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Simulation of Multipacting in ILC 1.3 GHz HOM Coupler

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Abstract

Recent measurements have shown heating of ILC 1.3 GHz HOM coupler in wide range of accelerating gradients starting from 5 MeV/m. A multipacting analysis was made to search for conditions for multipacting inside the coupler. The results show that there are geometrical conditions for multipacting near the output flange and if the surface is not cleaned properly there can be multipacting in wide range of energies.

Introduction

One of the major problems in the superconducting accelerator components is the electron multipacting. It is a phenomenon of resonant electron multiplication in which a large number of electrons build up an electron avalanche. This avalanche absorbs the RF energy, leading to significant power losses and heating of the device, making it impossible to raise the fields by increasing the input power. Multipacting may cause breakdown in high RF power components such as couplers, cavities and windows. Also part of multipactoring electrons can be captured by accelerating field and form dark current. In the superconducting structures a large rise of temperature can eventually lead to a thermal breakdown.

For a multipactor to appear place 2 conditions must take place:

1) Resonance must take place. An electron emitted from the surface is driven by the electromagnetic field and returns back to the same point of the surface after an integer number of RF cycles. (Resonant or geometrical condition)

2) The impacting electron produces more than one secondary electron.

If these 2 conditions met the number of particles will increase exponentially as

where *N* stands for the number of particles and *t* for time. The parameter α is called growth rate, it is usually measured in ns^{-1}. The growth rate is used for numerical describing of the multipacting.

Motivation

One of the SRF devices that may be subjected to multipacting is high-order mode coupler (or HOM). ILC-type HOM is pictured on fig. 1. Its complex geometry makes it difficult to clean the surface inside the couple properly. If the surface is not clean enough and there some chemicals on it secondary emission coefficient may be significantly greater than for clean surface leading to multipacting in the places where geometrical conditions exist.

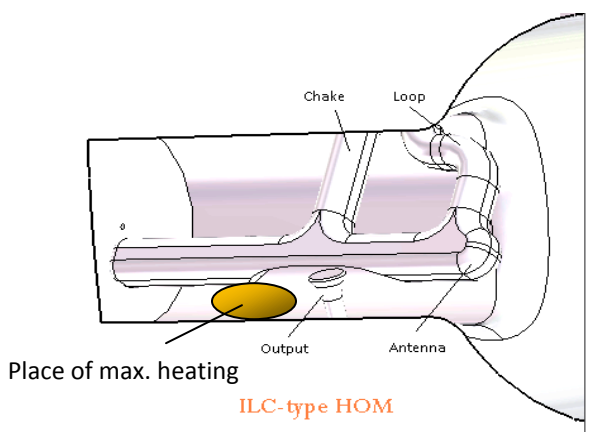

Figure 1 ILC-type HOM damper. The place where maximum temperature increase was fixed in test is shown.

Recent temperature tests on HTS held by Timergali Khabiboulline, Andy Hocker and others showed temperature rise of ILC 1.3 GHz HOM damper when the field is applied. The mean temperature increase rises with the RF power starting form 5 MeV/m. The biggest increase was found near the flange, also the top was slightly heated (fig. 2). Although the temperature rise lies in the affordable range it is important to study the effect to avoid unwanted issues in future.

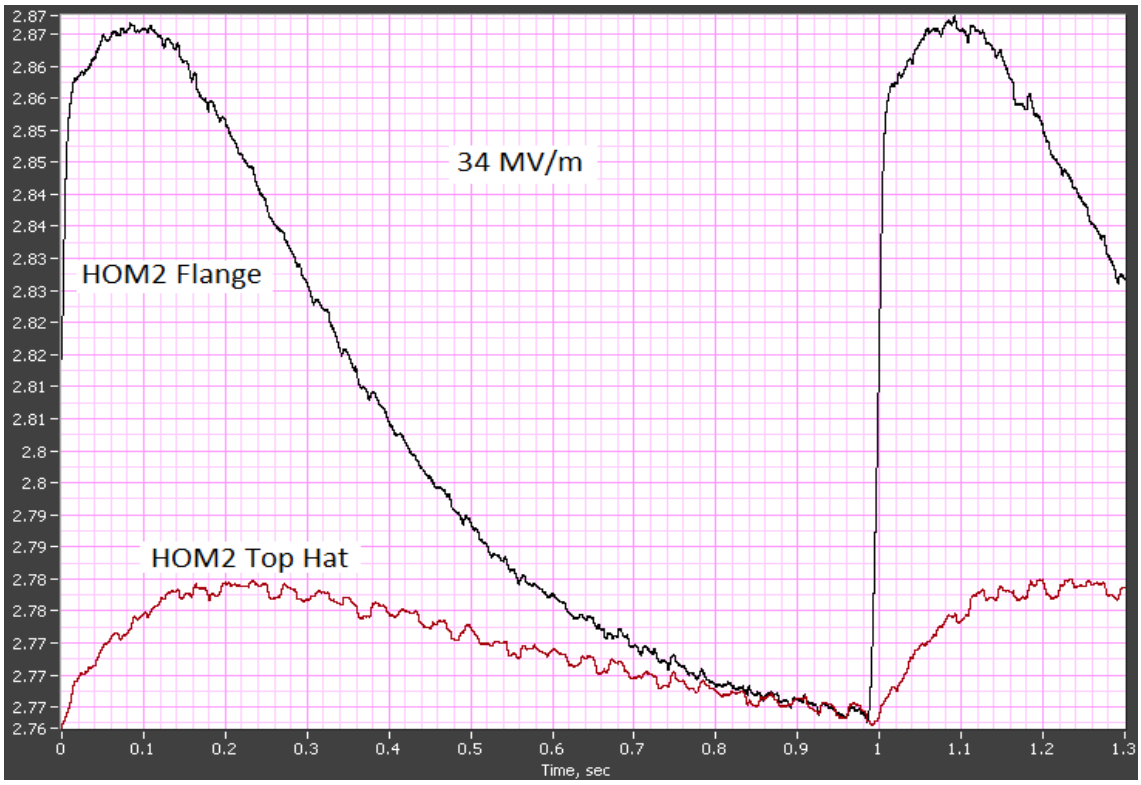

Figure 2 Temperature vs time when pulsed RF is applied. Pulse duration 1ms, interval - 1s. Accelerating gradient – 34MeV/m.

It is very possibly that the reason for this heating is a multipactor due to insufficient cleaning of the coupler. Previous multipacting simulations didn't find this phenomenon but they were made for clean material with max SEY 1.3 (at 0 angle) which may not be true. So a careful simulation of multipacting is needed.

Simulation

The analysis was made in two steps:

1) Eigenmode problem was solved to find field distribution within the coupler. Only the main mode was studied because the contributions of other modes are negligible in the operating conditions. The analysis was made for the structure consisting from ½ end cell and a HOM coupler. When the field distribution was obtained it was normalized on the maximum surface field. Knowing how the maximum surface field in the end cell depends on the accelerating gradient (roughly, it is 2 times bigger) it was possible to

make field patterns for any gradient.

2 commercial codes were used for the field calculation: CST Microwave Studio and HFSS. HFSS has the advantage of better accuracy because of its tetrahedral mesh. CST fields were calculated on hexahedral mesh.

2) Using the fields obtained on the previous step particle tracking simulations were done to find exact places of multipacting. Only HOM without the end cell was studied to decrease the calculation time. Simulations were held for different SEY curves corresponding to different treatments of the surface. 3 standard SEY curves for different treated Nb were taken from CST Studio material library and 3 more curves were added to fill the space (fig. 3). Initial particles were placed on a coupler wall and on the on one side of the antenna which is close to the flange. Since in this place the distance between the antenna and the wall is minimal it is more likely that multipacting occurs here.

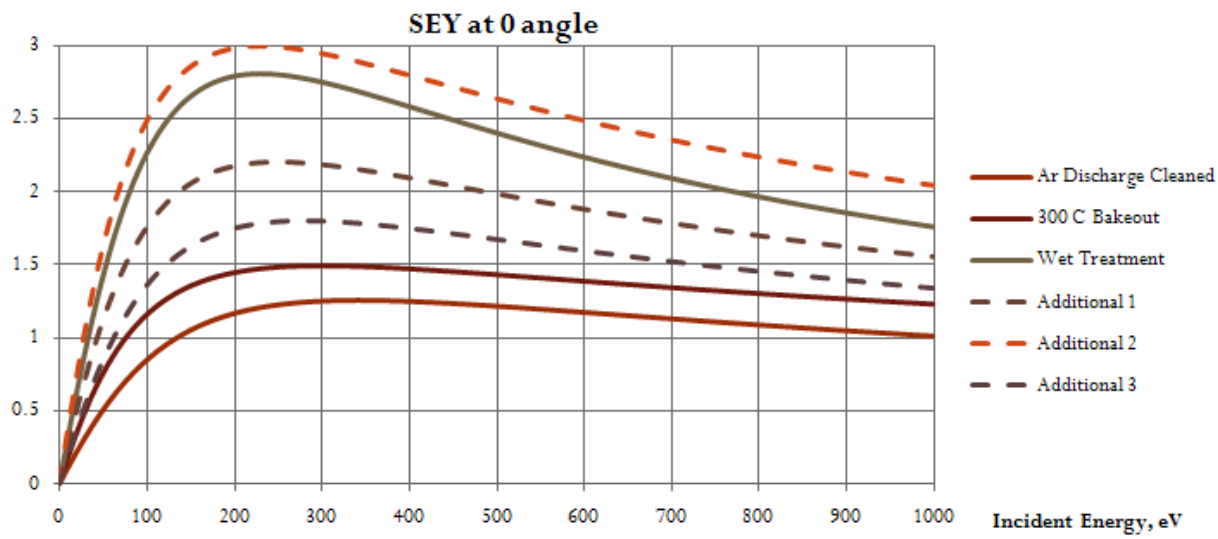

Figure 3 Secondary Emission Yield as a function of energy for different treated Nb

One of the HOMs was damaged during its transportation and it was important to know whether its changed geometry can lead to new regions of multipacting. So it was also studied to make compare its multipacting pattern with that of an undamaged one. The coupler and its model are shown on the fig. 4, the dent depth is 3 mm.

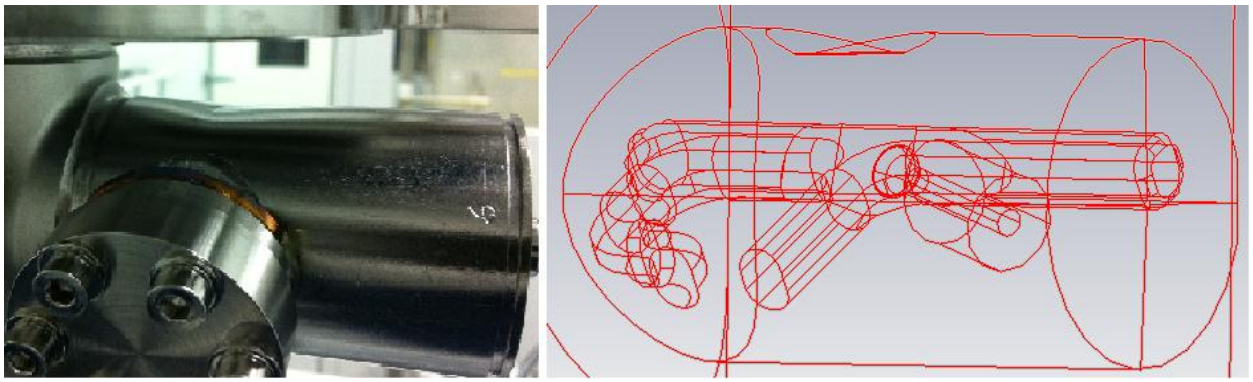

Figure 4 Photo of a dented coupler (left) and its computer model (right)

Results

2 places of multipacting were found at the energy region of 5-35 MeV/m. As it was expected there is a zone of 1-wall multipactor near the flange. The geometrical conditions here are met in the whole energy range studied. If the secondary emission is big enough (like Wet Treatment curve on fig. 3) an exponential increase of the number of particles can be observed in the range of 5-35 MeV/m. With the power increase the place moves to the bottom of the coupler and crosses the flange at approximately 20 MeV/m; typical pictures are shown on the fig. 5.

Figure 5 Typical pictures of multipacting at different accelerating gradients

Also simulations found a zone of 2-wall multipacting on the loop (fig. 6). The geometrical conditions for this place are met under gradients higher than 20 MeV/m. This zone of multipacting greatly influenced the quantitative results since the overall number of particles was measured. In the real world however it is unlikely that a multipacting occurs here because this place can easily be cleaned properly.

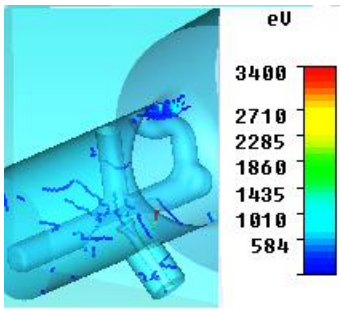

Figure 6 Multipacting on the loop, Eacc = 24 MeV/m

Quantitative results are shown on the fig. 7. Here the dependence of the growth rate on the accelerating gradient is shown. According to the Ar discharge curve on the plot, if the surface is clean enough multipacting should not take place except a relatively small energy region below 30 MeV/m. This result is consistent with the previous works made for the same emission properties of the surface. The energy range in which multipacting exists increases with the increase of max SEY and for Wet treatment curve multipacting is observed in the energy range 5-35 MeV/m. Simulations above 35 MeV/m were not performed. If the secondary emission is even bigger (like curve on Additional 2 on the fig. 3) than the process can start from such a small gradient as 3 MeV/m. Also at a given accelerating gradient the growth rate rises with increase of secondary emission.

Fig. 7 shows that a growth rate for high SEY rises with the RF power. This result is consistent to what was measured in the temperature tests.

As it was mentioned above the results at the energy range above 20 MeV/m are affected by multipacting on the loop. This issue takes place in the case when the material properties in the problem were homogeneous. In the real world some places in HOM would be more clean and some less. In particular, the loop should be pretty clean since it is right under the flow when the structure is objected to High Pressure Water Rinsing. So there shouldn't be a multipacting on the loop and the temperature tests support this.

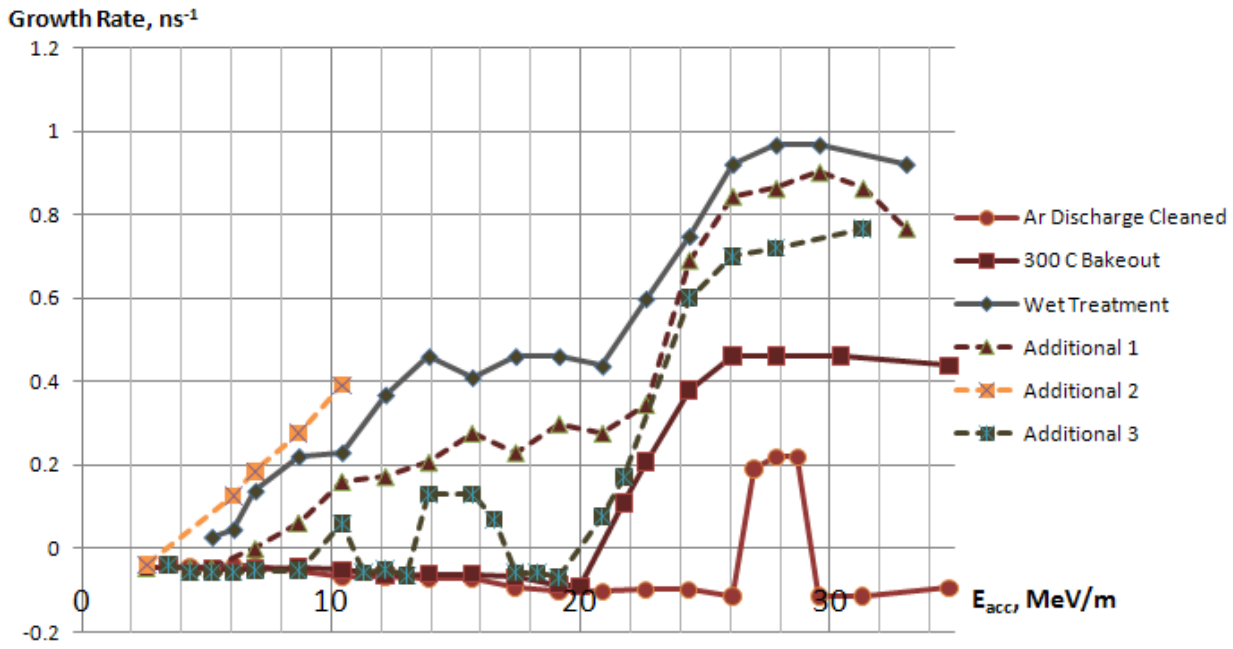

Figure 7 Growth Rate at different accelerating gradients and various SEY curves.

To check reliability of the results simulations on different meshes were performed and their results were compared.

Fields were computed on auto adjusting hexahedral meshes consisting of 2 million and 5 million mesh cells using CST and on a tetrahedral mesh in HFSS. Maximum surface field and field on the axis were compared and they show that the discrepancy between HFSS and the 5 million mesh cell CST field is relatively low. Because of the problems with exporting vast field arrays from HFSS it was decided to make all calculations on a slightly less accurate CST field.

Particle tracking convergence was tested on different meshes with numbers of cells differed up to 8.3 times. On the fig. 8 a part of a growth rate curve is pictured. It was calculated using two different meshes. Though some discrepancy in results exits the qualitative picture remains the same.

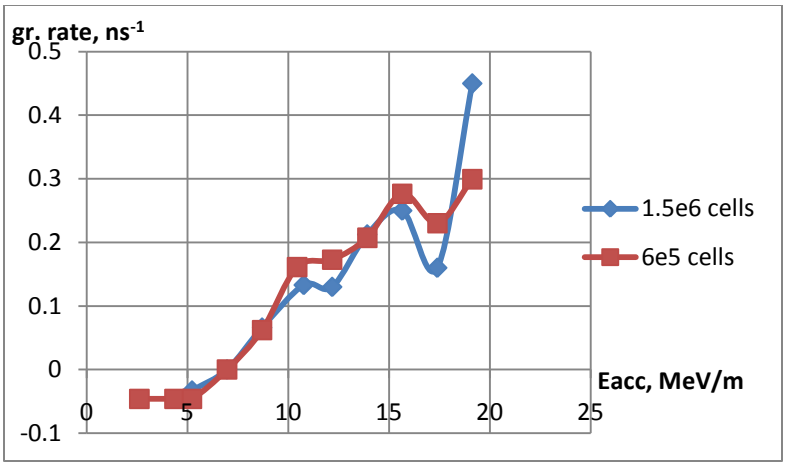

Figure 8 A part of a Growth Rate curve calculated on two different meshes

For a dented specimen the results are shown on fig. 9 and 10. No new areas of multipacting appeared, and the area multipacting between the antenna and the wall merged slightly to the top of the device. This is possibly because of that the dent changed field distribution within HOM. As one can see on the fig. 10, the growth rate on the operating gradient (about 30 MeV/m) decreased. It seems that no multipacting happens on the dented surface.

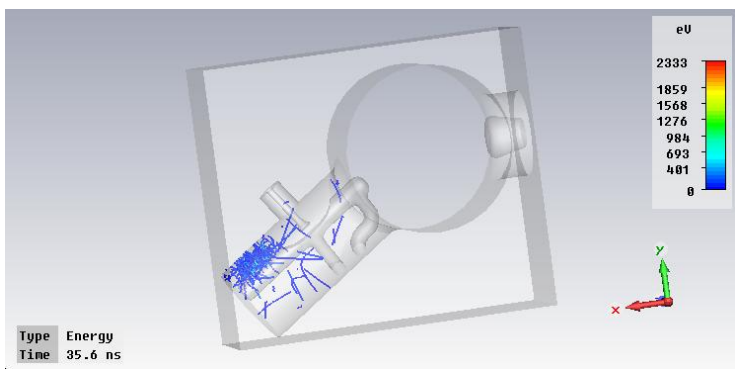

Figure 9 Typical picture of multipacting in dented HOM

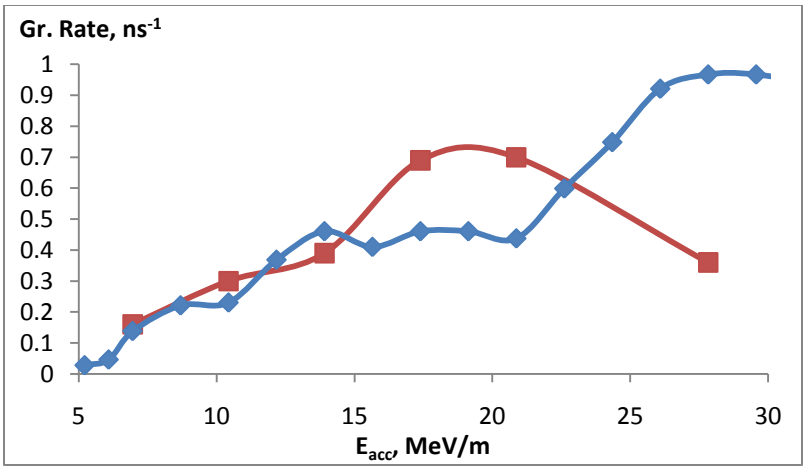

Figure 10 Comparison of growth rate curves for dented (red) and normal (blue) HOM. Secondary emission model: Wet Treatment curve (fig. 3)

Conclusions

Simulations of multipacting in ICL 1.3 GHz cavity HOM with different levels of surface cleaning have been performed. The results show that if the coupler is treated properly the multipacting should not take place except relatively small energy region near 30 MeV/m. However if the Nb is not sufficiently clean a multipacting in a wide range of accelerating gradients may exist in the HOM. In that case particle growth rate increases with the RF power which is consistent to what was measured in the temperature tests. Some discrepancy between the results of the simulations and the test can be attributed to the fact that real surface emission properties are not homogeneous as it were in the simulation.