MULTIPACTORING OBSERVATION, SIMULATION AND SUPPRESSION ON A SUPERCONDUCTING TE011 CAVITY*

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Abstract

A superconducting cavity of the same shape as used for the development of superconducting photo injectors has been built for the studies of high magnetic field induced Q slope due to the local heating. The multipactoring (MP) problem has been observed on the TE011 mode, 3.29GHz with magnetic field barriers. To understand and overcome this problem, 3D multipactoring simulations by Omega3P and Track3P have been done and found these to be one-point multipactors pulled out from the flat bottom surface by finite normal component of electric field. Asymmetric coupling ports on the side of the beam tube could have caused the distortion of the TE011 mode. The thermometry measurement later confirmed the predicted impact locations. A structure modification has been adopted based on the simulation prediction. Later experimental results with the new geometry indicated softer MP barriers and further simulations indicated that the field perturbation created by the input antenna has also contributed this problem.

INTRODUCTION

To study the quench and Q-slope effects of a high gradient superconducting cavity, it has been proposed to apply thermal gradients, such as those provided by a high-power laser, in the regions of anomalous RF losses in order to explore the contribution of pinned vortices [1].

For these experiments, a SRF cavity made from a half-cell of the TESLA shape with a flat plate at the equator and a cut-off tube at the iris was built from large grain Nb. The preferred resonant mode of operation is the TE011 because, theoretically, it has zero electric field normal to the surface and high magnetic field on the flat plate, at about 4 cm from the center, which is accessible by a scanning laser beam. The resonant frequency of the TE011 mode is at 3.29 GHz.

RF input coupling is obtained by inserting an "L-shaped" antenna in a 40 mm diameter side-port on the cut-off tube, while a coaxial RF pick-up antenna is inserted in a 10 mm diameter side-port, rotated 90° from the input side-port. Figure 1 shows the surface magnetic field distribution of TE011 mode on the cavity surface and thermometry sensor board attached to the bottom of the cavity ready for a high-power RF test.

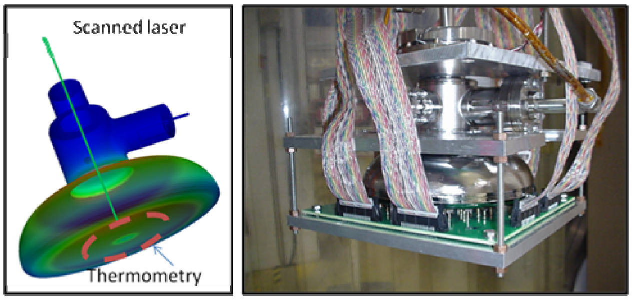

Figure 1: TE011 mode surface magnetic field simulated by Omega3P (left) and the thermometry setup with the laser experiment (right).

MULTIPACTORING PROBLEM

The initial RF tests of the cavity at 2 K showed significant MP problem. The peak surface magnetic field (B_p) was hold by MP at 40-55 mT as shown in Figure 2 no matter how the cleaning processes and low temperature baking doing. The MP barrier was hard and could not be processed away with up to ~50 W of input power for 1 hour. A "magnetic loop" input coupler was used in some of these tests but there was no difference in MP behavior.

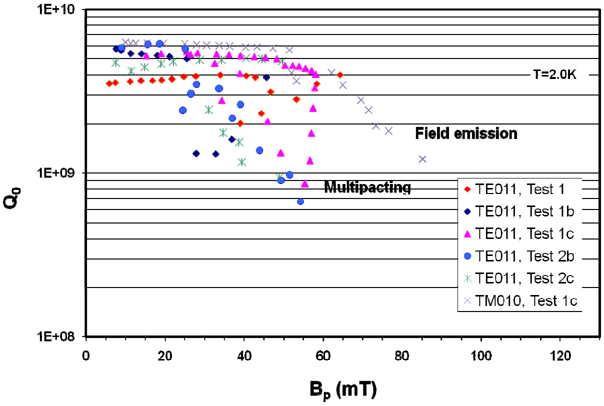

Figure 2: MP problem in TE011 mode with a hard barrier at 40-55mT. Field emission occurred when testing the TM010 mode.

SIMULATIONS TO UNDERSTAND THE MP PROBLEM

To investigate this MP problem, numerical simulation was done with the help of the ACD group at SLAC. The Omega3P [2] and Track3P [3] codes have been used for the eigen mode fields and particle tracking analysis. The CST's Microwave Studio (MWS) has also been used for assistant simulation.

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*Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177 and COMPASS of SciDAC-II. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

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Meshing the cavity vacuum geometry with Cubit [4] has used ~240k, 10-point tetrahedral elements in 4mm size. Omega3P was used first for the TE011 eigen fields. Three regions on cavity surface had been set up in Track3P for searching MP (Figure 3). Only region 3 gave the data of possible strong MPs by looking for the resonance trajectories.

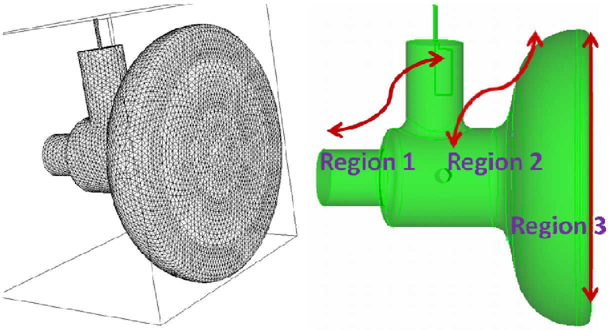

Figure 3: Tetrahedral meshing by Cubit (left) and the MP searching regions in Track3P (right).

An ideal TE011 mode cavity should have zero electric field normal to the cavity surface including the bottom plate. But the Omega3P simulation indicated that there is a finite normal electric field on the bottom plate in dipole like distribution which could be caused by the side coupling port and this field pulls electrons out of surface (Figure 4, left). The Track3P tracked those electrons' trajectories and found that once emitters gained very low kinetic energy, they could be quickly bent back by the strong magnetic field near the surface to generate secondary electrons. The secondary electrons follow the same resonant trajectories very near the plate surface. The right plot in Figure 4 shows the electron emitting locations on the bottom plate where the MP particles struck cavity surfaces in resonance trajectories within 50 RF cycles.

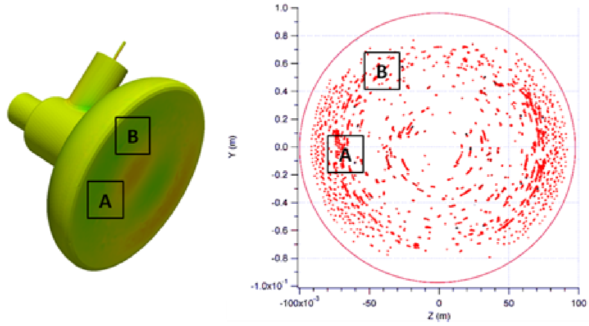

Figure 4: Normal electric field contour plot (left) and primary electron starting points on the bottom plate (right).

By tracking down individual trajectories started from locations A and B in Figure 4, we found that the emitter in A is the 1st order, one-point MP (one RF cycle between two impacts on the same cavity surface as the emission one) with impact energy at ~170eV and with the B field level of 157mT. The emitter in B is 2nd order, one-point MP with impact energy of 31eV at the B field level of 60mT. Their trajectory travel ranges are from 0.4 to 5 mm as shown in Figure 5 (the bottom plate surface is at x=67.4mm).

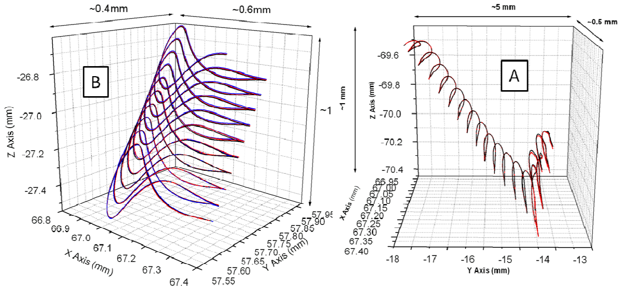

Figure 5: MP trajectories in TE011 cavity. A: with a hard barrier at 157mT; B: with a soft barrier at 60mT.

The trajectory A type of MP is a strong barrier since its electron impact energy ~160eV (Figure 6) falls near the peak of the range of Secondary Electron Yield (SEY) >1 for wet treated niobium surface. It is also the 1st order kind which can generate more electron population in vacuum space and absorbing more RF energy.

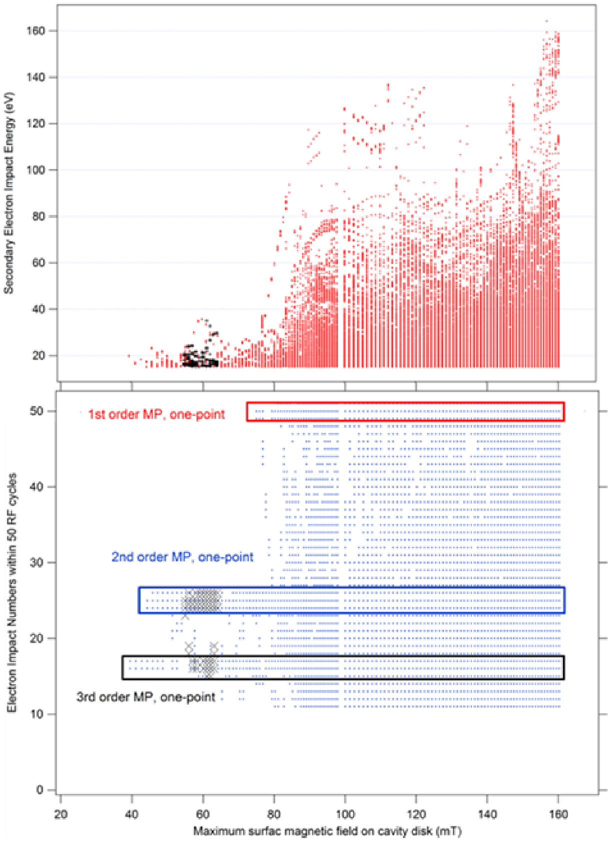

Figure 6: MP electron impact energy (top) and impact number (bottom) as the function of peak magnetic field on the bottom plate of TE011 cavity.

EXPERIMENTAL CONFIRMATION

The thermometry measurements on the TE011 cavity later confirmed these electron impact locations with a clear temperature rise (Figure 7) correlated to a "saw-tooth" behavior of the transmitted RF power on an oscilloscope, typical of MP. During the power process of MP and the field ramp, the strong MP barrier could easily

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drop the field level down to the soft barrier even after the soft barrier have been processed. This evidence suggests the simulation result of this kind, the 1st order MP behinds the 2nd or 3rd order MP, indicating a hard MP barrier to overcome.

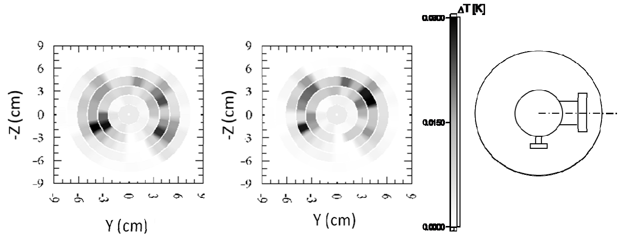

Figure 7: Examples of temperature rise during MP processing at B_p=50mT of TE011 mode confirmed to the Omega3P/Track3P simulations.

CAVITY GEOMETRY MODIFICATION AND EXPERIMENT RESULT

Symmetrizing the coupling ports had been proposed to solve the MP problem possibly. With a guideline of pushing the TM111 mode's frequency far away from the TE011 mode resulting in a reduced TM111 mode's degeneration, the ratio of normal to tangential electric field sampled at 2.35 mm off the bottom plate could be dropped to 5e-5 (calculated by Omega3P) with a structure of four 40 mm diameter side-port cans located in a symmetric crossway. The MWS later found that with an L-shaped input coupler inserted in one of cans, the perturbation of the normal field increased (Figure 9).

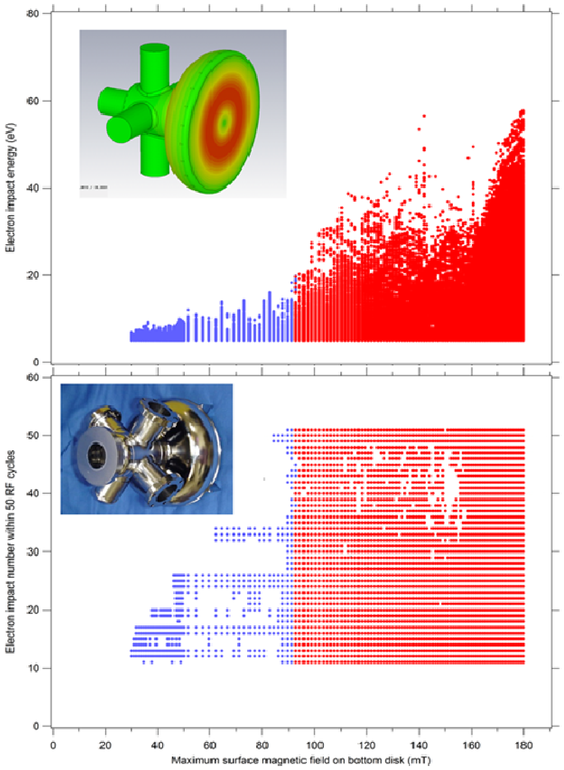

Figure 8: MP simulation prediction with a 4-cans structure, the impact energy becomes smaller compared to the original case in Figure 6 with single-can structure.

The presence of a small antenna in the coupler can was not included in the simulation early shown in Figure 8.

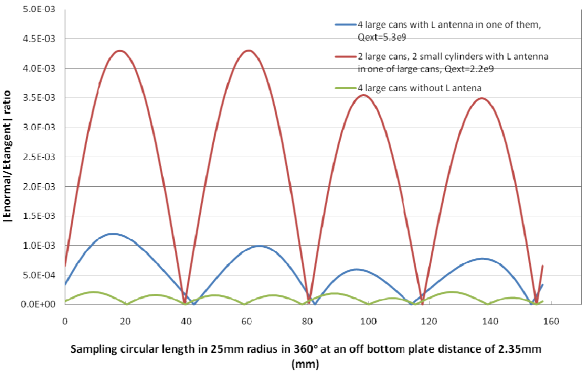

Figure 9: Normal electric field perturbed by the cavity's coupler geometry of cans and antenna.

The experiment with modified cavity geometry still showed the MP but with softer barrier (Figure 10). Helium processing helped overcoming the MP barrier and the Bp of ~140mT was achieved.

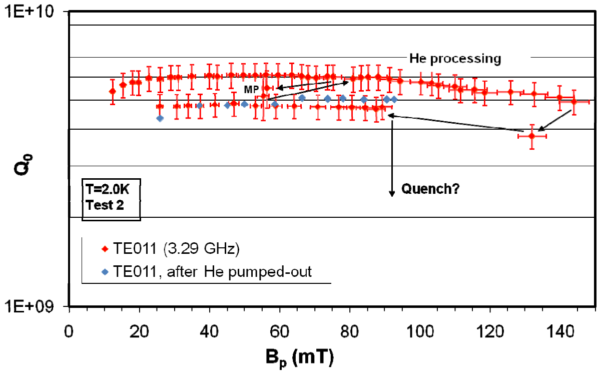

Figure 10: MP barrier in TE011 cavity became softer after the geometry modification with a 4-cans structure.

CONCLUSIONS

Further Omega3P/Trac3P simulations confirmed that the presence of the antenna geometry did enhance the MP more than the prediction in Figure 8 even with a coupling Q of 10^9. Such a small amount of field perturbation does require the high accuracy EM codes like Omega3P and Track3P. The difference between the geometries, software versions and experiment results need more detail studies. We are going to continue this study through the Scientific Discovery through Advanced Computing Phase Two (SciDAC-II) project.

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