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3D SIMULATION OF THE EFFECTS OF SURFACE DEFECTS ON FIELD EMITTED ELECTRONS

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Abstract

The ever-growing demand for higher RF gradients has considerably increased the risk of breakdown in accelerating structures. Field emission is the most common form of RF breakdown that generates free electrons capable of inflicting irreversible damages on the RF surface. This paper presents a simulation study to understand the effects of defects on local fields and behaviour of field emitted electrons in an RF cavity.

INTRODUCTION

Breakdown which occurs both in RF and DC systems has been the centre of attention for many years without any general agreement on what triggers this phenomenon [1]. Field emission is the most common problem encountered in super and normal conducting cavities. Grain edges, surface distortions and debris from past breakdown events have been identified as possible emission sites [2-3]. The presence of defects enhances the local electric field that accelerates emitted electrons. The heat and stresses exerted by these electrons bombarding the RF surface can lead to surface deformations, creating additional emitting sites and release electrons [3]. These secondary electrons can cause discontinuities in RF, generate noise, gas burst and damage metallic and insulator surfaces [4].

PROPOSED RESEARCH PROGRAM

Although breakdown has been studied for many years, the problem is complex and has many causes. A complete study of such factors is needed to understand the surface science and engineering issues that affect the performance of RF structures. As part of the UKRF collaboration R&D program, the goal is to provide a systematic approach based on experimental work and simulation studies.

Experimental Study

This work is carried out in close partnership with the US MuCool collaboration. The ultimate goal of MuCool is to develop muon-cooling systems for the Muon Collider and the Neutrino Factory. Further details regarding MuCool Test Area (MTA) are given in [5-7].

As demonstrated in figure 3 of [6], tests at the MTA show a striking drop in the RF gradient that can be achieved in a 805 MHz cavity when a solenoidal field is applied. This is of great concern for the Neutrino Factory and Muon Collider communities. The quality and condition of the RF surface plays an important role in determining the performance of the accelerating structure. In order to understand cavity performance and thereby develop better means of production, one needs to look into how fabrication procedures affect the RF surface. A series of high power RF tests have been performed by the MuCool collaboration on button-shaped samples using an 805 MHz closed cell pillbox cavity. This work was presented at PAC09 [8].

Simulation Study

Although RF breakdown may be initiated locally, its effects are felt globally in many forms such as high local Ohmic heating and field/fracture evaporation. Surface defects and impurities play a major role in altering the E and B fields, inducing local enhancements. Such points can then act as field emission sites, leading to eventual RF breakdown. In order to develop a better understanding of RF breakdown, it is vital to investigate how free electrons can initiate breakdown depending on the way surface defects alter the local E and B field of an RF cavity.

This study aims to model the field profile in an RF cavity and use the relevant data to track emitted electrons from the surface. Hence, the model will replicate the behaviour of the electrons and allow the physics of RF breakdown to be investigated.

Model Setup

To maintain compatibility with other collaborators, the model chosen is MuCool 805 MHz pillbox normal-conducting copper cavity shown below in figure 1.

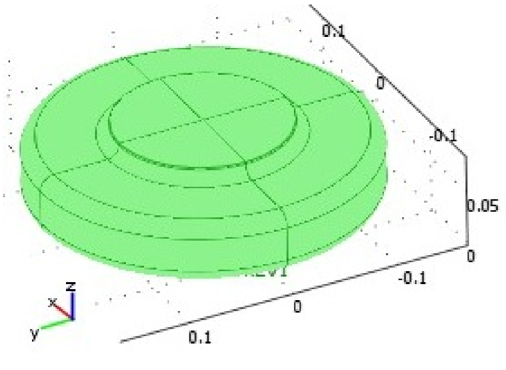

Figure 1: MTA 805 MHz copper pillbox cavity.

Comsol Multiphysics is used to generate a 3D E and B field profile using two different models. The first is a plain cavity. In the second model, a micron size defect is introduced. As predicted, the defect alters the field by inducing a local enhancement shown in figure 2.

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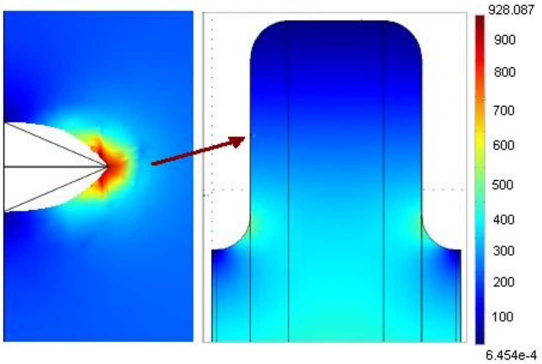

Figure 2: E field enhancement due to a surface defect

Once the field is generated, a home grown particle tracking code based on Matlab, models the behaviour of a free electron released from an emission site. This code is designed to extract field parameters at given points directly from Comsol, enabling the new position and velocity of the travelling electron to be calculated in Cartesian coordinates, using the Lorentz force.

Preliminary Results

In order to validate the code, we have used point A (0, 0, 0) as a benchmark. The physics suggest that the only E field is in the z direction (Ez) should exist. However, our initial results show that a level of error exists in the 3D field profile that is generated. This is more evident in x and y components. This can be reduced by increasing the number of elements, while reducing their average size. An example of mesh refinement is shown below in figure 3, where the iris of the cavity has a higher mesh density.

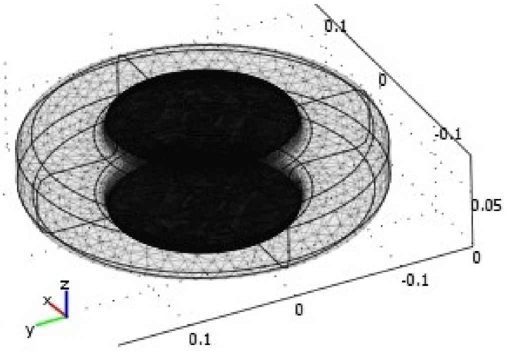

Figure 3: An example of an adaptive mesh refinement.

Although the noise level is reduced through mesh refinement, it is not possible to eliminate them fully due to software limitations. The solution lies within the geometry being modelled. As the cavity is axis-symmetric, it is possible to use a 2D model to meet the standard required for the elements quality. An early examination reveals the dramatic drop in the noise seen in the generated field profile. This demonstrates the ability of Comsol to generate better quality 2D meshes compared to conventional 3D models, while using less computing power. Table 1 demonstrates this in detail.

Table 1: Reduction in maximum E_x value (error) through mesh improvement at point A (0, 0, 0) as a benchmark

	No. of Elements	No. of Mesh Points	Error (V/M)
3D	20,830	51,430	2
	321,169	74,658	0.5
	984,870	234,446	0.4
2D	147,892	80,596	0

Once the correct field map is obtained, it is necessary to evaluate the tracker. The first step would be to compare the fields generated by the tracker to the one obtained with Comsol. As expected, Ez is at its maximum at the centre of the cavity. If Ez is plotted along the central line from one end of the cavity to the other, the maximum field would also be at the cavity's mid-point as demonstrated in figure 4. It is possible to see how the field obtained from Matlab correlates with the one generated through Comsol. Furthermore, a big improvement is observed when comparing the 2D axis-symmetric with initial 3D models as noted in table 1.

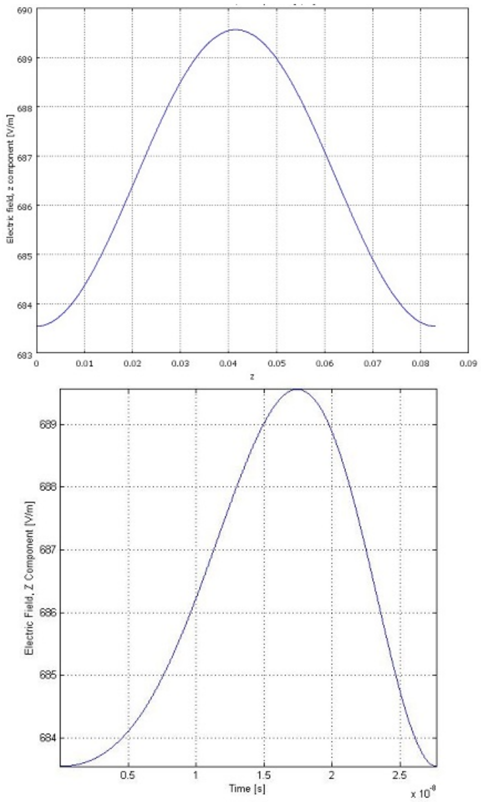

Figure 4: E_z vs. Z produced by Comsol (top), E_z vs. Time produced by Matlab particle tracker (bottom).

Although we only obtain 2D field parameter in cylindrical coordinates (r, z), it is possible to convert this into a 3D plot through several simple mathematical functions. This would provide parameters in a 3D

Cartesian coordinate system. Detailed mathematical functions used can be found in [9]. The second stage of validation consists of releasing an electron from point A, while computing its new velocity and position through a series of integrations using the field parameters.

At point A, only E_z is present with zero B field. As shown in figure 5, it is expected that electron travels in a straight line, demonstrates the ability of the tracker code to produce results in agreement with the theoretical assumptions. In order to test the particle tracker at positions where all six component of the E and B field are present, an electron is released from point B (0.02, 0.02, 0). The plot shown below clearly displays the ability of the tracker to predict the electron's path of motion while under influence of other field components.

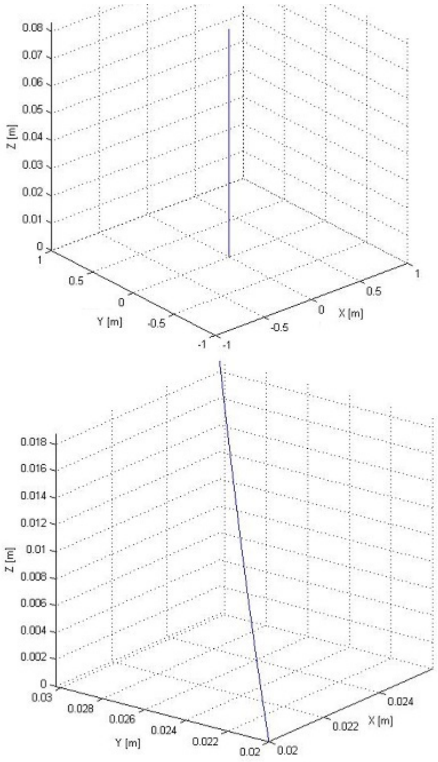

Figure 5: Electron motion at Point A [5eV-v_z] (top), Point B with [5eV, v_x-v_y-v_z] (bottom)

Approach Advantages

The main advantage of the tracker being developed in this study is the great flexibility it provides to the user in comparison to other counterparts out in the community. The results are fed directly from Comsol into Matlab, eliminating the need to follow a pre-defined grid. This in turn would allow different models to be used separately as an input source for the tracker. As a result, 2D symmetrical models can be used, reducing the computational demands and execution time dramatically. By doing so, the user would have the ability to place defects with various shapes at random location on the RF surface. As result, simple and robust 2D field maps are used, while electrons are tracked in 3D.

FUTURE PLAN

Although we are at early stages, we have some initial results demonstrating the ability of the home-grown particle tracker. Currently the introduction of a defect is only possible in a 3D model as it breaks the symmetry of the 2D model. To resolve this issue, two separate models need to be developed. First being the original model used above, this will provide the global field profile of the cavity. The second model would treat the defect as an isolated object, allowing it to be modelled in a 2D axis-symmetric fashion. The electrons will initially be tracked in the first model and the output can serve as initial conditions for the second global model. This would ensure maintaining axis-symmetry at all time and producing 3D plots. Further FEA analysis would be performed by extracting velocity at the point of impact. This in turn can be used to assess the possibility of secondary electron emissions. Moreover, the addition of a time varying E and B field can yield more realistic results.

REFERENCES

[1] Norem, J., Z. Insepov, and I. Konkashbaev, *Triggers for RF breakdown.* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2005. **537**(3): p. 510-520.

[2] Norem, J., A. Hassanein, and I. Konkashbaev. *Mechanisms limiting high gradient rf cavities*. in *Particle Accelerator Conference, 2003. PAC 2003.* . 2003.

[3] Norem, J. and M. Pellin. *Gradient Limits And SCRF Performance*. Available from: http://web5.pku.edu.cn/srf2007/download/proceedings/TUP08.pdf.

[4] Seviour, R., *The Role of Elastic and Inelasting Electron Reflection in Multipactor Discharges.* IEEE Transactions on Electron Devices, 2005. **52**(8): p. 1927 - 1930.

[5] Johnstone, C. *MUCOOL Test Area At FermiLab*. in *Particle Accelerator Conference*. 2005. Knoxville, Tennessee: IEEE.

[6] Norem, J., et al. *Recent RF Results From The MUCOOL Test Area*. in *Particle Accelerator Conference*. 2007. Albuquerque - New Mexico: IEEE.

[7] Norem, J., et al. *The RF Experimental Program In The FermiLab MUCOOL Test Area*. in *Particle Accelerator Conference* 2005. Knoxville, Tennessee: IEEE.

[8] Zarrebini, A., et al. *The Effects Of Field Emitted Electrons On RF Surface*. in *PAC09*. 2009. Vancouver.

[9] Weisstein, E.W. *Cylindrical Coordinates*. Mathworld - A Wolfram Web Resource 2010; Available from: http://mathworld.wolfram.com/CylindricalCoordinates.html