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MODELING OF THE SPARKS IN Q2-BELLOWS OF THE PEP-II SLAC B-FACTORY*

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Abstract

The PEP-II B-factory at SLAC has recently experienced unexpected aborts due to anomalously high radiation levels at the BaBar detector. Before the problem was finally traced, we performed a wake field analysis of the Q-2 bellows, which is located at a distance of 2.2 m from the interaction point. Analysis showed that the electric field in a small gap between a ceramic tile and metal flange can be high enough to produce sparks or even breakdowns. Later traces of sparks were found in this bellows.

INTRODUCTION

In 2005 PEP-II achieved a peak luminosity of 10^{34} cm^{-2} sec^{-1} with beam currents of 2.94 A in the low-energy ring (LER) and 1.74 A in the high-energy ring (HER) [1]. After shutting down for a month, we discovered we were unable to sustain LER currents much above 2 A without an abort occurring due to high radiation levels in the detector. The problem was the occurrence of very fast, very high pressure spikes in the vacuum chamber just upstream of the detector. The radiation levels in the detector caused by these gas events were too high and the beam had to be aborted [2]. This problem has quickly became chronic. A wide variety of experiments were conducted to isolate the source of the problem or eliminate possible causes.

The HOM tiles located in the Q2-bellows had always been considered suspect. Q2-bellows is situated at a distance of 2.2 m from IP. The ceramic tiles absorb HOM power of over 10 kW. Among other possibilities we considered that the tiles got very hot and perhaps outgassed because of breakdowns due to the high electric fields initiated by the high LER and HER currents. In addition to the geometrical wake (because of the very complicated geometry of the interaction region) the Q2-bellows also produces Cherenkov radiation. The reason for this is the high permittivity of the tiles. The ceramic tiles are open to the beam, so they capture and store some part of the beam field and then these fields are radiated. After we have checked the bellows drawings it became clear that the omega seal that is next to the tiles had been designed incorrectly. The metal seals were touching the tiles (which are insulators) instead of touching the metal surface under the tiles. Any sharp edge of a seal, which is very close to a ceramic tile may strengthen the electric field many times causing sparking or breakdowns. Then very fast high pressure spikes can be easily explained by these stochastic breakdowns. To study this possibility we carried out computer simulations of the excitation of the electromagnetic fields in the ceramic tiles by the fields of circulating LER and HER bunches.

SIMULATION MODEL

In the model we assume that the effect has more bunch charge dependence than total current dependence, and a higher current LER beam produces consistently higher fields and consequently higher radiation levels than the HER beam. The layout of the Q2-bellows in a vacuum chamber is illustrated in Fig. 1. If an omega seal touches a ceramic tile only, then a small gap opens up and the electromagnetic field can propagate inside the gap between two flanges. A sharp edge of the seal will concentrate the electric field, which will also be large at a ceramic edge. If the electric field is above the breakdown threshold, then ceramic atoms will explode and a lot of ions appear in the vacuum system. Tile material contains AlN+40% SiC.

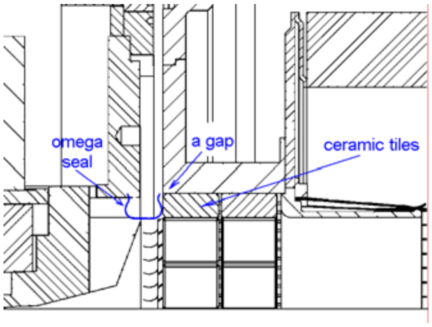

Figure 1: Layout of Q2-bellows (one half), which includes ceramic tiles and omega seal.

For the wake field simulation we used code NOVO [3], which was modified to include dielectric materials. The geometry of the simulation model is shown in Fig. 2.

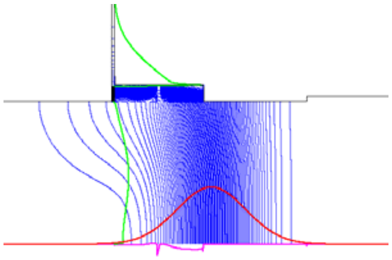

Figure 2: Simulation model. Electric displacement force lines.

The black box approximates the omega seal, the ceramic tiles are shown as a concentration of electromagnetic fields (blue lines). The red curve shows bunch shape. Green curve shows electric field distribution along the

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transverse plane that touches one side of a gap. The pink curve shows the electric field along the surface of a vacuum chamber and ceramic tiles. Bellows fingers are approximated as a step in the vacuum chamber. Snapshots of the eclectic field force lines at different time are shown at Fig. 3.

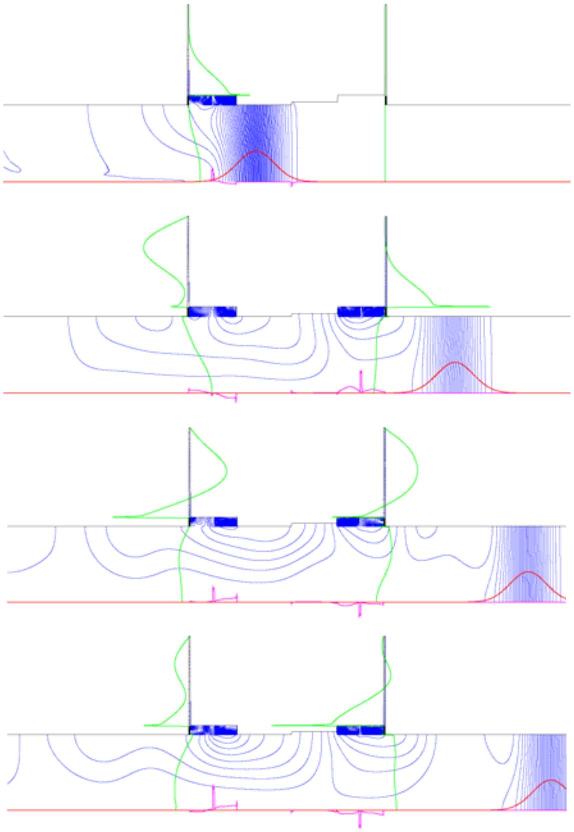

Figure 3: Snapshots of the electric displacement force lines at different times.

Strong fields at the sharp corners of the omega spring and in the gaps between tiles are induced several times during the passage of the bunch. The direction of these fields is also changing in time, so they may produce current emission from a metal surface or from the tile surface. The time duration of the fields in ceramic tiles depends upon the permittivity and dielectric losses, which are in our case are $\varepsilon = 30$ and $\tan\delta = 0.1$. We can estimate this time for a tile thickness d by the formula [4]

$$T_{tile} = 4\frac{d}{c}\frac{\sqrt{\varepsilon}}{\tan\delta}$$

For $d = 4$ mm the formula gives a field duration of $T_{tile} = 2.9$ nsec. This time is less than the time distance between two LER bunches (4.2 nsec), but is larger than the time between the arrival of the LER and HER bunches (2 nsec). So the field induced by a LER bunch can be strengthened by a HER bunch. However, fields in a cavity between stainless steel and copper flanges may survive for a much longer time. We may estimate the filling time of the order of 20 nsec, which means the fields in a cavity will increase 8 times (including HER bunches).

MAXIMUM FIELDS

To find critical points we studied the electric field distribution at different parts of the Q2-bellows. In this simulation the gap between the omega seal and the metal part was 0.5 mm and the bunch length was 13 mm. Fig. 4 shows the most critical point: the omega seal corner near a ceramic tile. Calculation with a mesh step of 0.1mm resulted in a maximum value for electric field of 17.7 V/m/pC.

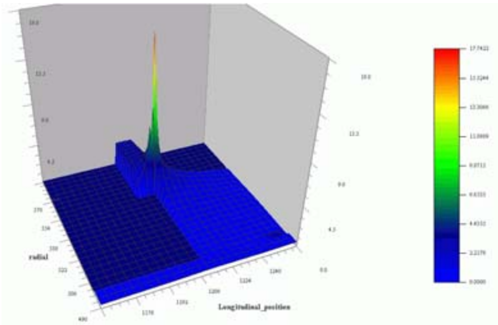

Figure 4: Electric field distribution in the region between an omega seal and ceramic tiles.

The sharp edge of a bellows shield metal finger strengthens the electric field up to 12.2 V/m/pC (Fig. 5).

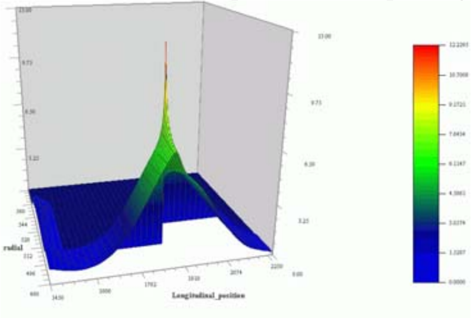

Figure 5: Electric field distribution near a metal corner of a bellows shield finger.

The open corner of a tile near the shield fingers is also a concentration point of the electric field (Fig.6). Peak value of the field reaches 14.1 V/m/pC.

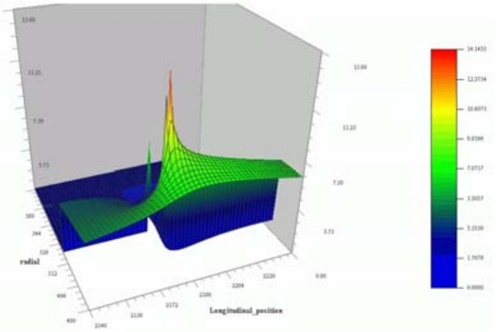

Figure 6: Electric field distribution at an open corner of a tile.

GAP SIZE AND LOSS FACTOR

The peak electric field at the corner of the omega seal will be higher if we decrease the gap size. Simulation results of the peak electric field as a function of the gap size is shown in Fig. 7. In our two-dimension model this function is approximated by the power function with an increment of 0.8.

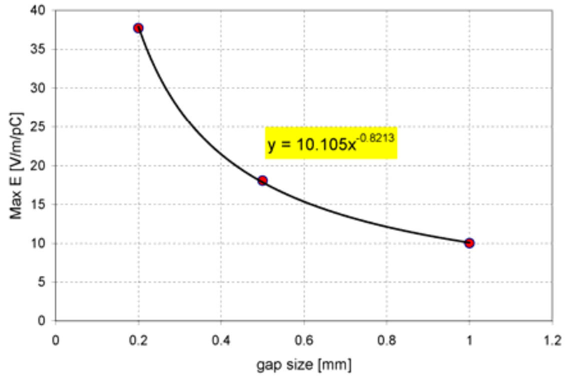

Figure 7: Peak electric field as a function of a gap size between an omega seal and a ceramic tile.

We also calculated theloss factor for a different bunch lengths. The results are shown at Fig. 8. They agree well with the estimation formula from [4-5].

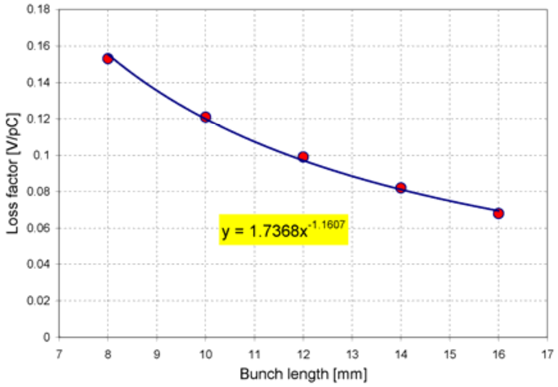

Figure 8: Loss factor as a function of a bunch length

DISCUSSION AND EXPERIMENTAL FOUNDINGS

Results from the previous section give us the possibility to make estimates of the peak electric field during the maximum beam current. At that time the LER current was almost 3A that corresponds to a bunch charge of 12.8 nC. According to our results the peak electric field excited by a bunch may be of order of 1.3 - 4.8 kV/cm for the gap size of 1 to 0.2 mm. If we consider that the field may stay in the cavity between the flanges for 20 nsec, then peak electric field can reach 10 – 39 kV/ cm. If the breakdown limit for the ceramic material is 30 kV/cm, then peak fields can reach this value at a gap size less than 0.28 mm.

In principle the tiles could be destroyed earlier, when we increased the rf voltage from 4.05 MV to 5.6 MV. Even though the currents were lower by approximately 20%, the bunch length change was enough to produce the same peak electric field.

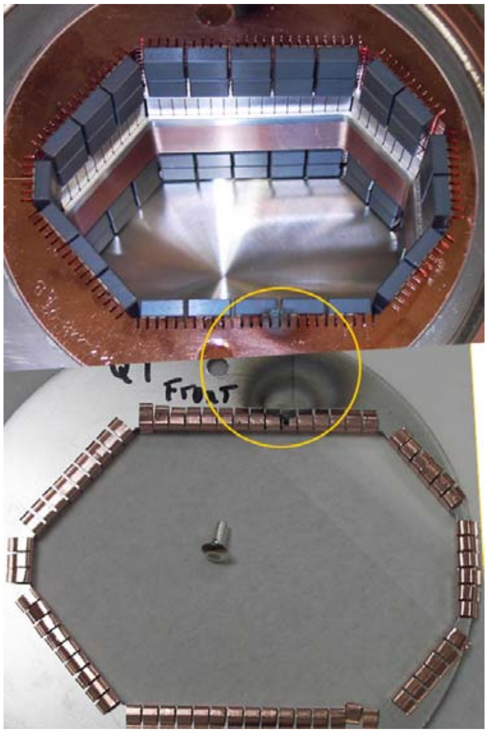

Figure 9: Q2-bellows and Ω-seal with traces of sparking.

After a great deal of experimental work from a very large pool of people the vacuum bursts were eventually identified as coming from a surface arc on the side of a HOM absorber tile located in the Q2-bellows [2]. Electrical burn marks and lost material in two ceramic tiles were found (fig. 10). A close look shows a small discoloration on the edge of the top row of tiles. The breakdown appears to start at the corner of the tile and then travel along the surface of the tile to the copper underneath the tile. The damaged tile is a little closer to the LER than to the HER. The omega seal that mated with the damaged tile has melted copper edges.

REFERENCES

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