INTRODUCTION

Analysis of coupled-bunch instabilities driven by the Higher Order Modes (HOMs) of the 7-cell PETRA-III cavity for the commissioning phase 1 of the NSLS-II storage ring have been carried out in [1]. The NSLS-II storage ring parameters are listed in Table 1. The analysis has been done with the numerical HOMs calculated in [2] and the main conclusion was that, in the transverse case, the beam could be potentially unstable at zero chromaticity. At positive chromaticity, it has been shown that the coupled-bunch instability can be damped by the combined effect of the slow head-tail instability and a proper detuning of the HOMs frequencies based upon temperature change. Although it was claimed that the beam should be stable longitudinally, it has been pointed out that a small uncertainty in the simulated frequencies could potentially drive a longitudinal instability as well.

During the commissioning phase 1 of the NSLS-II storage ring [3], longitudinal coupled-bunch instabilities have been observed at an average current $I = 10$ mA at chromaticity +2,+2. A longitudinal HOM with frequency $f_r = 1374$ GHz has been identified as driving the instability. Moreover, a horizontal instability at zero chromaticity has been observed in single bunch mode operation. We study growth rates from the HOMs of the PETRA-III cavity and compare the results with measurements.

PETRA-III CAVITY HOMS

The layout of the 500MHz PETRA-III 7-cell structure is given in Fig.1. The HOMs of the PETRA-III cavity listed in Table 2 are based on the numerical data computed by R. Wanzenberg [2], complemented by numerical simulations with GdfidL (see Fig.2 and Fig.3). Fig.2 shows the longitudinal long-range wakepotential computed up to $s = 2274$ m and Fig.3 shows the real part of the longitudinal impedance. The calculation shows a HOM at frequency $f_r = 1371$ GHz, not far from the measured one $f_r = 1374$ GHz. The difference in frequency may be due to the assumptions made in the numerical modeling of the PETRA-III 7-cell structure (geometry and temperature different from the real physical conditions). Indeed, the longitudinal wakefield has been simulated for a structure without tapered transition to the NSLS-II regular profile of the chamber. This might affect the shunt impedance as well, which could be higher. Lastly, we point out that the accurate estimation of the shunt impedance and quality fac-

**COMMISSIONING RESULTS**

During the commissioning of the NSLS-II storage ring in multi-bunch mode with 1000 bunches, a longitudinally instability have been observed preventing to store more than 10 mA. Preliminary analysis has shown that the instability may be driven by the PETRA-III HOM with frequency $f_r = 1374$ MHz. In further measurements the temperature of the cavity has been raised from $38.4^\circ$C to $39.2^\circ$C with another HOM with frequency $f_r = 1227$ MHz driving the longitudinal coupled-bunch instability. More measurements would be needed to further characterize the instability, however with the completion of the commissioning phase 1 and the installation of superconducting cavities to replace the PETRA-III cavity, this option shall not be pos-

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COUPLED-BUNCH INSTABILITY

To analyze the coupled-bunch instability driven by the PETRA-III HOM we assume $M = 1320$ Gaussian bunches uniformly filling the ring with average current $I_0 = 10$mA. The analytical growth rate $\tau^{-1}_\mu$ of the $\mu$th multi-bunch mode for the dipole mode $a = 1$ in the limit of short bunches is given by ($\mu = 0, \ldots, M - 1$)

$$\frac{1}{\tau^{-1}_\mu} = \frac{I_0 \eta}{4 \pi E_0 n} \sum_{p = -\infty}^{+\infty} \int_{-\infty}^{+\infty} \left( p \omega_0 + \mu \omega_s + \omega_s \right) e^{-\left( p \omega_0 + \mu \omega_s + \omega_s \right)^2} \Re Z_{||} \left( p \omega_0 + \mu \omega_s + \omega_s \right),$$

where $\Re Z_{||}$ is the real part of the impedance sampled at $\omega_0 = 2.88$ MHz, which gives rise to a growth time of $\tau = 200 \mu$s.

In Table 1 the simulated parameters of the HOMs with frequency $f_r = 1371$MHz are listed in bold symbols. As noted previously, the simulated frequency $f_r = 1371$MHz differs from the measured frequency $f_r = 1374$MHz. As a worse case scenario we estimate the growth time changing the measured frequency to $f_r = 1373.866$MHz, in which case the argument of $e^{-\left( p \omega_0 + \mu \omega_s + \omega_s \right)^2} \Re Z_{||}$ in Eq.(1) is sampled at its peak for $p = 1003$ and $\mu = 987$, as shown in Fig.4a. With quality factor $Q = 36000$, setting the growth time equal to half the longitudinal radiation damping time ($\tau_s = 27$ms) we obtain for the shunt impedance of the HOM $R_{sh, ||} = 0.6 \Omega$.

The growth rates as a function of bunch mode are plotted in Fig.4b, where bunch mode $\mu = 987$ is the fastest growing mode. Preliminary simulations in frequency domain have shown that the HOM with frequency $f_r = 1374$MHz has $R_{sh, ||}/Q = 28$ with $Q = 36000$, thus $R_{sh, ||} = 1 M \Omega/m$, implying that the HOM is capable to drive the observed coupled-bunch instability with a growth time of 8ms.

We conclude with a discussion of single bunch instabilities that may be driven by the transverse HOMs (see Table 1) of the PETRA-III cavity. During the commissioning of the NSLS-II storage ring, a horizontal instability at zero chromaticity has been observed preventing the single bunch accumulation to exceed 0.7mA [3]. The growth rate of the dipole mode in this case reads

$$\frac{1}{\tau} = \frac{I_0 \beta_x}{2 E_0 I_0} \sum_{p = -\infty}^{+\infty} e^{-\left( p \omega_0 + \omega_s \right)^2} \Re Z_{||} \left( p \omega_0 + \omega_s \right),$$

where $\beta_x = 20$m is the horizontal beta function at the location of the PETRA-III cavity. In Fig.5a we plot the growth rates from the HOMs of the PETRA-III cavity as a function of horizontal tune and frequency shift $\Delta$ of the HOMs. For simplicity, all the HOMs are assumed to shift in the same direction by the same amount. It is evident that there are regions of potential instabilities in the frequency-tune plane, where the growth time is smaller than the radiation damping time. In Fig.5b we show the real part of the impedance sampled at $p \omega_0 + \omega_s$ for $\nu_x = \omega_s/\omega_0 = 3.22$ and $\Delta = -1$MHz, which gives rise to a growth time of 18.2ms. We see that many HOMs contribute to the growth time of the zero-th bunch mode. The potential instability is driven by the long-range interaction (via the PETRA-III cavity wakefield) of the single bunch with itself over consecutive revolutions along the ring. For the sake of generality we also include the analysis in the vertical plane. As shown in Fig.6a, the vertical cavity has regions of potential instabilities in the frequency-tune plane as well. Fig.1b shows the real part of the impedance sampled at $p \omega_0 + \omega_{sy}$ for $\nu_y = \omega_{sy}/\omega_0 = 16.25$ and $\Delta = -1$MHz, which gives rise to a growth time of 13.3ms.

REFERENCES

Figure 4: Left: real part of the longitudinal impedance sampled at its peak for $p = 1003$ and $\mu = 987$. Right: growth rate as a function of bunch mode giving a growth time equal to half the longitudinal radiation damping time.

Figure 5: Left: growth rates from the HOMs of the PETRA-III cavity as a function of horizontal tune and frequency shift $\Delta$ of the HOMs. Right: real part of the horizontal impedance sampled at $p\omega_0 + \omega_\beta x$ for $\nu_x = 33.22$ and $\Delta = -1$MHz giving a growth time = 18.2ms.

Figure 6: Left: growth rates from the HOMs of the PETRA-III cavity as a function of vertical tune and frequency shift $\Delta$ of the HOMs. Right: real part of the vertical impedance sampled at $p\omega_0 + \omega_\beta y$ for $\nu_y = 16.25$ and $\Delta = -1$MHz giving a growth time = 13.3ms.