LONGITUDINAL COUPLED BUNCH INSTABILITIES ON THE NSLS X-RAY RING

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Abstract

Studies have demonstrated that an 862 MHz RF cavity higher order mode (HOM) cause longitudinal coupled-bunch (LCB) dipole and quadrupole oscillations at specific RF tuner positions with associated increases in longitudinal, horizontal, and vertical electron beam sizes. In the XRF2 cavity a reconfiguration of damping antennae removed the 862 MHz HOM. High speed I(t) stripline measurements showed that a strong quadrupole oscillation resulted when the HOM was induced in the XRF3 cavity. The reason that a symmetric six bunch pattern was found to be effective in damping this mode is explained.

1 INTRODUCTION

The NSLS X-Ray Storage Ring is a national user facility producing high intensity, high brightness synchrotron radiation at 60 X-Ray beamlines. Four 52.88 MHz cavity resonators driven by 125 kW amplifiers restore the synchrotron radiation energy loss of the electron bunches[1]. Beginning in January 1998, the storage ring will operate predominantly in two user modes: 440 mA at 2.584 GeV and 260 mA at 2.8 GeV with the standard asymmetric pattern of 25 bunches filled followed by 5 bunches empty. There will continue to be limited single bunch operation at 130 mA for timimg experiments. Symmetric bunch patterns of 3,5,6,10,15 and 30(all bunches filled) are used during machine studies periods.

For a symmetric distribution of m coupled electron bunches with identical charge in each bunch, the beam spectra will have the frequency components:

$$f^{+}_{\mu,n} = nmf_{rev} + sf_{rev} + \mu f_s$$

$$f^{-}_{\mu,n} = nmf_{rev} + s'f_{rev} - \mu f_s$$

where s, s' are the mode numbers satisfying $s + s' = m$, f_s is the synchrotron frequency, and μ is the multipole number of the coupled bunch mode. For the NSLS X-Ray Storage Ring the revolution frequency f_{rev} is 1.76 MHz and the synchrotron frequency f_s is 5 kHz.

This paper investigates the coupling between symmetric bunches that occurs when an RF cavity HOM of high quality factor overlaps one of the above $f_{\mu,n}$ frequencies.

2 EXPERIMENTAL TECHNIQUES

Signals summed from the horizontal plates of an X-ray storage ring stripline were used to record the beam-induced power spectrum. In addition, high speed I(t) stripline measurements[2] were performed to study the longitudinal bunch profile during an LCB instability driven by a high Q 862 MHz HOM in the NSLS XRF3 system. S_{21} transmission measurements were made during shutdown periods using the cavity input loop and an RF monitor loop to characterize the major cavity HOMs as a function of tuner position. A pinhole camera and Spiracon on an X-ray bending magnet diagnostic port (X28) recorded transverse beam sizes[3].

3 LCB MEASUREMENTS OF THE NSLS XRF2 SYSTEM

The tuner positions of the 4 X-ray cavities are varied during X-ray injection, ramping and stored beam conditions to maintain a constant detune angle. It was noted in 1995 that some of the experimental beam lines detected steps in beam intensity that correlated with particular XRF2 tuner positions. Studies using symmetric bunch patterns revealed that at a tuner positions of 3.6V (98.6mm) and 4.1V (117.6mm) a strong 862 MHz cavity HOM observed in S_{21} measurements could account for a large μ = +1(dipole) mode on the +9 revolution line above the RF line at 846.2 MHz. This mode corresponds to a monopole mode calculated using URMEL. A weaker μ = +1 mode appeared on the +8 revolution line at 860.3 MHz for the 3.6V tuner position. In Figure 1 S_{21} transmission measurements are shown for the 3.6 V tuner position. The 862 and 860 MHz revolution lines intersect HOMs at these frequencies causing LCB instabilities.

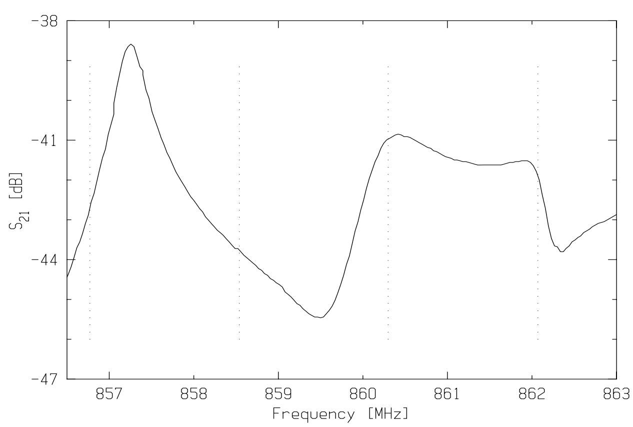

Figure 1: Transmission measurements for the XRF2 cavity with tuner at 3.6V. The revolution lines are shown by vertical dots.

At a tuner position of 4.1V, the 862 MHz revolution line intersects the 862 MHz HOM causing an LCB instability,

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as shown in Figure 2.

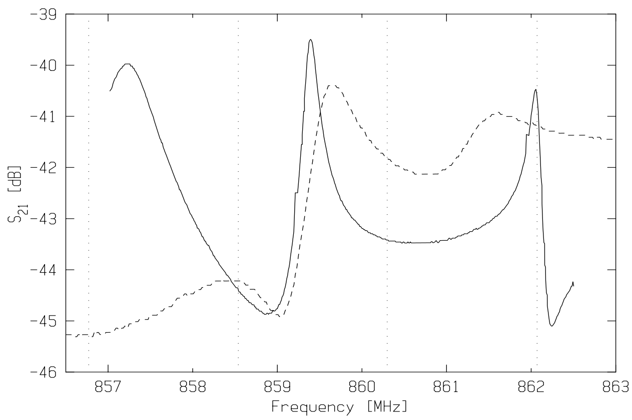

Figure 2: Transmission measurements for the XRF2 cavity with tuner at 4.1 V. The dashed line shows the modes after a reconfiguration of the damping antennae.

The 862 MHz mode was subsequently damped, as indicated by the dashed line in Figure 2, by changing the antennae configuration to resemble that of XRF1 where no 862 MHz LCB was observed. The damped S_{21} curve shows that the newly oriented XRF2 antennae reduced the Q value of the 862 MHz mode and shifted the peak frequency away from the revolution line thereby removing the LCB instability. The damping antennae also removed the 860 and 862 MHz LCB instabilities at the 3.6 V tuner position. Prior to the reorientation of antennae, the tuner range had been adjusted so that the tuner positions causing these LCB instabilities were avoided during operations.

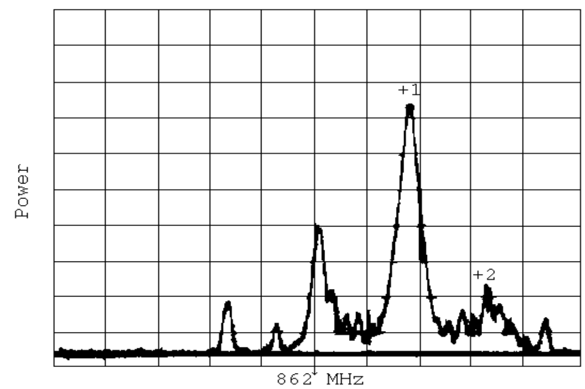

Figure 3: The μ = +1(dipole) sideband on the 862 MHz revolution line for XRF3 tuner position of 4.48V.

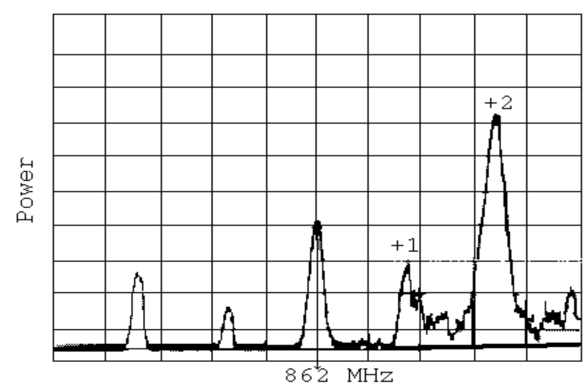

Figure 4: The μ = +2 (quadrupole) sideband on the 862 MHz revolution line for XRF3 tuner position of 4.51 V.

4 LCB MEASUREMENT OF THE NSLS XRF3 SYSTEM

The XRF3 system was found to have a very narrow (Q=9000) HOM at 862 MHz for a tuner position of 4.51V (127mm). At a tuner position of 4.48V (125.9mm) a strong μ = +1 sideband occured on the 862 MHz revolution line. As the tuner position was increased to 4.51V, the μ = +2 (quadrupole) sideband increased while the μ = +1 (dipole) sideband decreased. These sidebands are shown in Figures 3 and 4. In this tuner range, transmission data shows that the 862 MHz HOM peak has a 29 kHz/mm increase in frequency with tuner insertion length.

When these sidebands were present, an RF monitor loop on the cavity showed that a 862 MHz line increased by 54 dB putting it 20 dB above any of the other spectral lines from 117 MHz to 1617 MHz. When the quadrupole sideband was present the longitudinal bunch profile was measured with the stripline signal as shown in Figure 5. There was a clear quadrupole oscillation with a 1.1 nanosecond spacing of the lobes on the time axis, in agreement with a 1.1 nanosecond spacing expected for strong modulation with an 862 MHz HOM.

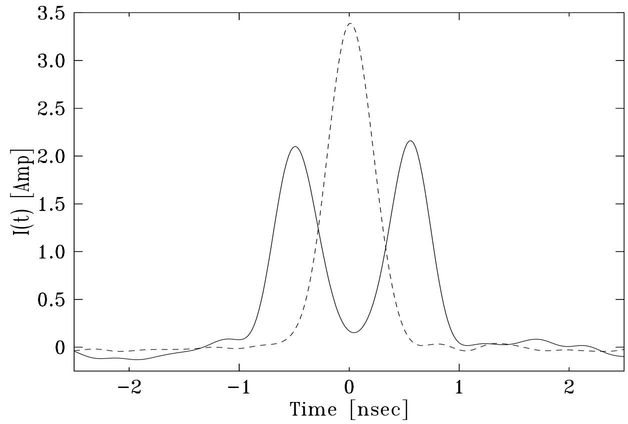

Figure 5: The bunch current distribution[2] measured at two phases of the quadrupole coupled bunch oscillation.

In addition to an increase in the longitudinal dimension of the beam, there were large increases in the transverse dimensions. For a 30 bunch pattern at 300 mA the horizontal beam size(1-σ) increased from 380 to 621 μm and the vertical size from 41 to 52 μm.

5 DAMPING OF THE 862 MHZ LCB INSTABILITY WITH SYMMETRIC SIX BUNCH FILL

For a symmetric six bunch fill (m=6), the 862 MHz LCB instability corresponds to $s = s' = 3$ modes. As a result, the f^+ and f^- frequencies occur above and below the 862 MHz revolution line. The growth rate of the LCB oscillation is proportional to

$$[ReZ(f^+) - ReZ(f^-)]$$

where Z is the cavity impedance. Since the f^+ and f^- dipole and quadrupole frequencies only differ by $2f_s$ and $4f_s$ respectively, $Z(f^+)$ and $Z(f^-)$ are approximately equal. As a result there is damping of the 862 MHz LCB oscillation for six bunch fills. This was evident from a comparison of the current thresholds for the 862 MHz LCB for 5 bunchs and 6 bunches. With the XRF3 tuner set to 4.51 V, the 862 MHz LCB instability threshold occured below 50 mA for 5 bunches. However, it was not observed on the stripline signal or on an XRF3 monitoring loop signal at the maximum six-bunch current of 240 mA.

6 CONCLUSION

It has been demonstrated that the 862 MHz HOM in the XRF2 and XRF3 cavities cause LCB oscillations with associated increases in longitudinal and transverse beam dimensions. Antennae have been successful in damping this mode in the XRF1, XRF2, and XRF4 cavities. A strong 862 MHz HOM remains in XRF3. Up to this point, the XRF3 tuner range has been adjusted so that the LCB induced by this HOM occurs at a tuner position traversed early in the fill to minimize its impact on user experiments. Longitudinal feedback measurements have been undertaken to study the feasibility of damping this mode, and the possibility of reconfiguring the XRF3 damping antennae will also be considered.

7 REFERENCES

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