Impedance Effects in the PS2: Update

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Introduction

At the Napa and Port Jefferson LARP workshops, estimates were given of: the effect in the PS2 of the resistive wall impedance on transverse coupled bunch instability, the transverse mode coupling instability, and the longitudinal microwave instability; the effect of the longitudinal space charge impedance; and the effectiveness of coating the SS walls with a thin layer of Cu.

The coupled bunch instability growth time estimate was 60 turns (SS, at injection); the single bunch instability thresholds were comfortably high—though the major contributors to impedance are still missing from the calculations.

We have a design for the vacuum flanges. So here we will discuss:

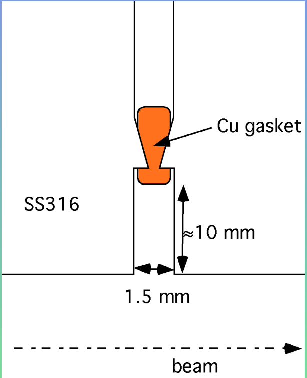
- The effect of the flanges on the single bunch instabilities—the microwave instability and the transverse mode coupling instability (TMCI)

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

Vacuum Flanges

- There may be 500–1500 flanges in the PS2.



Flange geometry. The cross-section of the beam pipe is elliptical with half-heights $a_x = 63$ mm, $a_y = 32.5$ mm.

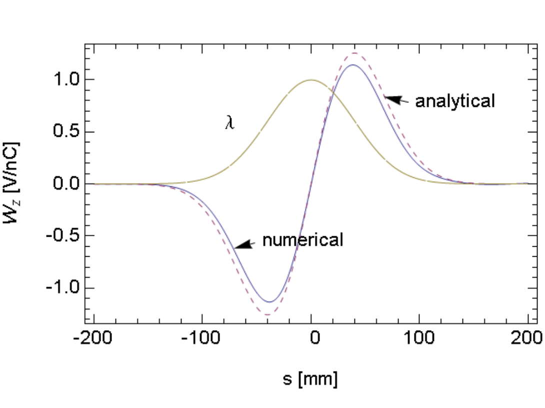
Calculations

- Consider as model a cylindrically symmetric, small rectangular cavity, at radius $b = 30$ mm; of depth $h = 10$ mm and gap $g = 1.5$ mm
- Calculate the longitudinal wake W_z for a long Gaussian bunch ($\sigma_z = 40$ mm) using I. Zagorodnov's code *ECHO2D*
- A small cavity is inductive to a long bunch, *i.e.* $W_z \approx -eNc^2 L\lambda'$; with inductance L approx. given by [see *e.g.* Handbook Acc Physics, p 233]

$$L = \frac{Z_0}{2\pi cb}\left[gh - \frac{g^2}{2\pi}\right]$$

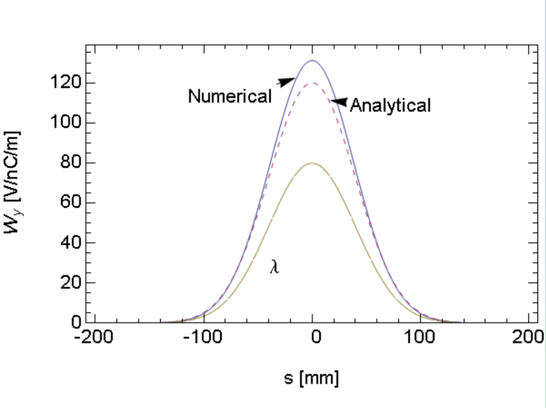
- From the Panofsky-Wenzel theorem the transverse wake is then given by $W_y = 2eNc^2 L\lambda/b^2$

Longitudinal Wake



Longitudinal wake of one flange, assuming a Gaussian bunch with length $\sigma_z = 40$ mm (blue) and the analytical approximation (dashes). The bunch shape λ is also given in yellow (head to left).

Transverse Wake



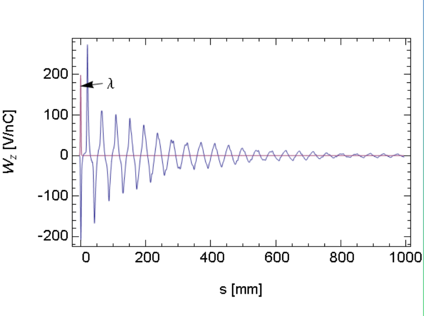
Vertical wake of one flange, assuming a Gaussian bunch with length $\sigma_z = 40$ mm (blue) and the analytical approximation (dashes). The bunch shape λ is also given in yellow (head to left).

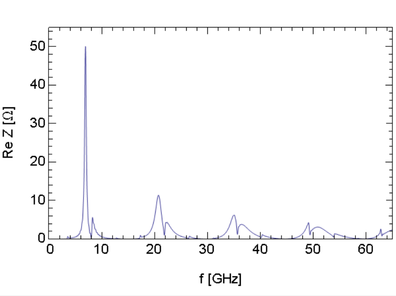
Flanges, Cont'd

- Fit to numerical wake wakes gives, for one flange, $L \approx 80$ pH. Analytical value $L = 71$ pH. If we assume 1500 flanges in the PS2, then $L_{tot} = 120$ nH.
- Microwave Instability: For all flanges $|Z/n| = 0.18\ \Omega$. The resistive wall wake contributes $|Z/n| = 0.26\ \Omega$ (at extraction). Thus $N_{th}/N_b = 24$ instead of 40. We're still comfortably below threshold.
- TMCI: The threshold depends on kick factor k_y. For the entire PS2, the resistive wall wake (SS) contribution $k_y = 19.3$ V/pC/m, the flange contribution (1500 flanges) $k_y = 18.5$ V/pC/m. Combining the two contributions $N_{th}/N_b = 4.4$ (before it was 8.7).

Higher Frequency Behavior

- Main frequency of flange should be $\lambda/4 = 10$ mm, or $f = 7.5$ GHz. Other modes at $(2n+1)\lambda/4 = 10$ mm, with $n = 1, 2, 3 \ldots$.





Left frame: Longitudinal wake excited by a $\sigma_z = 1$ mm bunch in flange; bunch shape is in red. Right frame: Real part of impedance of a flange.

HOM Heating

- Heating: In the cryogenic environment one wants to avoid even a few watts of HOM losses. The power loss in the flanges is given by $P_{hml} = -eNI\langle W_z \rangle$. However, the loss generated in the flanges by a $\sigma_z = 30$ cm bunch is so small it cannot be calculated by direct numerical integration.

  To see why, note that a flange will ring at $\lambda/4 = 10$ mm, or at $f = 7$ GHz. The quantity $\langle W_z \rangle \sim \exp[-(2\pi f \sigma_z / c)^2]$ $\sim \exp(-2000)$.

Where we would like to go from here

We are missing the geometric impedance contributions, from objects such as:

- RF cavities
- BPMs
- bellows
- injection and extraction kickers
- collimators and transitions
- pumping slots...

Original plan was to do estimates of many of these objects in FY2010 and more careful 3D calculations in FY2011 (by Cho Ng). Now we just aim to do estimates for important objects, and thus better estimates for the microwave and TMCI thresholds, in time to write the report.

Discussion

- The contribution of the vacuum flanges to the broad-band impedance of the PS2 was estimated. The effect of 1500 flanges is about the same as the resistive wall wake in both longitudinal and vertical planes.
- The estimate of the thresholds to the microwave and TMCI instabilities have been reduced by about a factor of two, though they are still a factor of, respectively, 25 and 4 above nominal current.
- HOM losses generated by the flanges are essentially zero.
- To get a more realistic estimate of the thresholds we need to include more impedance sources.