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Impedance Study for the PEP-II B-factory⋆

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The paper summarizes results of the impedance studies of the components of the B-factory. The prime goal of this activity was to support the design of the vacuum chamber and, at the same time, to get reasonable model of the machine impedance, which can be used later for detail studies of collective effects.

Coherent effects impose certain limitations on the magnitude of the impedance. The potential well distortion may give 10% bunch lengthening for the inductance $L =$ 225 nH or $Z/n = 0.2\ \Omega$ for the HER at the nominal 1A current. The microwave longitudinal and transverse instability set the limit on the effective impedance which is higher than the nominal machine currents. The transverse mode-coupling can be more dangerous but seems that we have a safety factor of the order of two. More serious limitations come from coupled bunch instabilities. Comparison with the damping time gives conservative limits on the impedance at a frequency f, the rms bunch length σ_B, and the nominal parameters of the rings:

$$(\frac{f}{GHz})(\frac{ReZ}{k\Omega})e^{-(2\pi f\sigma_B/c)^2} < 19.5\ (HER); \quad < 4.1\ (LER),$$

$$\frac{ReZ_\perp}{K\Omega/m}e^{-(2pif\sigma_B/c)^2} < 119.8\ (HER); \qquad < 26.6\ (LER).$$

The power deposited in the beam pipe by an uncorrelated train of bunches is $P = 4.16$ kW for the loss factor of $\kappa_l = 1$ V/pC.

The impedance generating elements are similar in both rings. They are mostly inductive, their contributions are summarized in the Table. The impedance of the LER ante-chamber replaces the impedance of the DIP screen, and wigglers give an additional contribution to the LER impedance budget.

The dominant contribution to the impedance comes, of course, from the damped RF cavities. The main longitudinal monopole and transverse dipole modes has been found numerically with the code URMEL and measured on a prototype cavity. The maximum narrow-band (NB) impedance of a single cavity is larger than the limit of stability requiring a feedback system. Optimization of the vacuum chamber should be considered, in this context, as an attempt to minimize the requirements on the feedback system. The same is true for the dipole modes.

The longitudinal antechamber was measured and modeled with MAFIA. Calculations carried out with different length, height and width of the entrance slot, and different depth of the ante-chamber. In all cases, the wakefield is inductive and small. No trapped modes were found.

The beam abort system requires a long and deep vacuum chamber under the beam, which is terminated with a dump. To minimize the impedance, the chamber is screened with shallow RF tapers (down and back up to the beam pipe). The minimal angle of the taper-up is limited by the radiation length and the thickness of the screen. MAFIA calculations of the tapers give an inductive wakefield with no narrow-band trapped modes found.

The interaction region is a complicated 3-D set of masks and tapers was modeled with MAFIA as a whole structure. The main issue for the IR is heating which comes from the trapped modes in the central Berillium pipe ±20 cm around the IP. The power deposition within the Berillium pipe depends on the loaded Q-factor of the modes. We estimate $Q_{ext} = 1200$ for a typical $f_m = 5.7$ GHz. In this case, only 10% of the power loss goes to the Berillium pipe wall. In principal, detuning from a resonance can be done by heating of the Berillium pipe. The power loss is enhanced for a train of bunches with bunch separation S_b for the resonance frequencies $\omega_r s_B/(2\pi c) = integer$. The frequency spectrum of a train of bunches also has frequencies at the multiples of the

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revolution frequency ω_0, but the total loss of the coherent modes is smaller than the uncorrelated power loss P_0.

The injection port generates impedance due to a slot in the tapered beam pipe wall and the taper. The impedance calculated with MAFIA was found to be mostly inductive with no indication of the trapped modes found.

The kicker ceramic has a thin titanium coating. The wakefield generated by the ceramic section is mostly resistive and is described by $R_\Omega = 5.7\ \Omega$, and the loss factor $k_l = 0.04$ V/pC.

The final version of the BPM uses a round button with $a = 1.5$ cm diameter. Such a design, as MAFIA calculations show, satisfies requirements for sensitivity, heating, and power output to the cables. Measurements confirmed the results of MAFIA simulations quite well. For a 4-button BPM and 3A current the sensitivity is defined by the impedance 0.5Ω at 1 GHz. Power output to a cable is found by direct calculations of the fields at the port. The 1 cm beam offset in the direction to a button can increase the power to the cable by a factor of 2. The power absorbed in the ceramic, and in the thin Ni layer are small. The Q factor given by these losses is $Q_0 = 534$. The loaded Q_L determined by MAFIA and confirmed in wire measurements on a BPM prototype is much smaller ($Q_L \simeq 60$). Theory and measurements predict that most of the power is radiated back to the beam pipe. It is too low to enhance the power loss in a train of bunches. Some enchancement (by a factor of 6.2) may occur if a button cable is accidentally disconnected. The effects of the button recess was studied and found to be insignificant.

The design of the bellows module uses fingers outside of the beam pipe and does not use large synchrotron radiation masks. Instead, the beam pipes are offset horizontally by a few mm and the transitions are tapered to produce sufficient protection from synchrotron radiation. The impedance of the quadrupole/dipole transition with the tapered beam pipe offset was modeled with MAFIA. No trapped modes were found. The impedance of the bellows module is generated by finger slots, slots in the bellows corners, small tapers of the synchrotron radiation masks, and the RF seals. All contributions are small and correspond to an inductive impedance. The estimate of the impedance of the RF bellows seals is valid also for the flange gap-rings. The main issue for the bellows is not the beam impedance but the heating and operational reliability of the fingers. Heating by radiation through the slots and by coupling to the eigen modes in the bellow cavity outside the fingers have been considered.

Ports of the lumped vacuum pumps are screened with a grid of long and narrow slots. The potential problem here is the possibility to have trapped modes. The theory predicts a trapped mode at the grid of the vacuum port in the arcs with quite high shunt impedance. To eliminate trapping, the beam pipe at the vacuum port may be recessed with the recess volume equal or slightly larger than the polarizability of the slots. Numerical simulations with MAFIA confirmed this statements. A mesh of small holes on the pump side should be used to prevent propagation of TE modes to the pumps.

The longitudinal and transverse kickers for PEP-II are modeled after those designed and measured for the ALS.

The misaligned beam pipes can generate additional impedance. It was estimated with empirical formulas and confirmed by ABCI. The tolerance for the misalignment is 2 mm. The impedance of the synchrotron radiation is suppressed exponentially and gives negligible contribution for the PEP-II impedance budget.

The cross-talk between spatially close components has been considered, modeled, and designed to avoid mode trapping.

The main contributions to the impedance of PEP-II come from the RF cavities and the resistive wall impedance. Components giving the main contribution to the inductive part of the impedance are summarized in Table 1. The transverse impedance is dominated by the modes of the RF cavities, and resistive wall estimated above. The rest of the ring gives small a contribution and, therefore, it may be suffice to have an estimate of such a contribution based on results for the longitudinal impedance.

Table 1. The PEP-II HER inductive impedance

Parameter	L (nH)	k_l (V/pC)
Dipole screens	0.10	
BPM	11.	0.8
Arc bellow module	13.5	1.41
Collimators	18.9	0.24
Pump slots	0.8	
Flange/gap rings	0.47	0.03
Tapers oct/round	3.6	0.06
IR chamber	5.0	0.12
Feedback kickers	29.8	0.66
Injection port	0.17	0.004
Abort dump port	0.23	0.005
Total	83.3	3.4