Status and future plans for instability studies for the ILC DRs

G. Stupakov

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Outline of the talk

- Brief review of the past work
- Current status
    - Microwave instability
    - TMCI
    - RW driven transverse multibunch instabilities
- Methodology of future research
- Plans and resources

ILCDR Configuration Studies

ILCDR Configuration Studies (CS) were published in February 2006. Documented preliminary analysis and made a relative comparison of the impedance and instabilities issues for 7 reference lattices. The OCS lattice in CS is close to the currently accepted OCS*.

The impedance budget for the ILCDR was interpolated from the PEP-II impedance model. Instabilities thresholds were evaluated based on simple analytical criteria (like Boussard formula, etc).

One of the results of CS was a conclusion of a relatively low threshold for the microwave instability.

DR workshop at Cornell, 2006

Compared various methods of analysis of the microwave instability and bench-marked the result

- mode analysis
- microparticles simulations
- Vlasov solver
- linearized Vlasov solver

Formulated an approach to use scaled vacuum chamber elements from design of existing machines for preliminary studies of the ILCDR stability issues

Standing meeting at SLAC, 2007; other activities

We had a standing meeting every other week at SLAC. Participants: K. Bane, S. Heifets, Z. Li, C. Ng, S. Novokhatski, G. Stupakov, M. Venturini.

A rescaled model of a SC rf cavity was used to calculate a broadband impedance. The impedance was used to analyze microwave instability. The result is documented in a paper presented at PAC 07.

Coupled-bunch modes were studied by K. M. Hock and A. Wolski (PRSTAB, 2007).

ILC DR parameters

The parameters somewhat changed since the publication of the ILCDR Configuration Studies. The current lattice is OCS8.

Circumference, (m)	6476.44
Average I_{beam}, (mA)	418
Number of bunches, N_b	2820
Average I_{bunch}, (mA)	0.15
Peak current, (A)	42.5
Vrf , (MeV/ring)	21.2
$Q_x/Q_y/Q_s$	49.23/53.34/0.06
α	3.94×10^{-4}
σ_z, (mm)	9
δ_0	1.29×10^{-4}

The nominal number of particles in the bunch is 2×10^{10}. The parameters α and σ_z has changed since CS.

Broadband impedance

In many cases, a broadband resonator impedance model is used with the wakefield given by the following formula

$$W_{||}(z) = \frac{\omega_0 R}{Q} e^{-\omega_0 z/2Qc} \left(\cos(\omega_1 z/c) - \frac{\sin(\omega_1 z/c)}{\sqrt{4Q^2-1}} \right) ,$$

with ω_0 and Q the frequency of the quality factor of the resonator, R the shunt impedance, and $\omega_1 = \omega_0 \sqrt{1 - 1/4Q^2}$. It is usually assumed that $Q = 1$.

Broadband impedance

A different model was proposed by Heifets and Chao (2000)

$$Z_{\parallel}(\omega) = \frac{-i\omega L/c}{(1 - i\omega a/c)^{3/2}} ,$$

The parameter a has to be chosen to give the loss factor $\kappa_{\parallel}$. $Z_{\parallel}(\omega)$ is the pure inductive impedance at low frequencies, but rolls off as $1/\sqrt{\omega}$ at high frequencies (according to the diffraction model).

CS use Heifets-Chao model for the BB impedance.

The magnitude of the overall (longitudinal) impedance of a machine can be characterized by the parameter Z/n defined as

$$\frac{Z}{n} = \frac{\sigma_z}{R} \sum_{n=-\infty}^{\infty} \left| \frac{Z_{\parallel}(n\omega_0)}{n} \right| e^{-(n\sigma_z\omega_0/c)^2} .$$

Broadband impedance

Assuming that the BB impedance is proportional to the number of lattice cells, it was estimated in CS that the inductance for the ILC DR is $L \approx 850$ nH, and the loss factor for the ring $\kappa_{\|} \approx 25$ V/pC.

Comparing these numbers with the calculated impedance for the B-factories PEP-II, KEKB, and NSLS-II, I think that this is an overestimation

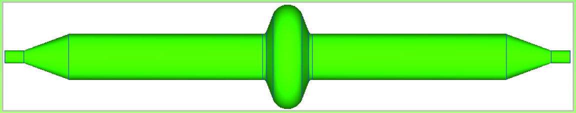
	PEP-II	KEK-B	NSLS-II
L [nH]	80	16	67
κ [V/pC]	3.4	10	19
C [m]	2200	3016	780

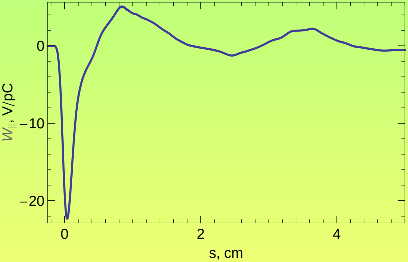
200-300 nH might be a more realistic number.

Impedance L, [nH]	Loss factor $\kappa_{\|}$, [V/pC]	Z/n, [mΩ]
300	25	155

Broadband impedance for SC cavities

Scaled (to 650 MHz) Cornell RF cavity with tapers (C. Ng, Z. Li)

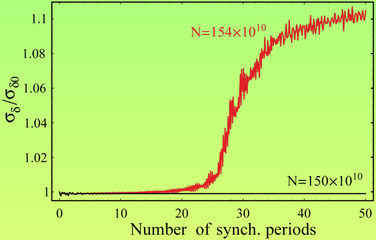


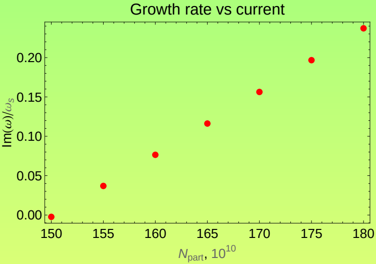


Short range longitudinal wake computed with $\sigma_z = 0.5$ mm bunch (Ng, Li at SLAC; I. Zagorodnov at DESY)

Microwave instability

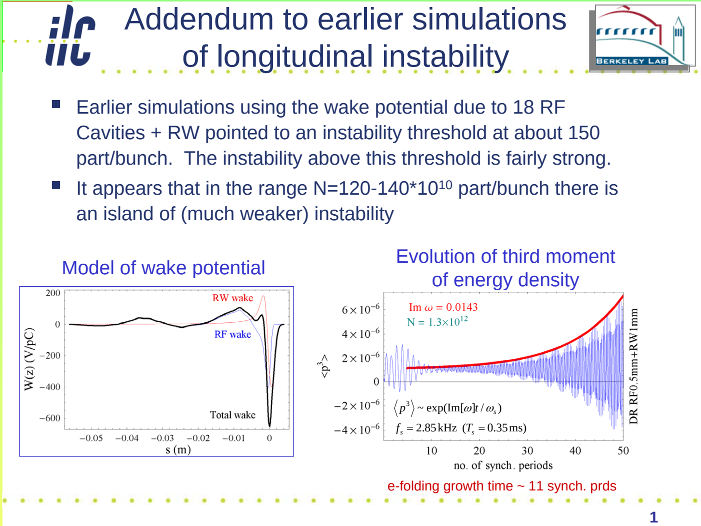
The ring design specifies 18 SC cavities. Microwave instability was simulated using the computed wakefield + the resistive wall wake (Venturini et al., PAC07)





The threshold bunch current is very large, $N \sim 1.5 \times 10^{12}$.

Microwave instability



Addendum to earlier simulations of longitudinal instability

- Earlier simulations using the wake potential due to 18 RF Cavities + RW pointed to an instability threshold at about 150 part/bunch. The instability above this threshold is fairly strong.
- It appears that in the range N=120-140*10^{10} part/bunch there is an island of (much weaker) instability

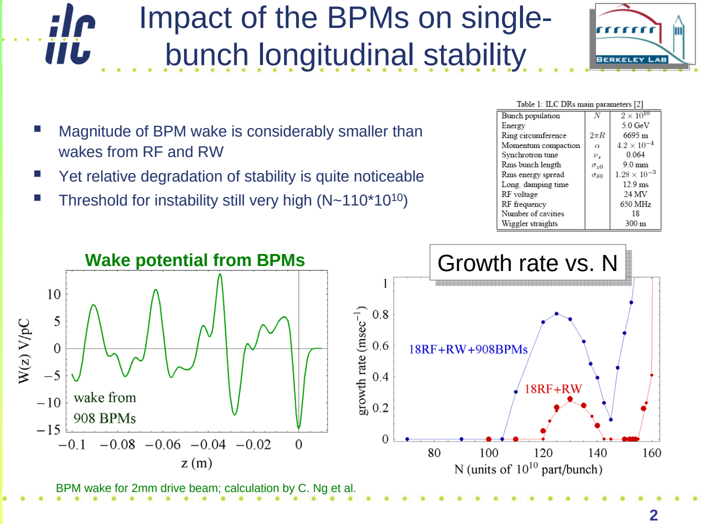
Model of wake potential

Evolution of third moment of energy density

e-folding growth time ~ 11 synch. prds

1

Microwave instability



Impact of the BPMs on single-bunch longitudinal stability

- Magnitude of BPM wake is considerably smaller than wakes from RF and RW
- Yet relative degradation of stability is quite noticeable
- Threshold for instability still very high ($N \sim 110 \times 10^{10}$)

Table 1: ILC DRs main parameters [2]

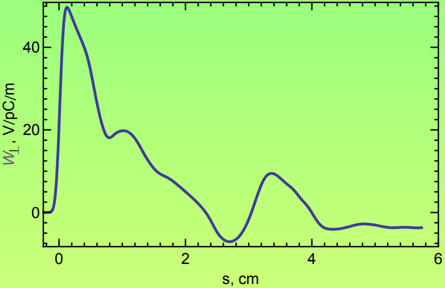
Bunch population	N	2×10^{10}
Energy		5.0 GeV
Ring circumference	$2\pi R$	6695 m
Momentum compaction	α	4.2×10^{-4}
Synchrotron tune	ν_s	0.064
Rms bunch length	σ_{z0}	9.0 mm
Rms energy spread	$\sigma_{\delta 0}$	1.28×10^{-3}
Long. damping time		12.9 ms
RF voltage		24 MV
RF frequency		650 MHz
Number of cavities		18
Wiggler straights		300 m

Wake potential from BPMs

Growth rate vs. N

BPM wake for 2mm drive beam; calculation by C. Ng et al.

Transverse short range impedance and TMCI

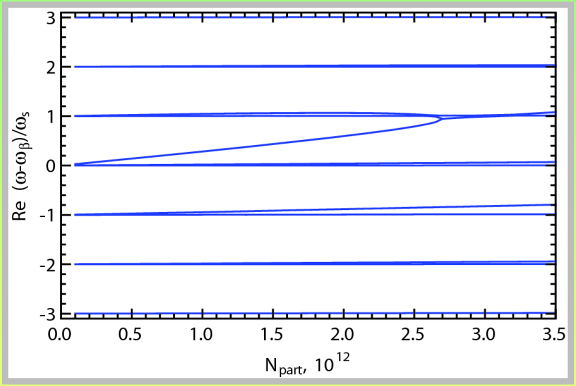


The transverse wake for the SC cavity was calculated by I. Zagorodnov; $\sigma_z = 0.5$ mm.

We studied the transverse mode-coupling instability (TMCI) using the Satoh-Chin formalism. The frequencies of the coherent modes are found by solving an eigenvalue problem. The instability threshold is defined by coupling between two neighboring modes.

Transverse short range impedance and TMCI

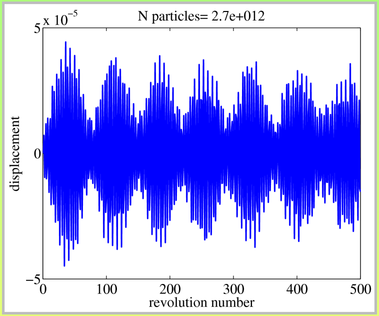
The Sato-Chin analysis is implemented as a Mathematica code. Zero chromaticity is assumed.

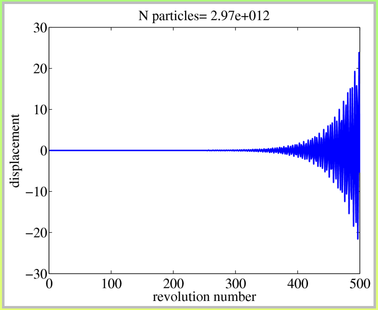


The threshold of the instability at $N \sim 2.7 \times 10^{12}$.

Transverse short range impedance and TMCI

Simulations with a Matlab code (S. Krinsky) show a larger threshold current. Parameters: β-function at the location of the cavities 31 m, $\nu_y = 0.34$.





Resistive wall impedance

Aluminum beam pipe is implied everywhere with the resistivity $\rho = 2.7 \cdot 10^{-6}$ Ohm·cm.
The transverse resistive-wall wake field for a beam pipe with circular cross-section of radius b and length l is given by:

$$W_{\perp}(z) = \frac{A_{\perp}}{\sqrt{z}}, \quad A_{\perp} = \frac{2}{\pi} \sqrt{\frac{Z_0 c}{4\pi} \frac{c}{\sigma_c}} \frac{l}{b^3},$$

and σ_c is the conductivity of the vacuum chamber.
We assume the following chamber radius in sections of the rings

Section	Radius, b [mm]
Arc	22
Wiggler	8
Straight section	49

Transverse Coupled-Bunch Instabilities

The growth rate of the l-th coupled-bunch(CB) mode of the transverse multibunch instability is given by imaginary part of the coherent frequency shift:

$$\Delta\omega_y(l) = -i\frac{I_{beam}\omega_0}{4\pi(E/e)}\sum_{p=-\infty}^{\infty}\beta_y Z_y[\omega_\beta + (pM+l)\omega_0]$$

$Z_y(\omega)$ is the transverse impedance, $I_{beam} = eN_eMf_0$ is the average beam current, $f_0 = \omega_0/(2\pi)$ is revolution frequency, E is the beam energy, and M is the number of bunches in the ring. The formula assumes a uniform distribution of bunches.

Transverse Coupled-Bunch Instabilities

The main impedance contribution to the growth rate of the coupled-bunch instability is from the resistive-wall impedance. The fastest growing mode is

$$\operatorname{Im}\Delta\omega_y = \frac{4\pi}{Z_0 c}\frac{c}{4\gamma}\frac{\langle I\rangle}{I_A}\sqrt{\frac{1}{C(1-[\nu_y])}}\langle\beta_y A_y\rangle\,,$$

$\langle I\rangle$ is the average current, $I_A = 17$ kA, C is the circumference, $[\nu_y]$ is the fractional part of the tune, and $\langle\beta_y A_y\rangle$ is the weighted resistive-wall wake field.

$$\langle\beta_\perp A_\perp\rangle = \frac{2}{\pi}\sqrt{\frac{Z_0 c}{4\pi}\frac{c}{\sigma_c}}\frac{1}{C}\int ds\,\frac{\beta_\perp}{b^3} \tag{1}$$

Resistive wall impedance

Computed values $\langle \beta_\perp A_\perp \rangle$ for the OCS8 lattice

Section	$A_\perp$ [V/pC $\cdot \sqrt{\mathrm{m}}$]	$\langle \beta_\perp A_\perp \rangle$ [V$\cdot \sqrt{\mathrm{m}}$/pC]
Arc	69.1	$2.0 \cdot 10^3$
Wiggler	112.1	$1.4 \cdot 10^3$
Straight section	2.6	60
Total ring	183.7	$1.4 \cdot 10^3$

The growth time for the multibunch transverse instability due to resistive wall impedance.

Growth time, [ms]	2.2
Growth time in number of turns	100

WP5 effort

Work Package 5 – Impedance and Impedance-Driven Instabilities

Institution	FTEs	Names
ANL, USA	1/4	Dong, Chae
Cockcroft Institute, UK	2	Korostelev
IHEP, China	0.2	Gao, Zhou
KEK, Japan	1	
LBNL, USA	3/4*	Venturini(?), Li, Byrd
SLAC, USA	1	Ng, Li, Bane, Stupakov

* email from A. Jackson, 12-6-07

WP5 effort - instabilities

Available tools

- Microwave instability: Vlasov code (Ventirini), linearized Vlasov (Stupakov), elegant, ...
- TMCI: analytical (Satoh-Chin), Matlab, elegant, ...
- Coupled mode multibunch: analytical, (?)

Organization:

- Web site space
- Feasibility to reproduce and verify results
- Impedance database (including geometry used, input files, wake files . . .)
- Standardized format for the computed wakefields (ascii files, sdds?)
- Communication tools (email list, phone meetings, . . .)