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Preliminary Instability Studies in RHIC

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Data

A slow, single bunch, horizontal instability appeared on the RHIC injection porch with positive chromaticity. Data taken on 1 June 2001 are summarized in Table 1. The data for the growth rate are shown on the last page of this document.

Table 1

parameter	symbol	value
species	Z, A	$Au79^{+}$
energy	γ	10.5
particles/bunch	N_b	$1 \to 2 \times 10^8$
rms bunch length	σ_t	8.5ns
chromaticity	Q'_β	$-2 \to 2$
tune	Q_β	28.2
growth rate	$Im(\omega_\beta)$	$\approx 1.2s^{-1}$
pipe radius	b	3.6cm

The purpose of this note is to show that these data are consistent with the resistive wall impedance.

Analysis

The coherent betatron frequency in the weak coupling limit of the Wang formalism[1] is

$$\Delta\omega_m = m\omega_s - i\frac{\bar{I}c}{4\pi 2^{|m|}|m|!(Am_p/Ze)Q_\beta}\sum_{n=-\infty}^{\infty} Z_\perp[(nM+s)\omega_0+\omega_\beta]e^{-\tilde{n}^2\sigma^2}(\tilde{n}\sigma)^{2|m|}, \qquad (1)$$

$m = \ldots, -1, 0, 1, \ldots$ is the synchrotron mode number, ω_s is the angular synchrotron frequency, $\bar{I}$ is the average current, M is the number of bunches, s is the coupled bunch mode number, E_T/q is the total proton energy divided by its charge, $\sigma = \sigma_t/\omega_0$ is the rms bunch length in units of machine azimuth, $\tilde{n} = nM + s + Q_\beta - Q'_\beta/\eta$, and $\eta = 1/\gamma_T^2 - 1/\gamma^2$ is the slip factor. This is a standard formula that can be found in ZAP, Chao's book, etc.

For the purposes of this note take the transverse impedance to be give soley by the resistive wall impedance.

$$Z_{\perp,rw} = \frac{2\rho_e Rc(1 - i\text{sgn}(\omega))}{\omega b^3 \delta} \qquad (2)$$

The skin depth is given by

$$\delta = \sqrt{\frac{2\rho_e}{\mu_0 |\omega|}} \tag{3}$$

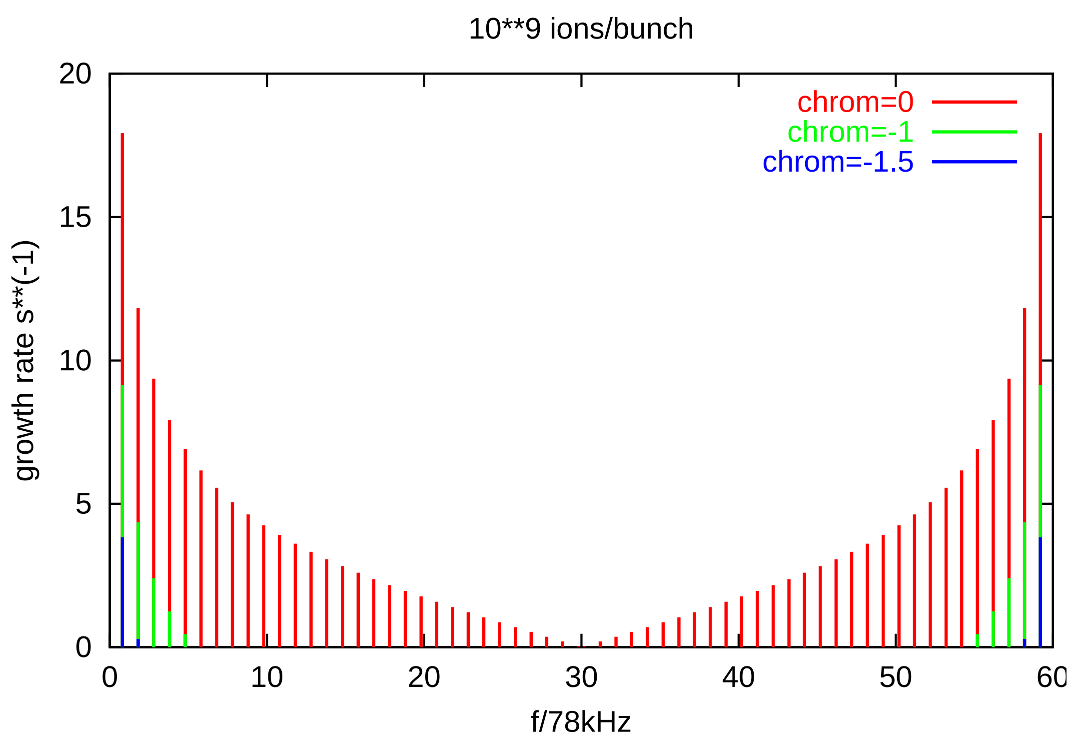
where ρ_e is the electrical conductivity, μ_0 is the vacuum permeability, and $\omega = 2\pi f$ is the angular frequency, with all quantities in MKS. For cold stainless steel the conductivity is $\rho_e = 7.3 \times 10^{-7}\Omega$m[2], which is only slightly smaller than the room temperature value.

Taking one bunch ($M = 1$) with $N_b = 10^8$ and the other parameters in Table 1 the growth rates are given in Table 2. Also given in the table is the number of ions per bunch for which the calculated and measured growth rates agree N_{fit}

Table 2

Q'_β	$Im(\omega_\beta)$ s^{-1}	N_{fit}
1.0	0.44	2.7×10^8
1.5	0.66	1.8×10^8
2.0	0.86	1.4×10^8

Given the uncertainties there is no reason to assume that the transverse impedance in RHIC is significantly larger than previously thought [3] A more stringent test is suggested in this figure.



This shows the coupled bunch growth rates for 60 bunches and 10^9 ions/bunch for various chromaticities, as a function of observed frequency. The frequency dependence of the growth rate is due to the frequency dependence of the resistive wall impedance. Experimental tests should be fairly easy.

References

[1] J.M. Wang, SLAC summer school, (1985).

[2] Gary McIntyre, private communication.

[3] Collective Instabilities in RHIC, S. Peggs & W.W. MacKay *eds.*, RHIC/AP/36 (1994).

$$\mathrm{Im}(\Omega) = \frac{\dot{X}}{X} = \frac{31\,mm}{53\,mm * 0.5\,s} = 1.2\,s^{-1}$$