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LONGITUDINAL BEAM STABILITY IN THE SUPER B-FACTORY*

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Abstract

We give an overview of wake fields and impedances in a proposed Super B project, which is based on extremely low emittance beams colliding at a large angle with a crab waist transformation. Understanding the effects that wake fields have on the beam is critical for a successful machine operation. We use our combined experience from the operation of the SLAC B-factory and DAΦNE Φ-factory to eliminate strong HOM sources and minimize the chamber impedance in the Super B design. Based on a detailed study of the wake fields in this design we have developed a quasi-Green's function for the entire ring that is used to study bunch lengthening and beam stability. In particular, we check the stability threshold using numerical solutions of the Fokker-Plank equation. We also make a comparison of numerical simulations with the bunch lengthening data in the B- factory.

SUPERB PARAMETERS

The SuperB project is based on extremely low emittance beams colliding at a large angle with a crab waist transformation [1]. Machine parameters, which are relevant for the RF and wake field analyses, are specified in Table 1.

Table 1: Main Super- B parameters

LER/HER	Unit	LNF site
E+/E-	GeV	4 / 7
L	$cm^{-2}\ s^{-1}$	1×10^{36}
I^+/I^-	Amp	2.7/2.7
Circumference	m	1400
Number of bunches		1740
Momentun compaction		$3.2\ 10^{-4}$ / $3.8\ 10^{-4}$
S.R. energy loss	MeV/turn	1.16 / 1.95
Relative energy spread		$8.0\ 10^{-4}$ / $5.8\ 10^{-4}$
Horizontal emittance	nm	2.8 /1.6
Vertical emittance	pm	7 / 4
Bunch length	mm	5 / 5
RF Voltage	MV	8 / 12
RF frequency	MHz	476

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In the SuperB project, we plan to use SLAC PEP-II RF stations and cavities [2].

LOSS FACTOR AND BUNCH LENGTHENING IN PEP-II

To get better approximation of the wake fields in Super-b we use measured values for loss factor [3, 4] and bunch lengthening in PEP-II [5], as these machines are very similar to each other. Fig. 1 shows a history plot of the HOM loss factor of the high-energy ring (HER) and low-energy ring (LER) of PEP-II.

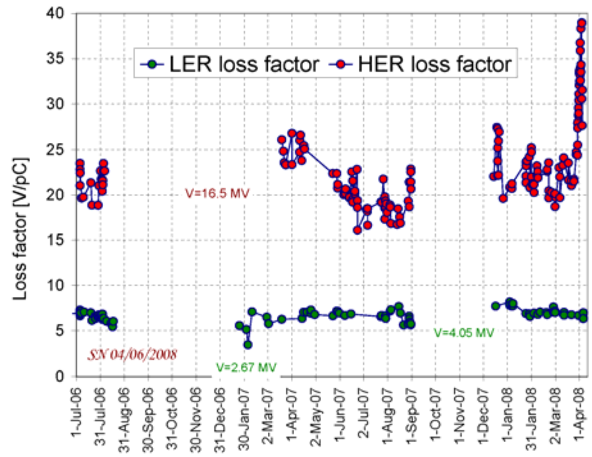

Figure 1: Loss factor of PEP-II rings over the last two years: LER-green circles, HER-red circles.

Bunch lengthening in PEP-II LER as a function of the bunch current is shown in Fig. 2, and bunch lengthening in HER ring is shown in Fig. 3.

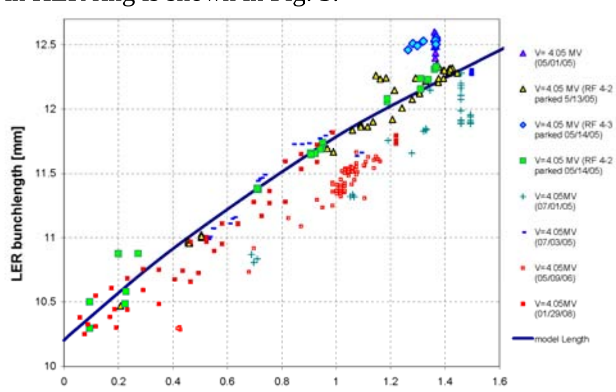

Figure 2: LER bunch length as a function of a bunch

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current measured in multi-bunch regime at different RF station combination and simulated (solid line).

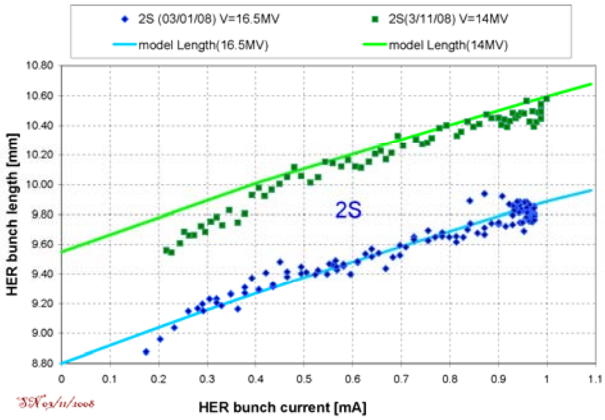

Figure 3: Measured and simulated (solid lines) HER bunch length as a function of a bunch current at the 2S for two different RF voltages: 16.5 MV (blue diamond) and 14 MV (green squares). Measurements were done in multi-bunch regime.

We have developed quasi-Green's wake functions for the LER and HER taking into account all vacuum elements and additional "model wake fields" (especially for HER) to fit the measured loss factor and the bunch lengthening. These functions are shown in Fig. 4.

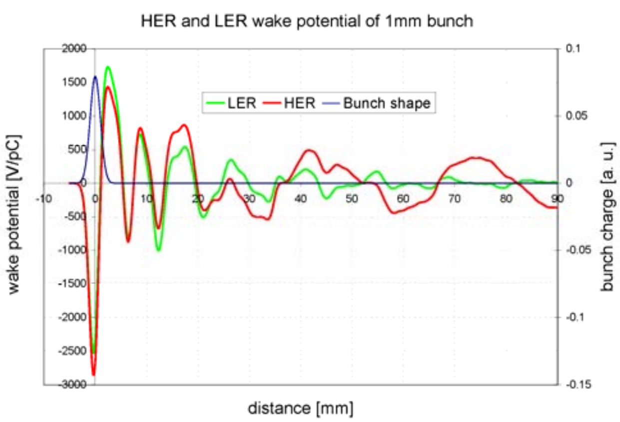

Figure 4: HER (red) and LER (green) wake potentials of a 1 mm bunch, which were used as quasi-Green's functions to calculate the bunch lengthening.

To find the microwave instability threshold and bunch lengthening we solve numerically Fokker-Plank equation using these quasi-Green functions.

$$\frac{\partial}{\partial t}\psi + \dot{x}\frac{\partial}{\partial x}\psi + \dot{p}\frac{\partial}{\partial p}\psi = \frac{\partial}{\partial p}\left\{ D_1 p\psi + D_2 \frac{\partial}{\partial p}\psi \right\}$$

Phase distribution function $\psi = \psi(t,x,p)$ is a function of canonical coordinates: relative longitudinal position x and relative longitudinal momentum p.

$$\dot{x} = \frac{1}{M_\rho} p \quad M_\rho = -\frac{E}{\alpha_\rho c} = const$$

E is beam energy, α_ρ is a momentum compaction.

The radiation damping D_1 and the diffusion parameter D_2 have also uniform distribution in the ring. We define them as a function of a radiation damping time τ_d and steady state energy spread σ_e

$$D_1 = \frac{2}{\tau_d} = const \quad D_2 = \frac{2}{\tau_d}\sigma_e^2 = const\ .$$

Time derivation of the longitudinal momentum is the force of the RF and the wake fields $F_{RF}(t,x)$ and $F_W(t,x)$

$$\dot{p} = F_{RF}(t,x) + F_W(t,x)$$

For solving the Fokker-Plank equation, we use same computer algorithm, which was used for the stability study of the longitudinal motion in a ring [6], [7] and in simulations of electron cloud multipacting in a solenoidal magnetic field [8]. Results for bunch lengthening in PEP-II for LER and HER are shown in Fig. 2-3 by solid lines. Instability threshold was found to be at the bunch current of 3 mA, that agrees well with maximum bunch current achieved in PEP-II.

LOSS FACTOR AND BUNCH LENGTHENING IN SUPER-B

The SuperB project uses the smaller momentum compaction than PEP-II. This means that requirement for the impedance of the vacuum chamber is more stringent. We may characterize wake fields by main parameters as loss factor κ and inductance L (or energy spread due to wake fields). Loss factor defines the RF phase shift of a bunch and inductance defines the bunch lengthening

$$\delta x \approx \sigma_0 \Lambda k \qquad \delta\sigma \approx \sigma_0 \Lambda * L$$

with a machine parameter $\Lambda = \frac{\sigma_0}{\Pi} \frac{Q_{bunch}}{\alpha E \left(\frac{\Delta E}{E}\right)^2}$

Machine parameter Λ contains a momentum compaction in the denominator, so in order to have same bunch lengthening for smaller momentum compaction we need smaller inductance. Together loss factor and inductance determine the microwave threshold. Therefore, for smaller momentum compaction machine we need to decrease both loss factor and wake field energy spread. Assuming that we can decrease these parameters by a factor of 2 in comparison with PEP-II, we perform simulations of the bunch dynamics for SuperB parameters using quasi-Green's function with half amplitude. Results for bunch lengthening in SuperB are shown in Fig. 5 for LER and Fig. 6 for HER at different RF voltages. Microwave thresholds are 3 A for both rings at RF voltage of 12 MV for HER and 8 MV for LER.

How can we decrease the impedance of the rings? First, we plan to check every element, which we used in the PEP-II vacuum chamber in order to modify or to use a new design on the way to decrease the impedance. Besides, we will use less resistive material of the chamber to decrease the resistive-wall wake fields (in PEP-II LER straight sections were build from stainless steel).

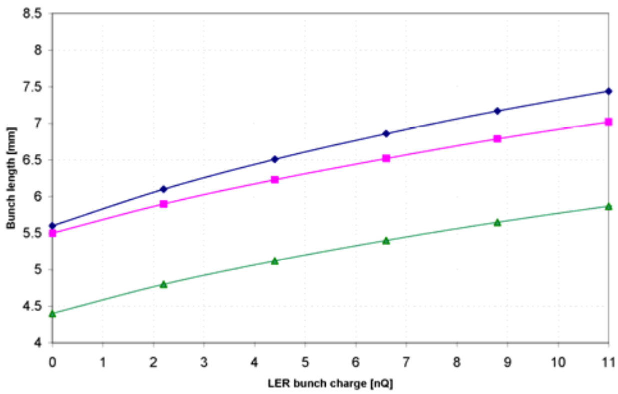

Figure 5: Bunch lengthening as a function of a bunch charge in Super-B for LER at different RF: green line for 12 MV, pink line for 8 MV and blue line for 6 MV.

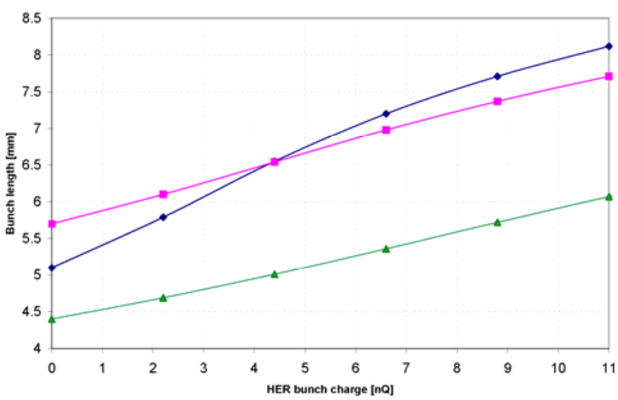

Figure 6: Bunch lengthening as a function of a bunch charge in Super-B for HER at different RF: green line for 20 MV, pink line for 12 MV and blue line for 8 MV.

IP region will not contain open absorbing ceramic tiles, which gave additional losses in PEP-II. Symmetrical collimators produce less HOM losses than asymmetrical. BPM button will be modified.

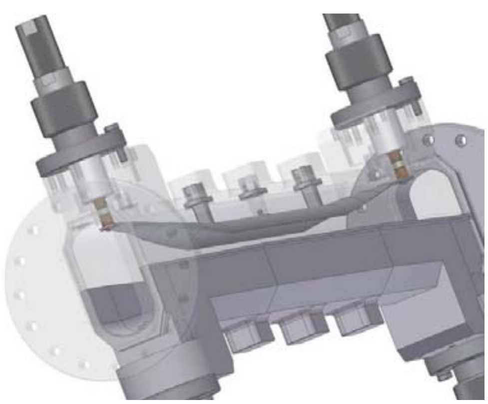

Figure 7: DAΦNE new injection kickers
(Courtesy D.Alesini)

We may use new low impedance devices, developed at INFN Frascati for DAΦNE Upgrade [9]. Fig. 7 shows a drawing of new injector kickers that has special shape of an electrode, which was optimized for smaller impedance and better matching with coaxial cables. Fig. 8 shows a new shielded bellows that has not only very small longitudinal impedance, but also a transverse one. That is very important because any transverse field excited by other elements like collimators may penetrate through the shielded fingers and excite resonance modes in the cavity behind the shielding (this experience we had at PEP-II).

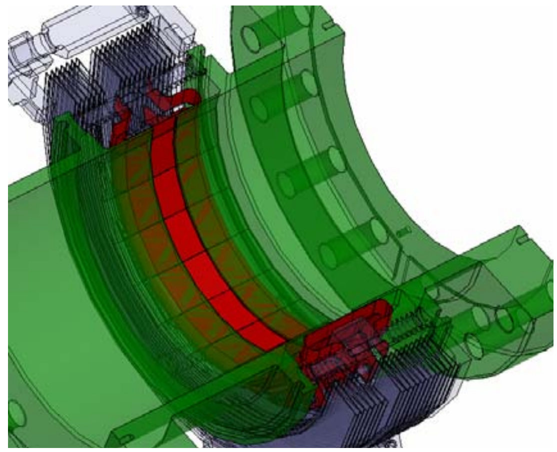

Figure 8: DAΦNE shielded bellows
(Courtesy F. Marcellini)

We also plan to gain from KEKB group's experience in developing and testing low impedance vacuum chambers capable to cope with high intensity beams having short bunches [10].

CONCLUSIONS

We have shown that bunch lengthening and the microwave instability in the SuperB rings can be kept under control by designing a vacuum chamber with the coupling impedance by a factor of two smaller with respect to that of PEP-II. This can be done by exploiting the experience of the operating B- and Φ- factories in designing low impedance vacuum chamber components, modifying existing vacuum chambers and using less resistive materials in order to decrease the resistive wall contribution.

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