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RF Heating and Temperature Oscillations due to a Small Gap in a PEP-II Vacuum Chamber*

A. Novokhatski, J. Seeman and M. Sullivan
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

Abstract

Wake fields excited in a small gap of a vacuum chamber by ampere beams can have enough amplitude to heat the chamber. The electric component of these fields can be above the arcing limit. Usually flange connections in a vacuum chamber contain a vacuum gasket and an inner RF gasket. If a small gap occurs between the RF gasket and flange surface, wake fields can heat the flanges. The flanges are usually made of stainless steel, which efficiently absorbs RF power. Some flanges consist of two parts (like a vacuum valve flange) and are mechanically connected but have poor thermal contact. A temperature rise can lengthen the inner part of the flange and make firmer the thermal contact to the outer part of the flange. The heat will then flow to the outer part of the flange, which is air and water-cooled. This cooling lowers the flange temperature and the thermal contact becomes poor again. This "quasi" periodic mechanism can explain the nature of temperature oscillations observed at several locations in PEP-II, the SLAC B-factory.

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Abstract

Wake fields excited in a small gap of a vacuum chamber by ampere beams can have enough amplitude to heat the chamber. The electric component of these fields can be above the arcing limit. Usually flange connections in a vacuum chamber contain a vacuum gasket and an inner RF gasket. If a small gap occurs between the RF gasket and flange surface, wake fields can heat the flanges. The flanges are usually made of stainless steel, which efficiently absorbs RF power. Some flanges consist of two parts (like a vacuum valve flange) and are mechanically connected but have poor thermal contact. A temperature rise can lengthen the inner part of the flange and make firmer the thermal contact to the outer part of the flange. The heat will then flow to the outer part of the flange, which is air and water-cooled. This cooling lowers the flange temperature and the thermal contact becomes poor again. This "quasi" periodic mechanism can explain the nature of temperature oscillations observed at several locations in PEP-II, the SLAC B-factory.

INTRODUCTION

During the 2001 PEP-II run [1] an unusual behaviour of the valve body temperature was observed in the low energy (positron) ring, in region 2. A high positron current elevated the temperatures on different vacuum chamber elements like bellows and vacuum valves. Mainly the temperatures, measured by thermocouples, varied monotonically in accordance with the positron current. However, thermocouples placed on vacuum valve 2175 showed oscillations of temperature with a period of 3-8 minutes. The amplitude of the oscillations was of the order 5–20 degrees Fahrenheit. The oscillations happened from time to time, when the positron current reaches 1000 mA level and more. A typical temperature oscillation is shown in Fig. 1.

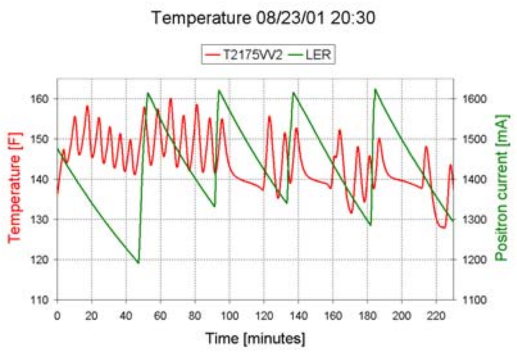

Figure 1: Vacuum valve temperature and positron current.

The red curve (more rapidly oscillations) presents the signal from the thermocouple attached to body of the vacuum valve. The green curve (slow function) shows the time dependence of the positron current during several top-offs. This unusual behaviour of the temperature cycling initiated the wake field study of very small gaps to understand the RF heating.

WAKE FIELDS AND RF HEATING

It was supposed that the gasket (RF gap ring), which is placed in the connection between the vacuum valve and the vacuum chamber, could have dimensions that are incorrect thereby producing a very small gap.

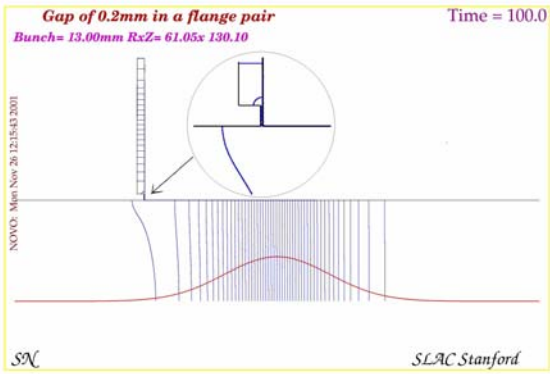

Figure 2: Electric force lines of the field excited by a bunch, travelling in the vacuum chamber with a small gap.

It was suspected that the gap size could be of order of the 100 microns. Flange connection has also a vacuum (main) gasket, which is situated at a larger radius. The positron beam through a small gap could excite a cavity formed by the flange sides and these gaskets.

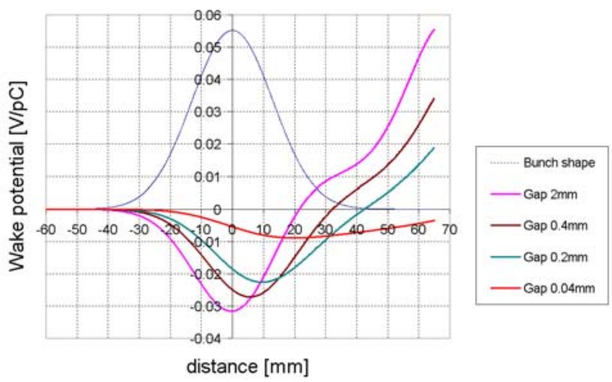

Figure 3: Wake potentials for a bunch length of 13mm for different gap sizes.

The vacuum gasket is a round ring of radius 60.2mm, while the RF gap ring has an elliptical shape with half

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**novo@SLAC.Stanford.edu

axes 25mm and 42.5mm. Wake field calculations were performed for an azimuthally symmetric model of the vacuum chamber for the radii equivalent to the half axes. Code named “NOVO” [2] was used for the calculations, as only this code has the required resolution for such small gap sizes, like 100 micron or less. Wake field calculations for a gap size of 40 micron needs 20 million mesh points. A picture of the electric force lines of the fields excited by the bunch passing a gap is presented in Fig. 2. The gap size is 200 microns and the bunch length is 13mm. Wake field potentials are shown in Fig. 3. Loss factor dependence upon the gap size for different radiuses is shown at Fig. 4.

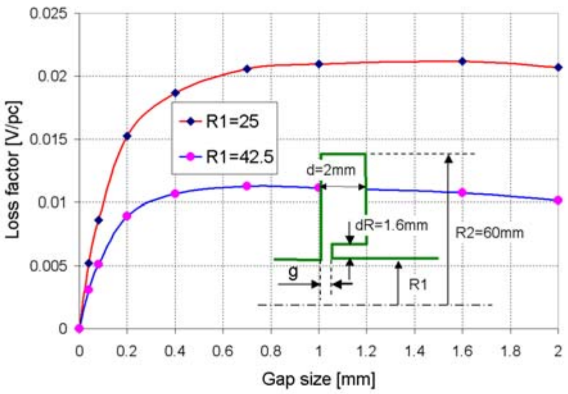

Figure 4: Loss factor as a function of the gap size.

It can be seen that the loss factor is almost constant but vanishing quickly at the gap size of 100-200 microns. The RF power P dissipated in the flanges wall can be estimated as half of the beam power loss (assuming that the other half part propagates in the vacuum chamber)

$$P = 0.5 \times K \times \frac{I^2}{Nf_{rev}}$$

K is the bunch loss factor, I is the positron beam current, N is the number of bunches in the beam, f is the revolution frequency. This estimation gives an RF power of 100-200 W for a gap of 200 microns and I=1600 mA, N=728, f=136 kHz.

In addition to the RF heating, the amplitude of the electric fields that are excited in the gap, can be high enough to exceed the breakdown level. Results of calculations for the electric field amplitude in the gap are shown in Fig. 5. The amplitude increases when the gap size goes down.

The behaviour of the loss factor and the corresponding electric field with the gap size can be easily understood from a simple model of an equivalent LC circuit. In this model we consider a gap to be an additional capacitor, then the total capacitor is

$$C = C_{LC} + C_{gap}$$

According to the geometry (Fig. 3) we can estimate the capacitors to be:

$$C_{LC} \sim \frac{R_2^2 - R_1^2}{8d} \qquad C_{gap} \sim \frac{R_1 dR}{2g}$$

with a loss factor which is inversely proportional to the total capacity

$$K \sim \frac{1}{C} \sim \frac{1}{C_{LC}} \frac{g}{g + 4d\dfrac{R_1 dR}{R_2^2 - R_1^2}} \sim \frac{g}{g + 0.12}$$

Here the gap size is measured in millimetres.

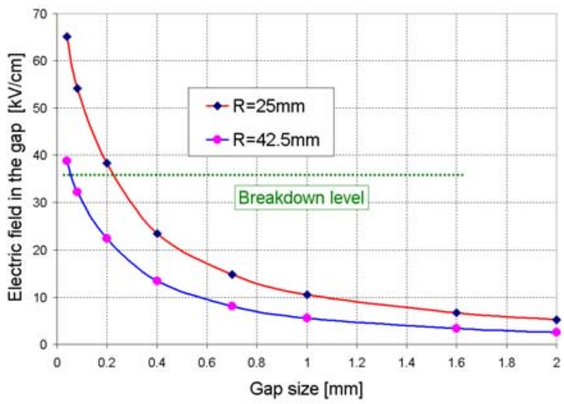

Figure 5: Amplitudes of the electric field in the gap for different gap sizes.

The derived formula says that the loss factor changes when the gap becomes of order of 120 microns. A good comparison of the loss factor with this analytical estimation can be seen from the Fig. 6.

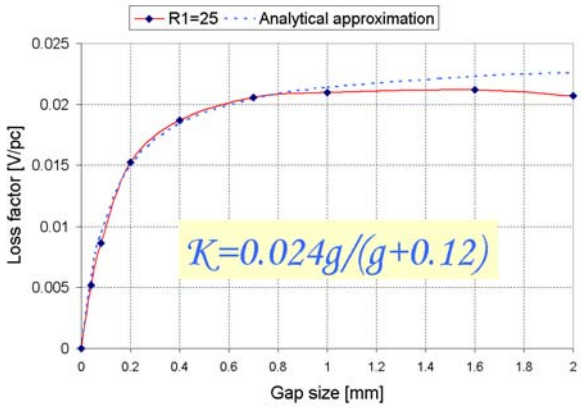

Figure 6: Comparison of the calculate values for loss factor K with the analytical approximation.

This model also gives an estimation of the amplitude of the electric field in the gap

$$E = \frac{V}{g} \sim \frac{1}{\omega C g} \sim \frac{1}{\sqrt{g(g + 0.12)}}$$

So the amplitude of the electric field is inversely proportional to the square root of the gap size. This means that the gap size must be very near zero to avoid any kind of breakdowns. It is interesting to note that thise calculations and predictions for possible breakdowns in the gap were performed before the time when the vacuum chamber flanges were disconnected and traces of the breakdowns tracks were actually observed. Fig. 7 presents a photo of the disconnected flanges and a gap ring. Traces of breakdowns can be easily seen by discolorations on the stainless steel flange at the right. After replacing the ring with one that has the proper size, the RF heating and the temperature oscillations stopped.

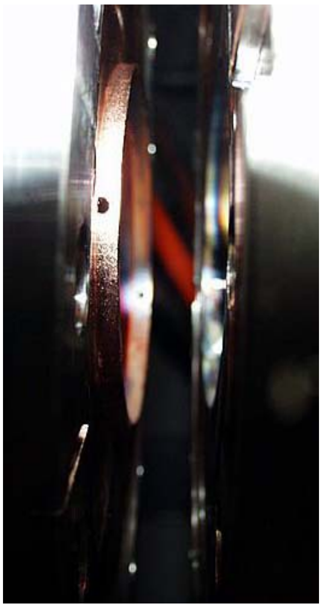

Figure 7: Photo of the disconnected flanges and RF gap ring.

TEMPERATURE OSCILLATIONS

We have studied different models to understand how the temperature oscillations could occur. Here we discuss one model. A vacuum valve flange consists of two stainless steel parts, as it shown at Fig. 8. Parts are connected through a circular ring and radial gaps could be from both sides of the ring. When the inner part of the flange is heated, as was discussed before, the size of these gaps decreases with the temperature and thermal contact is improved. The heat energy flows to the outer flange part, which is cooled though with a fan and a copper water-cooled disk. The temperature then goes down and the radial opens up once again..

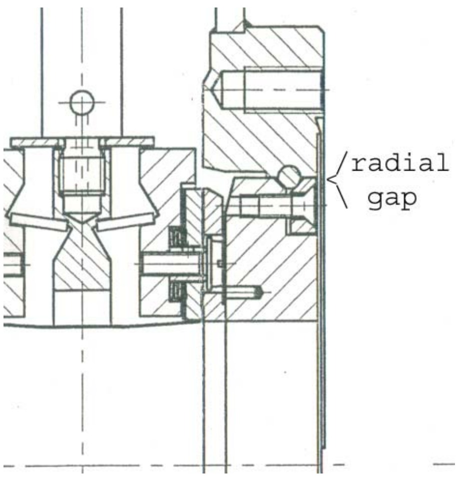

Figure 8: Vacuum valve flange geometry.

This process is demonstrated in Fig. 9, where the results of a two-dimensional simulation are presented.

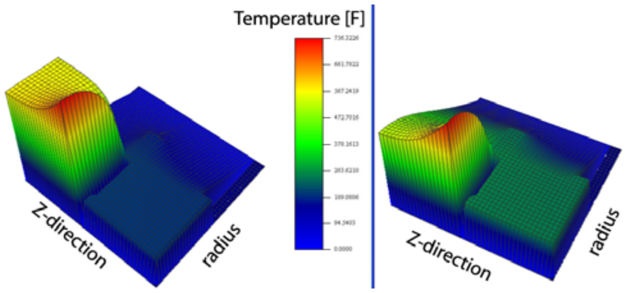

Figure 9: Temperature distribution in the vacuum valve flange connection for different stages of the thermal contact. Maximum temperature is achieved at the inner edge of the stainless steel vacuum valve flange.

The left figure shows the temperature distribution at the time when the gap size is large and the thermal contact is small. The right figure shows the temperature distribution at the time when the gap size is small. Comparison of the simulated and measured temperatures is presented at Fig.10.

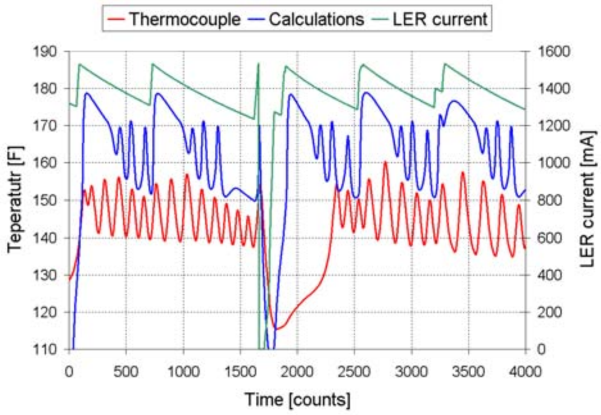

Figure 10: Comparison of the simulated temperature oscillations (blue middle curve) and measured temperatures from the thermocouple (red down curve) with the positron beam current (green upper curve) as a function of time.

The theoretical prediction is in good qualitative agreement with the temperature behaviour. Additional geometry details are needed for better agreement. As it was discovered, the period of oscillation depends upon the distance between the radial gap and the cooled flanged part.

ACKNOWLEGEMENTS

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[1] J. Seeman et al., “PEP-II Status and Future Plans”, EPAC2002, Paris, France, 2002, p.434.

[2] A. Novokhatski, “Code ‘NOVO’ for wake field calculations”, in preparation.