

ANALYSIS OF COUPLED BUNCH INSTABILITIES IN THE NSLS-II STORAGE RING *

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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 $I = 10\text{mA}$ at chromaticity $+2,+2$. A longitudinal HOM with frequency $f_r = 1374\text{GHz}$ 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 $s = 2274\text{m}$ and Fig.3 shows the real part of the longitudinal impedance. The calculation shows a HOM at frequency $f_r = 1371\text{GHz}$, not far from the measured one $f_r = 1374\text{GHz}$. 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-



Figure 1: 500MHz PETRA-III 7-Cell Structure.

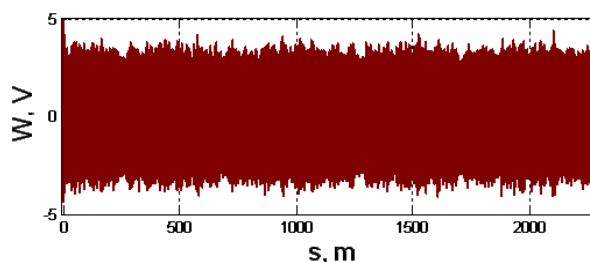


Figure 2: Longitudinal long-range wakepotential computed up to $s = 2274\text{m}$. Numerical simulation done with GdfidL.

tor from the time domain wakefield calculation requires the computation up to a much longer distance s .

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 $f_r = 1374\text{MHz}$. In further measurements the temperature of the cavity has been raised from 38.4°C to 39.2°C with another HOM with frequency $f_r = 1227\text{MHz}$ 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-

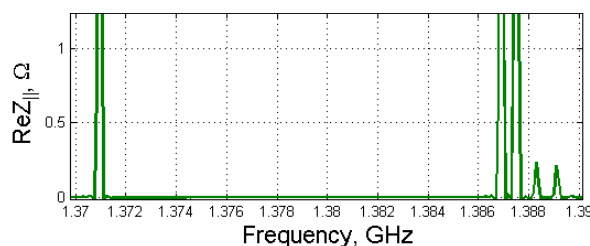


Figure 3: Real part of the longitudinal impedance from the wakepotential plotted in Fig.2, showing the HOM with frequency $f_r = 1371\text{GHz}$.

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sible. In the next section we will investigate the growth rates induced by the HOM with $f_r = 1374\text{Mhz}$.

Table 1: NSLS-II Storage Ring Parameters (Bare Lattice)

Parameter	Symbol	Value	Unit
Beam energy	E_0	3	GeV
Average current	I_0	25	mA
Harmonic number	h	1320	
Circumference	C	792	m
Bunch length	σ	10	ps
Energy spread	σ_p	7×10^{-4}	
Energy loss per turn	U_s	288	keV
Momentum compaction	η	3.7×10^{-4}	
Horizontal tune	ν_x	33.22	
Vertical tune	ν_y	16.26	
Synchrotron tune	ν_s	0.007	
Long. radiation damping	τ_s	27	ms
Transv. radiation damping	τ_x	54	ms

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 $I_0 = 10\text{mA}$. The analytical growth rate τ_μ^{-1} of the μ th multi-bunch mode for the dipole mode $a = 1$ in the limit of short bunches is given by ($\mu = 0, \dots, M - 1$)

$$\frac{1}{\tau_\mu} = - \frac{I_0 \eta}{4\pi E_0 \nu_s} \sum_{p=-\infty}^{+\infty} (pM\omega_0 + \mu\omega_0 + \omega_s) \times e^{-(pM\omega_0 + \mu\omega_0 + \omega_s)^2 \sigma^2} \text{Re}Z_{||}(pM\omega_0 + \mu\omega_0 + \omega_s). \quad (1)$$

In Table 1 the simulated parameters of the HOMs with frequency $f_r = 1371\text{Mhz}$ are listed in bold symbols. As noted

Table 2: HOMs Parameters of the 7-cell PETRA-III Cavity

Symbol	Longitudinal HOMs				Transverse HOMs			
	f_r	ω_r	$R_{sh, }$	$Q_{ }$	f_r	ω_r	$R_{sh,\perp}$	Q_{\perp}
Unit	MHz	MHz	MΩ		MHz	MHz	MΩ/m	
Value	500	31.6	36900	860	5403	14.7	55700	
	501	3147.48	0.0053	37500	867	5447	17.5	56800
	502	3154.07	0.0575	38100	869	5460	56.1	58200
	503	3160.35	0.0006	38800	871	5473	19.7	59400
	505	3172.92	0.0017	39800	1043	6553	83.6	40400
	507	3185.48	0.0001	40800	1046	6572	26.2	40900
	508	3191.76	0.0001	41400	1089	6842	17.0	49400
	712	4473.50	0.0091	30300	1465	9205	15.5	54600
	716	4498.63	0.0124	31100	1545	9707	26.8	44300
	722	4536.33	1.13	32300				
	728	4574.02	3	33600				
	733	4605.44	0.7245	35000				
	738	4636.85	0.479	35500				
	739	4643.14	0.457	36000				
	1130	7099.79	0.0002	34300				
	1140	7162.62	0.0008	35500				
	1150	7225.45	0.0006	37100				
	1170	7351.11	0.025	38900				
	1250	7853.75	0.067	55100				
	1260	7916.58	0.155	55200				
	1270	7979.41	0.01	49500				
	1371	8632.57	1	36000				

previously, the simulated frequency $f_r = 1371\text{Mhz}$ differs from the measured frequency $f_r = 1374\text{Mhz}$. As a worse case scenario we estimate the growth time changing the measured frequency to $f_r = 1373.8666\text{Mhz}$, in which case the argument of $\text{Re}Z_{||}$ 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 ($\tau_s = 27\text{ms}$) we obtain for the shunt impedance of the HOM $R_{sh,||} = 0.6\text{M}\Omega$. 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 $f_r = 1374\text{Mhz}$ has $R_{sh,||}/Q = 28$ with $Q = 36000$, thus $R_{sh,||} = 1\text{M}\Omega/\text{m}$, implying that the HOM is capable to drive the observed coupled-bunch instability with a growth time = 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

$$\frac{1}{\tau} = \frac{I_0 \bar{\beta}_x}{2E_0 T_0} \sum_{p=-\infty}^{+\infty} e^{-(p\omega_0 + \omega_{\beta_x})^2 \sigma^2} \text{Re}Z_{\perp}(p\omega_0 + \omega_{\beta_x}),$$

where $\bar{\beta}_x = 20\text{m}$ 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 Δ 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 $p\omega_0 + \omega_{\beta_x}$ for $\nu_x = \omega_{\beta_x}/\omega_0 = 33.22$ and $\Delta = -1\text{MHz}$, 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 include also the analysis in the vertical plane. As shown in Fig.6a, the vertical case has regions of potential instabilities in the frequency-tune plane as well. Fig.1b shows the real part of the impedance sampled at $p\omega_0 + \omega_{\beta_y}$ for $\nu_y = \omega_{\beta_y}/\omega_0 = 16.25$ and $\Delta = -1\text{MHz}$, which gives rise to a growth time of 13.3ms.

REFERENCES

- [1] G. Bassi et al., Paper TUPPP042, Proceedings of IPAC 2012, New Orleans, USA.
- [2] R. Wanzenberg, private communication.
- [3] A. Blednykh et al., Paper TUPRI069, these Proceedings.

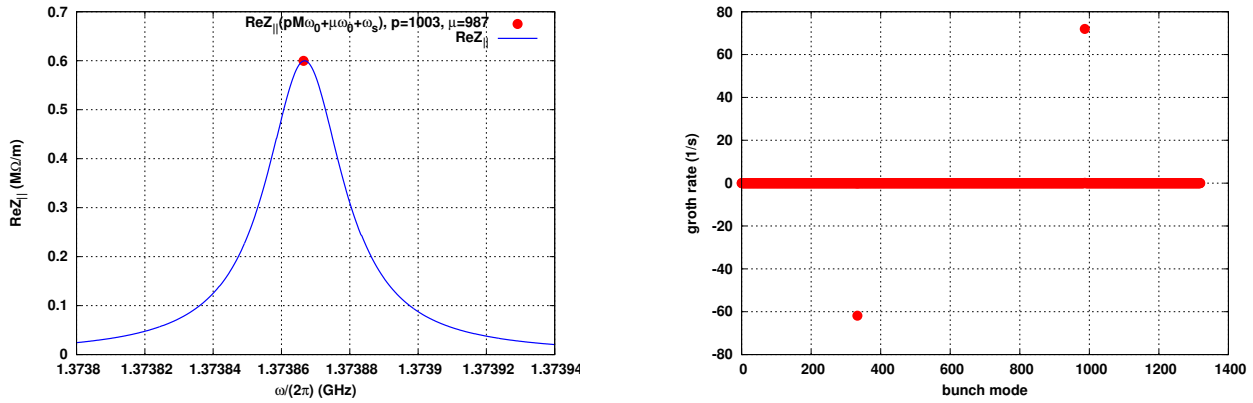


Figure 4: Left: real part of the longitudinal impedance sampled at its peak for $p = 1003$ and $\mu = 987$. Right: growth rate as a function of bunch mode giving a growth time equal to half the longitudinal radiation damping time.

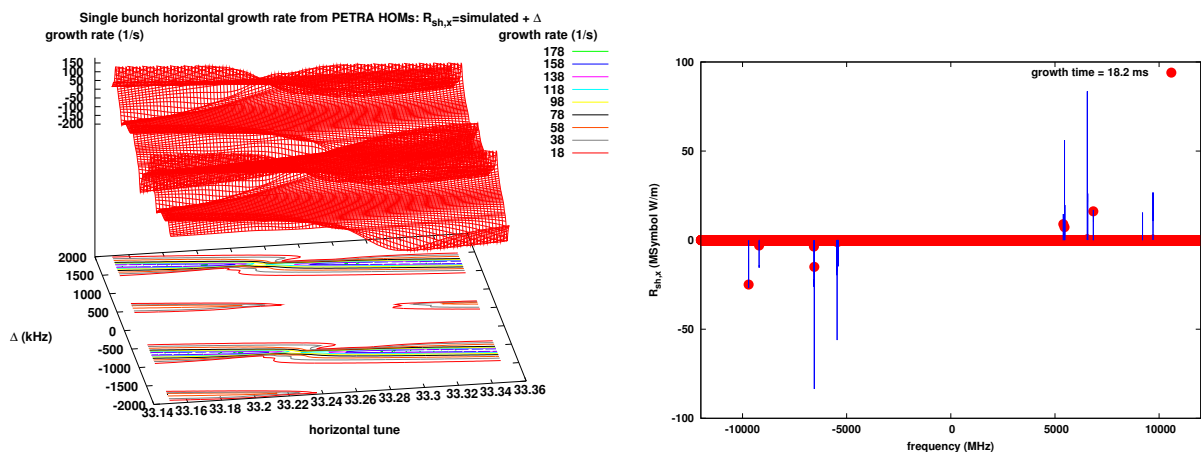


Figure 5: Left: growth rates from the HOMs of the PETRA-III cavity as a function of horizontal tune and frequency shift Δ of the HOMs. Right: real part of the horizontal impedance sampled at $p\omega_0 + \omega_{\beta x}$ for $\nu_x = 33.22$ and $\Delta = -1$ MHz giving a growth time = 18.2ms.

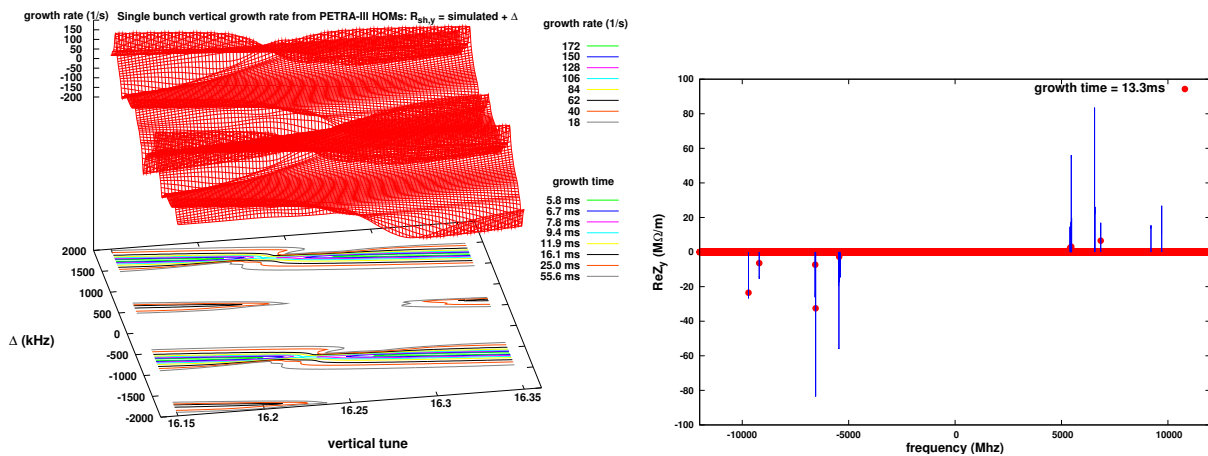


Figure 6: Left: growth rates from the HOMs of the PETRA-III cavity as a function of vertical tune and frequency shift Δ of the HOMs. Right: real part of the vertical impedance sampled at $p\omega_0 + \omega_{\beta y}$ for $\nu_y = 16.25$ and $\Delta = -1$ MHz giving a growth time = 13.3ms.