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OVERALL HOM MEASUREMENT AT HIGH BEAM CURRENTS IN THE PEP-II SLAC B-FACTORY*

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Abstract

We describe a simple method of measuring the total Higher Order Mode (HOM) losses and the synchrotron radiation losses in a storage ring based on a straightforward model of a beam – cavity interaction and a precise knowledge of the rf power distribution. This method works well at higher currents. The comparison of the measured HOM losses and the estimates is given for both Low Energy Ring (LER) and High Energy Ring (HER) rings of the PEP-II SLAC B-factory.

INTRODUCTION

Intensity dependent effects play an important role in operation of the high luminosity colliders. Achieving a luminosity of more than 10^{34} cm^{-2} sec^{-1} in the PEP-II B-factory was partially due to the increase of operating currents [1]. Higher current means more power in coherent and incoherent radiation. This power dissipates in the vacuum chamber elements. In 2005 we increased LER rf voltage from 4.05 MV to 5.6 MV and immediately found a strong evidence of the power of the Higher Order Modes. Several BPM buttons were destroyed. The temperature of the LER chamber increased in average by 4 ^{0}F (Fig.1), and a temperature rise in some bellows was much higher.

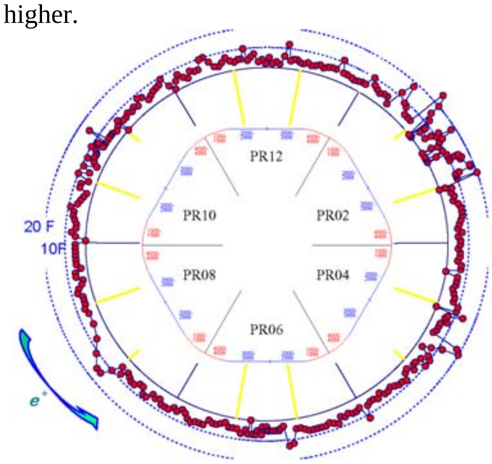

Figure 1: Temperature rise in the LER quad chambers due to rf voltage change from 4.05 MV to 5.6 MV.

How much power radiates in the form of HOMs? We already measured [2-3] some part of this power captured in different absorbers (Fig. 2) at the level of several kilowatts; however the total power may be much higher.

To measure the total HOM power we use rf power balance method, and the quality of synchrotron radiation power to scale linearly with a beam current. We assume that we can measure rf power with accuracy better than ratio of the HOM power to the synchrotron radiation power.

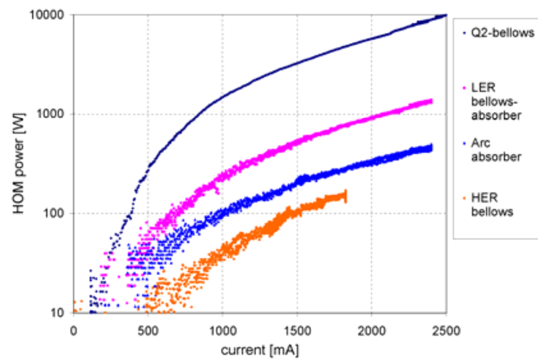

Figure 2: Measured HOM power in the PEP-II absorbers.

In 1981 rf power balance method was used at Cornell to measure loss factor of a single bunch. The result was in good agreement with the one obtained by a phase shift measurement [4]. We will use this method in a multi-bunch regime, so we will measure not only a single bunch loss factor, but also multi-bunch coherent HOM losses.

REFLECTION FROM A CAVITY

We can estimate reflected wave amplitude by the expression $U_{refl}(t) = -U_{frwd}(t) +$

$$+\frac{2\beta}{\beta+1}\int_0^{\infty}\left[U_{frwd}(t-\tau_l x)+U_b(t-\tau_l x)\right]e^{(i\Delta\omega\tau_l-1)x}dx\ ,$$

which includes forward amplitude U_{frwd} of the wave coming from a klystron and amplitude U_b excited by a beam; coupling coefficient β; cavity frequency shift $\Delta\omega$ and loaded filling time $\tau_l = \frac{2}{\beta+1}\frac{Q_0}{\omega_{cav}}$. Fig. 3 shows an example of reflected power for the case of high current (2.4 A) and strong detuning (-240 kHz), when a bunch train has an abort gap of 23 bunches.

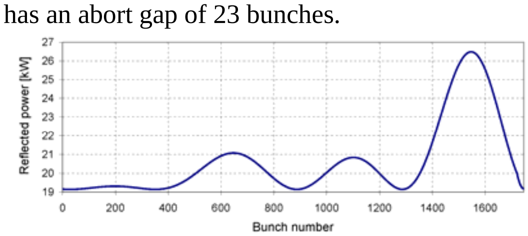

Figure 3: Calculated reflected power.

Reflected power measured at LER for approximately same parameters is shown in Fig. 4.

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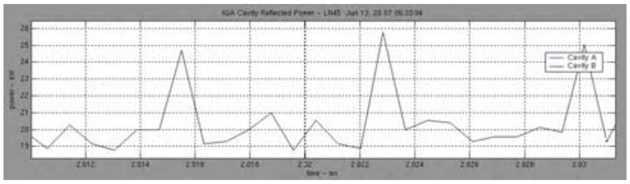

Figure 4: Reflected power from a cavity in the LER.

RF POWER BALANCE

PEP-II has eight cavities in the LER and twenty eight cavities in the HER. When cavity phases are mismatched, electromagnetic power may be delivered from one cavity to another through the beam partial acceleration and deceleration. For this case we need to include all cavities in the power balance equation

$$\sum_{cav} P_{cav}^{forward} = \sum_{cav} P_{cav}^{reflected} + \sum_{cav} P_{cav}^{loss} + P_{beam}$$

A sum also helps to decrease the stochastic error. Cavity loss power is corrected if a cavity voltage changes with a beam current $P_{cav}^{loss} = P_{cav}^{loss}(0)\left(\frac{U_{cav}(I)}{U_{cav}(0)}\right)^2$.

The power, which is delivered to a beam, immediately radiates as incoherent and coherent radiation. Due to incoherent radiation (synchrotron radiation) the beam loss power has a linear term, and due to coherent radiation (HOM losses) it has a quadratic term

$$P_{beam} = U_{S.R.} \times I + Z_{HOMs} \times I^2$$

There, naturally, can be some limitations on HOM power measurement. For example, at the interaction region (IR) the power can be transferred from one beam to another through the excitation of IR parasitic cavities. We observed this effect at several resonant frequencies during the spectrum IR measurement. Fortunately these resonances have low Q-value. Next effect is a bunch lengthening, which may distort the quadratic current behavior of the HOM losses.

RESULTS OF MEASUREMENTS

We usually do measurements during the transient period when particles are injecting in the ring from the scratch.

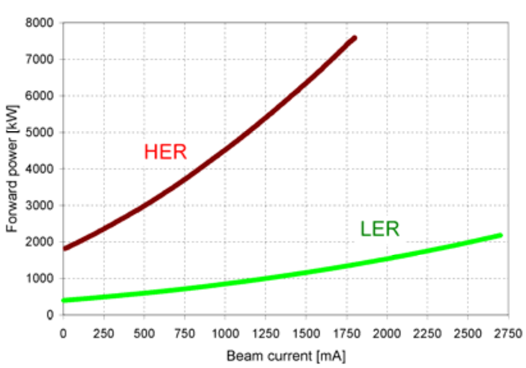

Figure 5: Total forward power in HER and LER.

A Fig. 5 shows the total forward power in LER and HER as a function of beam current. The reflected power from all cavities is shown in Fig. 6. To calculate the beam loss power we take the difference between the forward and the reflected power and subtract the cavity losses. The result is shown in Fig. 7. Finally we subtract the linear part from the beam loss power. This result is shown in Fig. 8 with a quadratic approximation.

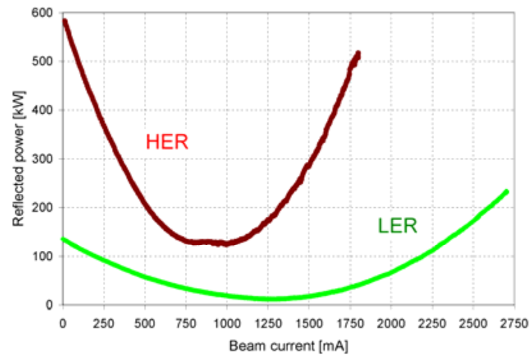

Figure 6: Total reflected power.

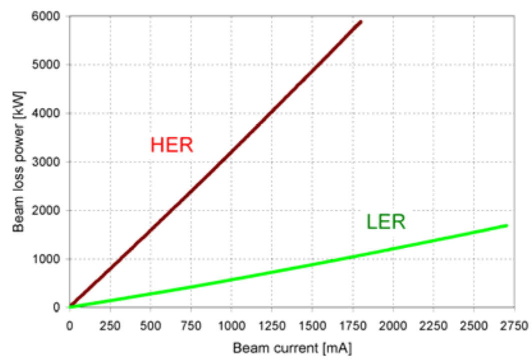

Figure 7: Beam loss power.

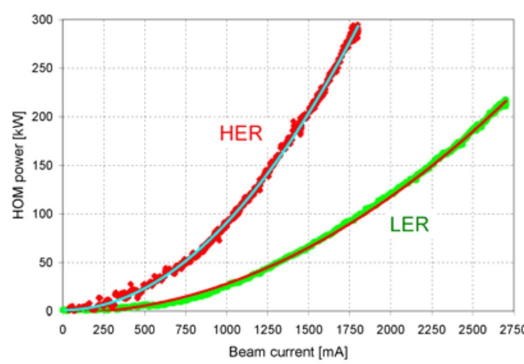

Figure 8: Total HOM power.

As a quadratic dependence of the rest (HOM) power versus beam current is evident, we can calculate HOM loss factor κ using the formula $\kappa = \frac{P_{HOM}}{I^2} N_b f_{rev}$, where N_b in number of bunches and f_{rev} is a revolution frequency. A linear term of the beam loss power gives the synchrotron radiation (S.R.) energy loss per turn.

Synchrotron radiation

Comparison of the measured and the predicted [5] S.R. energy losses may give an estimate of the error in the HOM power measurements. Fig. 9 shows the measured S.R. energy loss during the PEP-II run in 2006 and in 2007. Averaged measured numbers are less than the predicted by 10% in the HER and 17% in the LER, however scaling with a beam energy works with much better accuracy. During off-resonance run, the HER beam energy is 0.75% less, that corresponds to -3% of the S.R. loss. Our method gives -3.2%. We also found good agreement with predicted energy loss for the case when the LER wiggler was partially on [6]. Our measurement showed 11% rise in the energy loss.

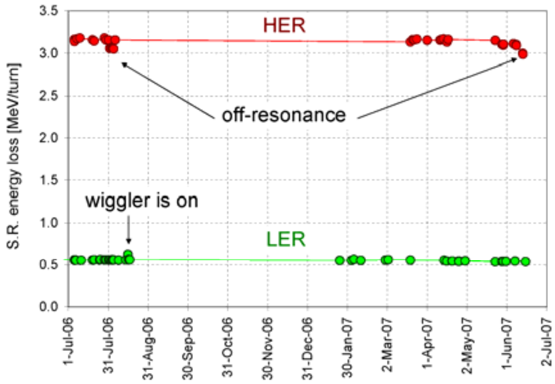

Figure 9: S.R. energy loss per turn.

HOM loss factor

History of the HOM loss factor measurement is shown in Fig. 10. The LER loss factor stayed almost constant. It changed when rf voltage was changed. We found that the loss factor scales linearly with the rf voltage. The HER loss factor considerably changed in 2007 because two new rf cavities were added to the ring and the HER part of IR was modified.

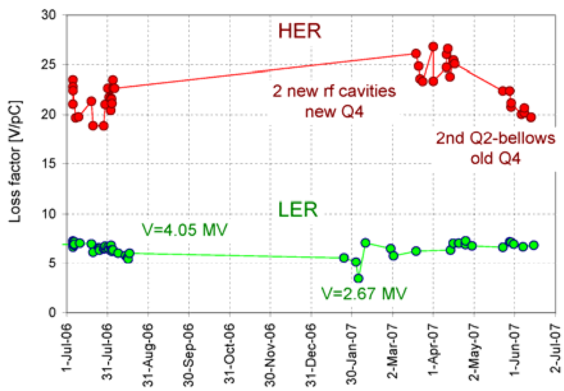

Figure10: HOM loss factor.

But later a vacuum leak was found and a new chamber was replaced by an old one. Additionally a new Q2-bellows [3] was installed at the A-side of IR. In average the HER loss factor is more than three times larger than the LER loss factor. To understand this difference we revised old wake field simulations [7] and made a new estimate of the HOM power. Table 1 shows calculated power in the different vacuum elements and the total ring power (more details are given in reference [8]).

Table 1: Calculated and measured HOM power in PEP-II.

	LER 2900 mA	**HER 1800 mA**
Vacuum element	**Power [KW]**	**Power [KW]**
RF cavities	63.46	76.16
Collimators	18.11	16.7
Kickers	17.3	6.08
Screens	1.24	5.5
BPMs	9.4	3.6
IR wakes	13.66	5.26
Resistive wall	71.74	36.15
Total power	195	167
Measured power	**210**	**298**

We have good agreement for the LER loss factor, but still need to find an additional HOM power in the HER. We may suspect the chamber flanges and the shielded bellows, because they all have temperature rise. Additional contribution may come from the HER distributed pumps or other vacuum elements.

ACKNOWLEDGEMENT

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