orbit harmonic as beam current decays

2.1 Calculation of HOM Impedance

From observation, the current threshold for this cavity HOM is 242mA; its impedance can determine from Eqtn **2**, substituting the radiation damping time for $\tau_{//}$ as it is the net damping that is observed.

where:
$$
\begin{aligned}
I_{th//} &= 242mA \\
E_o &= 2 \text{ GeV} \\
Q_s &= f_s \times \text{orbit period} = 0.0224143 \\
f_s &= 70 \text{ kHz} \\
\tau_{//} &= 2.09 \text{ ms} \\
\alpha &= 0.029 \\
F_i &= 1389.9 \text{ MHz} \\
R_s &= \text{unknown}
\end{aligned}
$$

which gives a longitudinal impedance R_s =0.709MΩ

Previous experimental data has also shown that the threshold current substantially reduces to 150mA when the 6T super-conducting wiggler is not operational. The action of insertion devices in the storage ring is to reduce the radiation damping time of the machine and consequently increase the current threshold for cavity instabilities. Using Eqtn **2** again to determine the threshold current for this machine condition confirms the original impedance calculation:

$$
\begin{aligned}
I_{th//} &= \text{unknown} \\
E_o &= 2 \text{ GeV} \\
Q_s &= fs \times \text{orbit period} = 0.01601 \\
f_s &= 50 \text{ kHz} \\
\tau_{//} &= 2.27 \text{ ms} \\
\alpha &= 0.0292 \\
F_i &= 1389.9 \text{ MHz} \\
R_s &= 0.709 \text{ M}\Omega
\end{aligned}
$$

giving a threshold current $I_{th//}$ = 156mA.

Applying the SRS RF parameters to Eqtn **1** implies that if the mode is longitudinal:

$$ f_{125,2}^{\pm} \;=\; 2Bf_{rev} \;\pm\; (125f_{rev} + f_s) $$

where:
$$
\begin{aligned}
B &= 160 \text{ bunches} \\
f_{rev} &= 3.123 \text{ MHz} \\
f_s &= 70 \text{ kHz}
\end{aligned}
$$

The beam would then execute a synchrotron oscillation with a dipole coupled bunch mode $\mu = 125$, giving a frequency of 1389.9MHz, which correlates exactly with the cavity HOM observed.

3 CONFIRMATION OF MODE ORIENTATION

To confirm that the cavity mode was a longitudinal mode causing synchrotron oscillation instability, the synchrotron frequency f_s was varied from its reference setting of 70kHz by adjusting the cavity accelerating voltage. As the cavity volts were being adjusted, its effect on photon and electron beam position monitors, synchrotron tunes, beam profiles and the cavity HOM amplitude were all recorded (see Table 1).

Table 1: f_s Variation Results

Tunes			HOM Amplitude (dBm)				Beam Profile (H, V μm, L ps)		
fs^*	fr^*	fv^*	1	2	3	4	H	V	L
71	592	1093	-98	-83	-99	----	1498	195	81
70	592	1092	-88	-73	-99	-87	1506	199	89
69	592	1093	-88	-73	-100	-86	1516	198	89
68	592	1093	-87	-73	-100	-86	1511	199	89
66	592	1093	-88	-73	-101	-86	1511	200	90
64	592	1093	-88	-74	-102	-87	1507	201	93
62	592	1093	-90	-75	-103	-88	1500	197	91

* measured in kHz

Reference f_s setting

Increasing the cavity voltage, causing an increase of f_s from 70kHz to 71kHz, had the effect of greatly reducing the HOM amplitude on three of the four cavities, eliminating the mode completely from cavity 4. With the mode's amplitude decreased, Table 1 also shows that the bunch volume reduces by 11%. Coupling this result with the fact that the betatron oscillations did not vary as the cavity volts were adjusted confirms that the cavity instability mode is acting longitudinally.

As f_s is varied, the resonant frequency of the cavity changes, which means that the tuner position servo system has to compensate by adjusting accordingly. This

then alters the cavity geometry causing the cavity HOM's to shift in frequency, and this was observed on each cavity probe signal by scanning on a high frequency spectrum analyser (HFSA) (see Figure 3).
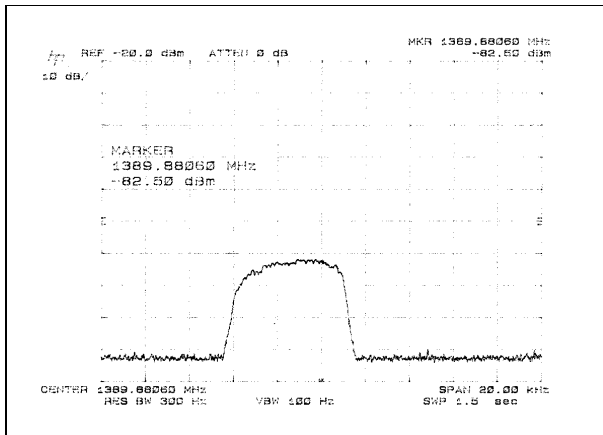

Figure 3: Frequency Shift of 1390MHz HOM Observed on Cavity 2 as f_s Adjusted

The associated change in tuner position as f_s is varied for cavity 2 is shown below in Figure 4.
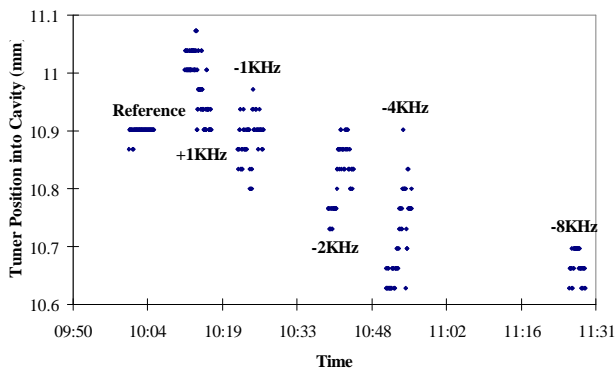

Figure 4: Cavity 2 Tuner Position as a Function of f_s

The tuner position change from its reference position to (f_s + 1kHz) is very small (~0.1 to 0.2mm) due to the variation in cavity volts. However when one considers that for normal user beam conditions, typically from 250mA to 120mA, the total tuner position movement in 24hours is 0.3mm, then the small movements observed in Figure 4 become significant.

4 LCB INSTABILITY CURE

It was decided, as a definite increase in tuner position was observed which caused the cavity mode to disappear, and as the cavity probe signal was significantly greater on cavity 2, that the temperature on cavity 2 would be adjusted to move the tuner such that the 1390MHz mode could not be excited at high currents[4].

It was necessary to perform a calibration of cavity 2

tuner position as a function of temperature to determine in which direction the temperature needed to be moved to effectively reduce the reference tuner position. An inverse relationship was observed between cavity temperature and tuner position meaning that to reduce the tuner position, the cavity temperature needed to be increased. The temperature was increased from 50°C to 53°C. At this temperature the cavity tuner position was now operating at 1mm more than its original reference setting. Observations of the cavity probe signals on normal user beam (<260mA) have found no 1390MHz resonance on all of the RF cavities. Sweeping the cavity voltage on subsequent beam studies operation has also found that the HOM could no longer be sufficiently excited at currents <260mA.

5 CONCLUSIONS

The main objective of this set of experiments was to observe a definite presence of a cavity HOM on each of the cavity probe signals at high currents, which was achieved. Then by adjustment of the cavity voltage, excitation of the cavity mode could be varied, confirming that the mode was longitudinal, indicated by synchrotron side-bands about the 125th harmonic, with no observable beam blow up transversely or transverse tune shift.

The cavity tuner position indicated that as the mode was excited, the tuner position was above a certain threshold level below which the mode was not observable. By adjustment of the cavity temperature, the tuner position could be offset so that under normal user beam conditions the cavity HOM was not excited. Cavity 2 temperature was therefore changed from 50°C to 53°C which enabled a higher current user beam to be stored with no observable evidence of the 1390MHz cavity HOM on any of the cavity probe signals.

Should the SRS be required to run without the super-conducting wigglers, then the maximum achievable current, before beam blow up due to cavity induced instabilities, will be reduced. Further work needs to be done to assess each cavity operating tuner position setting and temperature to enable similar adjustment.

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