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A MODEL OF AN ELECTRICAL DISCHARGE IN THE FLANGE CONTACTS WITH OMEGA SEALS AT HIGH CURRENTS IN PEP-II.*

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Abstract

During PEP-II operation with high currents in the High Energy Ring (HER), elevated temperatures were found at many locations in the vacuum chamber where we have an RF seal for the flex flange. Most of these omega RF seals were badly damaged and had evidence of metal vaporization from sparks and electrical discharge. We suggest a physical model, which may explain this effect.

INTRODUCTION

To achieve more and more luminosity in the PEP-II SLAC B-factory we steadily increased currents in both rings. At the level of 1.7-1.8 A in the HER we found stochastically distributed vacuum bursts almost everywhere in the arcs [1]. Thermocouples attached to flanges also showed random temperature rises and oscillations. The RF omega seals installed between these flange joints keep the inside of the beam pipe RF smooth. This flex joint flexes in order to compensate for beam pipe motion due to synchrotron radiation heating. Unfortunately, we found that the flexibility was not adequate at the higher HER beam current. As a result, nearly every one of the omega seals were damaged and partially melted (Fig. 1). Some copper parts of the flanges where the seal touched the surface show traces of breakdown (left photo in Fig. 2).

FLANGE TEMPERATURE RESONANCES

Fig. 1 shows plots of some typical behavior of the flange temperatures with the HER current. Here we present temperatures of five consecutive flanges in Arc 1.

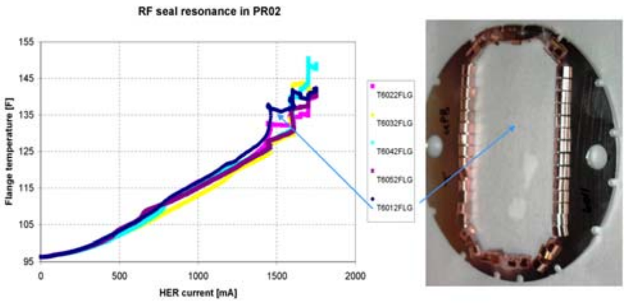

Figure 1: HER temperature resonances and omega seal.

At first, the temperature is linear with the current, as the synchrotron radiation heating is proportional to the current. Then at some current, the temperature jumps up. This suggests that at some current, or more precisely at some chamber temperature, a gap appears in the beam pipe joints and the beam starts generating wake fields. These fields go into the gap and heat the stainless steel disk, which supports the omega seal (Fig. 1). If the gap environment has high a Q-value for RF modes, then the heating may be much stronger. As there is no special water-cooling, the disk temperature can go very high and be limited only by thermal radiation. Resonance temperature behavior can be explained by the coupling through the gap and the existence of high Q-value RF modes.

It was interesting to find out that the space outside the omega seal really has a large volume. Fig. 2 shows neighboring flanges and an omega seal with a support disk.

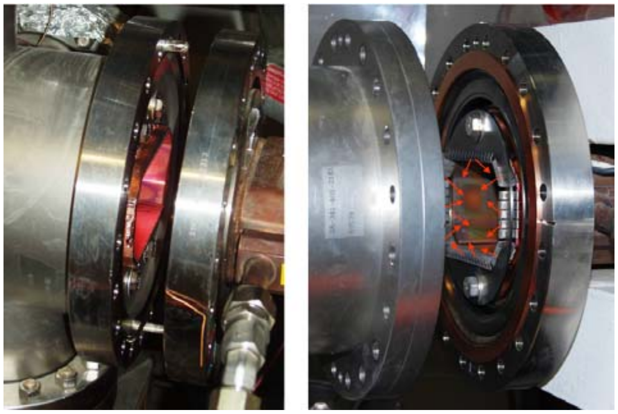

Figure 2: HER flanges and flexible omega seal. Red arrows show the how the seal may be cooled by thermal radiation.

The left beam pipe in Fig. 2 branches out from the flange disk, making a sort of coaxial RF cavity. If an omega seal starts to open a gap, then the open gap starts to behave like a capacitor of a quarter-wave cavity. Let us define the volume outside the seal as a “sealed cavity”.

COMPUTER MODEL

To make a quick estimation of the fields inside this cavity we made a simple 2-d model, which is shown in Fig. 3. In this model, an omega seal does loses contact with the flange on both sides. We assume both open gaps have the same size. We made analyses using the code “NOVO” [2]. A bunch, moving in the beam pipe

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excites electromagnetic fields in the cavity through these gaps. The blue lines in Fig. 3 show the electric force lines of the excited field. The bunch shape and wake potential of an eleven-millimeter bunch are shown in Fig. 4 for the case, when the gap size is 0.5 mm. The wake potential has a resistive character so the beam loses energy exciting the sealed cavity and the beam pipe.

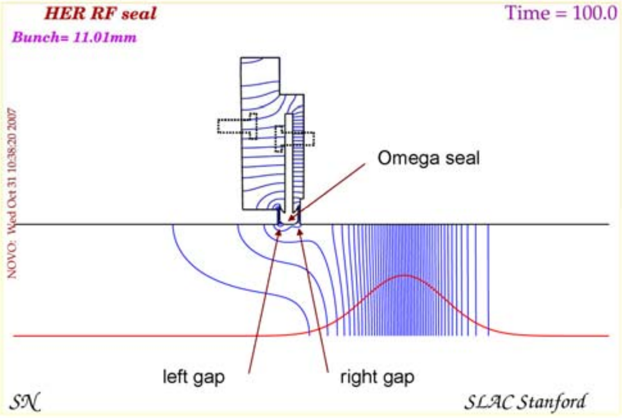

Figure 3: Computer model: HER flanges forming a sealed cavity and a flexible omega seal.

We had calculated the absorbed power P in the sealed cavity according to the formula

$$P = \frac{1}{2} K \tau_b I^2 \cdot$$

We assume that half of the power goes inside the sealed cavity and half of the power travels in the beam pipe. The beam current I =1.8 A, the bunch spacing τ_b = 4.2 nsec. The loss factor K as a function of the gap size is shown in Fig. 5 for a bunch length of 11 and 8.8 mm. We had an 11 mm bunch in the HER at RF voltage of 16.5 MV. We were planning to change the momentum compaction by replacing the 60-degree lattice to 90-degree lattice and increasing the RF voltage up to 18 MV. In this case, the bunch lengths would have been shorter, equal to 8.8 mm. One can see that there is only a slight difference in the loss factor for the different bunch lengths in the case of smaller gap size. So, we would not have had more problems with the shorter bunches, untill the bunch length becomes comparable to the gap size.

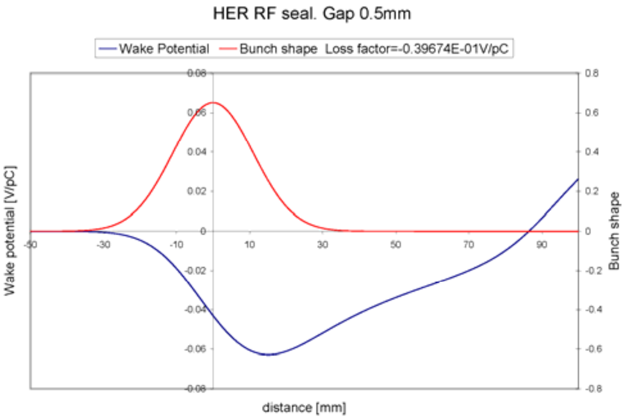

Figure 4: Wake potential of a 11 mm bunch.

The loss factor goes approximately as the square root of the gap size. We therefore predict that the electric field inside the gap can reach high values. The electric field inside the gap as a function of the gap size is shown in Fig. 6.

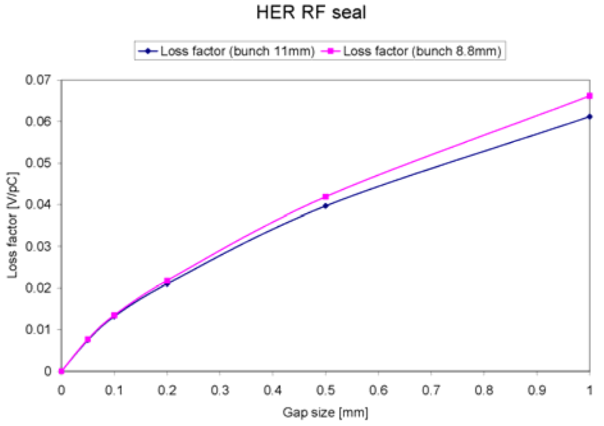

Figure 5: Loss factor of a sealed cavity.

Electric field increases with the smaller gap size and reaches a breakdown limit (we assume 30 kV/cm) when the gap size is less than 0.05 mm for a HER current of 1.8 A. These results show that breakdowns may happen in a gap. The traces of breakdowns are clearly seen on the chamber edge in the left plot of Fig. 2.

Can we simulate the omega seal melting too? The absorbed power in the sealed cavity at a gap size of 0.05 mm is approximately 60 W. Is it enough to melt the copper?

THERMAL EMISSION CONSIDERATION

The stainless steel disk that supports the omega seal absorbs power that comes into the cavity. Its temperature increases until thermal radiation between the seal and the beam pipe (Fig. 2) starts to work. .We can estimate this power using the Stefan-Boltzman law for black body emissive radiation:

$$P_{BB} = A\varepsilon\sigma T^4 \qquad \sigma = \frac{2\pi^5\kappa^4}{15c^2h^3} = 5.67\times10^{-8}\,\frac{W}{m^2K^4}$$

We assume that temperature T is of order of the Copper melting (1300K). The area is the surface of the seal facing the beam chamber $A \approx 1.7\cdot10^{-3}\,\mathrm{m}^2$ and we assume an emissivity $\varepsilon \approx 0.2$. For these parameters, the thermal emission power is 55 W, which is very close to the power absorbed in the sealed cavity. Naturally, at this high temperature, there can be other ways for the radiation power to escape, for example, through stainless steel flanges. These effects will increase the power needed to reach the meting temperature. However, breakdowns and arcing in the gap will localize the power in the omega seal.

SPECTRUM MEASUREMENT

The left flange in Fig. 2 has two holes, which connect the gap environment to a vacuum pump. Through these holes the fields excited in the gap may propagate to the pump. We attached an antenna to a high voltage pump connector to study the spectrum of these fields. We had used similar type of antenna before to measure the HOM spectrum of the fields propagating to other pumps [3]. We installed an antenna in the 6141 pump in Arc 1. Here the omega seal was already changed to a more flexible one. However, even with a good contact there is still coupling to the beam chamber trough the tiny slots (Fig. 1) in the seals. Interestingly, we saw a good signal from the antenna, even with the good seal RF. Fig. 7 shows the spectrum measured in a single-bunch operation, when the beam excites harmonics of 136.3 kHz. Of course, this spectrum includes modes of the sealed cavity and modes of the pump cavity coupled to the sealed cavity through two holes.

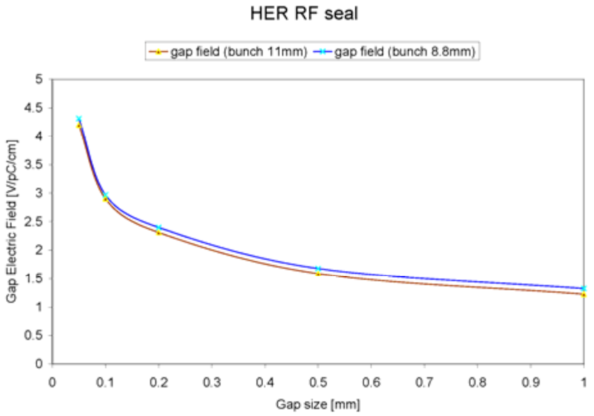

Figure 6: Electric field in the gap.

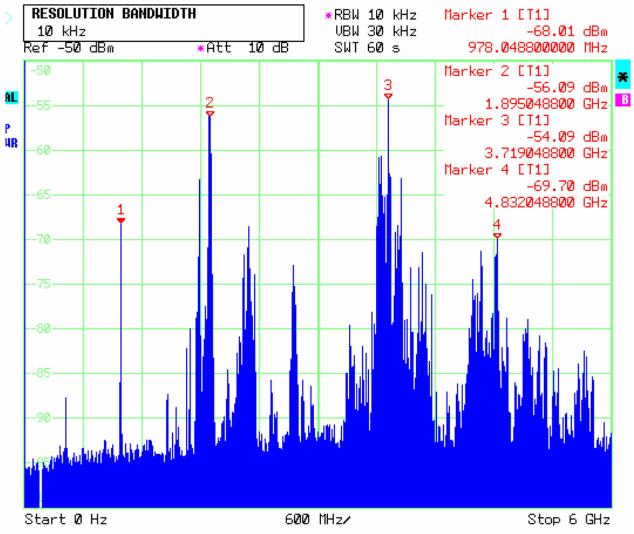

Figure 7: Single-bunch spectrum.

There are several high Q-value modes. Fortunately, not all of them are excited in a multi-bunch operation, when we have only harmonics of 219 MHz. Fig. 8 shows the spectrum in the multi-bunch operation.

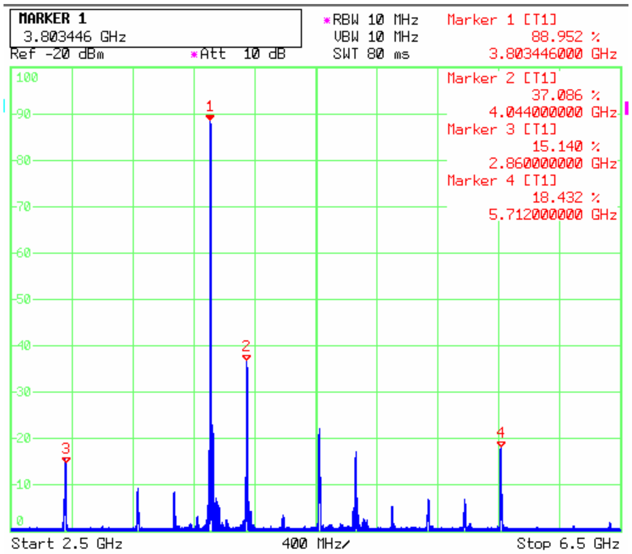

Figure 8: Multi-bunch spectrum.

The transient along the HER bunch train at 3.8 GHz is shown in Fig. 9. One can see that the damping time of this mode is at least one μsec, which means we have a high Q-value of this mode.

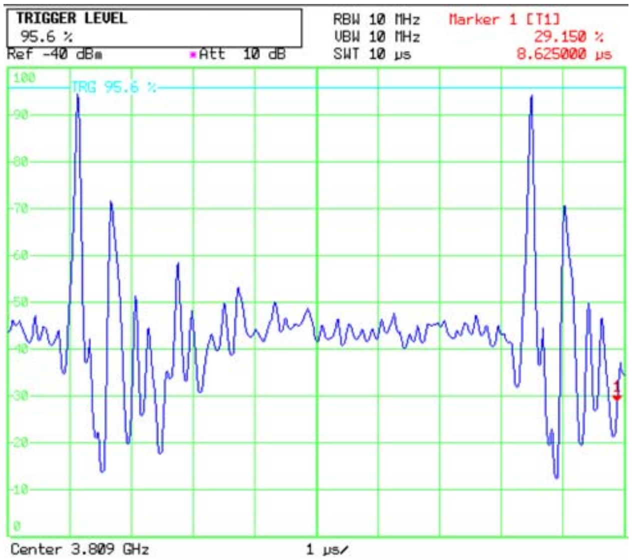

Figure 9: Transient at f=3.8 GHz.

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