Impedance Effects in the PS2

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Introduction

In this talk we give preliminary estimates of

- Microwave instability
- Transverse mode coupling instability
- Transverse coupled bunch instability
- Intrabeam scattering

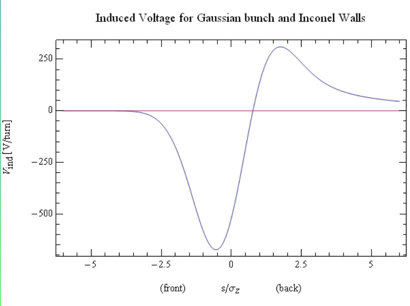
Selected PS2 Parameters

Parameter	Value	Units
Circumference, C	1346.4	m
Chamber half apertures, a_x by a_y	6 by 3.5	cm
Initial, final energies, E_0, E_f	4, 50	GeV
Bunch population, N_b	4.2	10^{11}
Average current, I	2.7	Amp
Long. emittance ($4\pi\sigma_t\sigma_\delta$), ϵ_l	0.6	eV-s
Norm. emittances $\gamma\epsilon_x = \gamma\epsilon_y$	3	π μm
Rms bunch length, σ_{t0}, σ_{tf}	3.8, 1	ns
Rms rel. energy spread, $\sigma_{\delta 0}$, $\sigma_{\delta f}$	3.2, 1	10^{-3}
Transition gamma, γ_t	35i	
Slippage factor, η_0, η_f	-0.037, -0.0012	
Synchrotron tune, ν_{s0}, ν_{sf},	18, 0.8	10^{-3}
Vertical tune, ν_y	8.2	
Average beta function, $\bar{\beta}_y$	31	m

Longitudinal Wake

- skin depth at (injection) bunch frequency: $\delta = 88\ \mu m$ (Inconel625), 67 μm (SS316), 16 μm (Al), 10 μm (Cu)
- bunch wake scales as $\sigma_z^{-3/2}$
- average voltage loss per turn, for Gaussian bunch:

$$\langle V_{ind} \rangle = -\frac{\Gamma(3/4)}{2^{5/2}\pi^2} \frac{ecN_bC}{b\sigma_z^{3/2}} \sqrt{\frac{Z_0}{\sigma_c}}$$



Voltage induced by a Gaussian bunch in the PS2, assuming Inconel walls; $\langle V_{ind} \rangle = -309$ V/turn.

Boussard Criterion for Microwave Instability

- Boussard criterion:

$$\frac{e\hat{I}|Z/n|}{2\pi|\eta|\mathcal{E}\sigma_\delta^2} \lesssim 1 \ , \quad \text{or} \quad \frac{N_{th}}{N_b} \lesssim \frac{(2\pi)^{3/2}\sigma_z|\eta|\mathcal{E}\sigma_\delta^2}{e^2 c N_b |Z/n|} \ ;$$

  this criterion gives a very rough estimate of the threshold to the microwave instability.

- resistive wall impedance:

$$\frac{Z}{n} = (1-i)\frac{\mathcal{C}}{2\pi b}\frac{1}{\delta_s \sigma_c}\frac{\omega_0}{\omega} \ ;$$

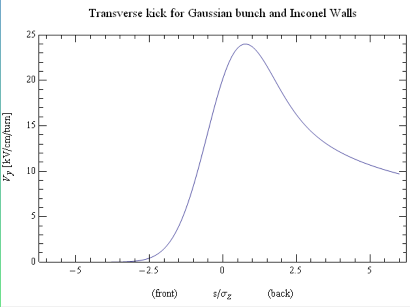
  in Boussard criterion evaluate at $\omega = c/\sigma_z$.

- for PS2 with Inconel: $|Z/n| = 0.67\ \Omega$, $N_{th}/N_b = 1900.$ (at injection), $= 18.$ (at extraction).
- threshold at extraction is much lower because $|\eta|\sigma_\delta^2$ is ~ 300 times smaller at extraction than at injection.

Transverse Wake

- bunch wake scales as $\sigma_z^{-1/2}$
- average kick per cm offset per turn:

$$\langle V_y \rangle = \frac{\Gamma(1/4)}{2^{3/2}\pi^2} \frac{ecN_b C}{b^3 \sigma_z^{1/2}} \sqrt{\frac{Z_0}{\sigma_c}}$$



Transverse kick induced by a Gaussian bunch in the PS2, assuming Inconel walls; $\langle V_y \rangle = 17$ *kV/cm/turn.*

Transverse Mode Coupling Instability

- The threshold can be approximated by (see S. Krinsky, BNL 75019-2005-IR)

$$\frac{N_{th}}{N_b} \sim 0.7 \frac{4\pi\mathcal{E}\nu_s}{e^2 N_b \bar{\beta}_y k_y \mathcal{C}} \ ,$$

  with the vertical kick factor $k_y = \langle V_y \rangle / e N_b \mathcal{C}$.
- for Inconel at injection, $N_{th}/N_b = 12.$, at extraction 6.6.

Transverse Coupled Bunch Instability

- The main contribution to the growth rate of the coupled-bunch instability is normally the resistive wall impedance
- The growth rate of the fastest growing mode in a round, thick-walled pipe (see e.g. A. Wolski, et al, LBNL-59449, Feb. 2006):

$$\Gamma = \frac{c}{4\gamma}\frac{m_e I}{m_p I_A}\sqrt{\frac{\mathcal{C}}{1-[\nu_y]}}\langle\beta_y A_y\rangle$$

with

$$A_y = \frac{4}{\pi^{1/2} b^3}\sqrt{\frac{1}{Z_0\sigma_c}}$$

- For Inconel at injection $\Gamma = 4800\ s^{-1}$, at extraction $\Gamma = 470\ s^{-1}$; the growth times are equivalent to respectively 45., 475. turns

Intrabeam Scattering (IBS)

- The growth in six-dimensional phase space due to local, two-particle scattering of protons is described by the IBS theory of Bjorken-Mtingwa (B-M).
- The growth rates are defined as

$$\frac{1}{T_x} = \frac{1}{\epsilon_x}\frac{d\epsilon_x}{dt}\ , \quad \frac{1}{T_y} = \frac{1}{\epsilon_y}\frac{d\epsilon_y}{dt}\ , \quad \frac{1}{T_p} = \frac{1}{\sigma_p}\frac{d\sigma_p}{dt}\ .$$

- We have solved B-M's formulas applied to the PS2 lattice.
- At injection $[T_x,\ T_y,\ T_p]=$ [35, 55, -2000] min, at extraction they equal [30, -1.5×10^4, 600] min.
- Note that, in the beam frame, at injection the (relative) longitudinal temperature, $\sigma_p^2/\gamma^2 = 3.5 \times 10^{-7}$, is significantly larger than the transverse temperature, $\epsilon/\beta \approx 2 \times 10^{-8}$.

Conclusions

- We have given preliminary estimates of the importance of the microwave instability, the transverse mode coupling instability, the transverse coupled bunch instability, and the intrabeam scattering growth rates
- All threshold currents are much larger than the nominal current
- As a more accurate picture of the total impedance is obtained, and instability simulations are performed, more realistic threshold currents will be obtained
- For the transverse multi-bunch instability more accurate calculations of the low-frequency skin depth will be performed
- IBS growth times are long compared to the time the beam remains in the PS2 (1.2 s), so IBS can be ignored

Proposed PS2 impedance tasks

2009

First estimates of single bunch instabilities

- microwave, transverse mode coupling instabilities
- evaluate space charge impedance
- intrabeam scattering growth rates

Resistive wall, multi-bunch transverse instability

2010

Build impedance model using best available data or from components of existing machines

- numerical calculation of impedance components, e.g. rf bellows, kickers, BPM's, transitions
- estimate single bunch growth rates and characteristics of instabilities

2011

Refine and iterate as time and funding permits

- write an impedance and instabilities section in the PS2 conceptual design report

Participants in this proposal

SLAC: K. Bane, G. Stupakov, C. Ng

Effort: 0.5 FTE (FY09), 1.0 FTE (FY10), 0.5 FTE (FY11)

Travel: 2 person-weeks (FY09), 3 person-weeks (FY10), 2 person-weeks (FY11)