DUAL MODE ACCELERATING CAVITY TO TEST RF BREAKDOWNS DEPENDENCE ON RF MAGNETIC FIELDS*

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Abstract

RF Breakdown experiments on short accelerating structures at SLAC have shown that increased rf magnetic fields increase the probability of rf breakdowns. Moreover, the breakdown rate is highly correlated with the peak pulse-heating in soft-copper single-cell standing-wave structures of disk-loaded waveguide type. In these geometries the rf electric and magnetic fields are highly correlated. To separate effects of rf magnetic and electric fields on the rf breakdown rate, we have designed an X-band cavity with a geometry as close to that of a standing-wave accelerator cell as practically possible. This cavity supports two modes: an accelerating TM mode and a TE mode with no-surface-electric field but with a strong magnetic field. The cavity has been constructed and will be tested at the Accelerator Structure Test Area (ASTA) at SLAC.

INTRODUCTION

Dedicated experiments to determine effects of RF magnetic fields on RF breakdown in waveguides show that when the magnetic field is increased in locations of peak electric fields, the breakdown limit decreases [1]. During the NLC program it was discovered that moderate electric field at the same location as high magnetic fields (for example at sharp edges of the couplers) leads to "magnetic breakdowns" [2]. It was also discovered that in soft Cu disc-loaded waveguide type single-cell-SW structures the breakdown rate is highly correlated with peak pulse heating [3]. To untangle the effects of the magnetic field from that of the surface electric field, we suggested the idea of a dual-mode cavity in which an additional magnetic field component can be added by the use of another RF mode with a degenerate resonance in the same cavity. This idea has been implemented in an X-band dual mode coaxial cavity [4]. Here we propose a dual mode cavity geometry close to that of the standing wave accelerating cavities that are being tested for breakdown rates at high Power RF at SLAC. The design and low power tests on such a cavity have been completed, and high power tests are scheduled for the Fall of 2011 at SLAC.

DUAL-MODE STRUCTURE DESIGN

The HFSS [5] simulation code was used to design the X-band dual-mode structure, with the goal of supporting an accelerating TM_{020} mode and a TE_{011} mode with no surface electric field but strong surface magnetic field.

Fig. 1 shows the solid edge model of the structures. The structure can be fed with a TE_{01} mode converter from one end and/or a TM_{01} mode launcher from the other end. The simulated S-parameters for the modes inside the cavity are shown in Fig. 2. Both modes are resonant at the same frequency and the reflection of each mode is 0.08 (-22 dB) or less. Both modes are slightly over-coupled as shown in Fig. 3. The cold tests measurements at room temperature show remarkable agreement between the simulation results and the experimental measurements. Figs. 4 and 5 show the cold test measurements for each mode, while Table 1 compares the simulated and experimentally measured basic parameters.

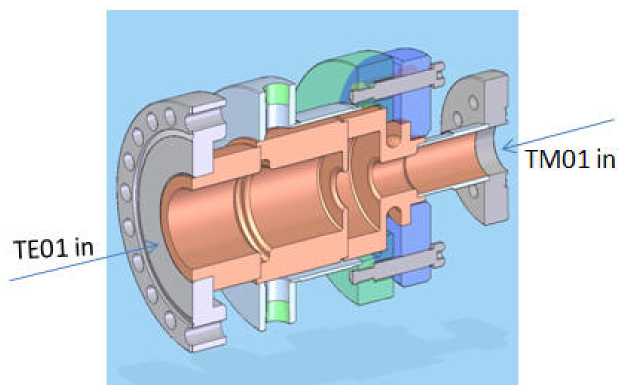

Figure 1: Solid Edge model of the TE_{011}-TM_{020} dual mode Structure

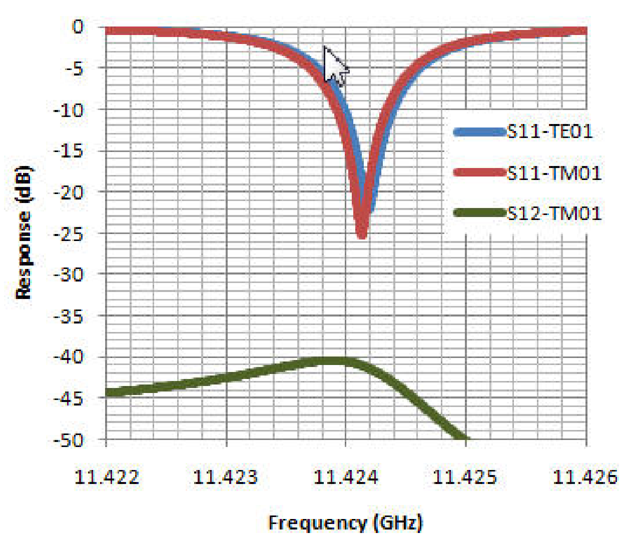

Figure 2: Simulated S-parameters for the TE_{011}-TM_{020}

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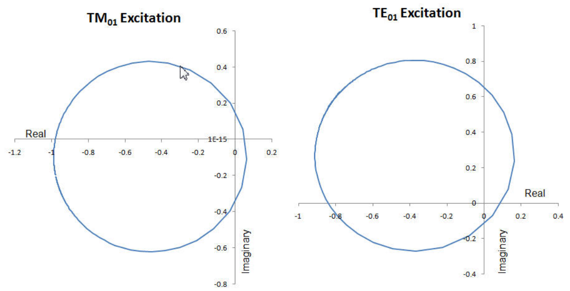

Figure 3: Smith chart from simulations showing each mode is slightly over-coupled

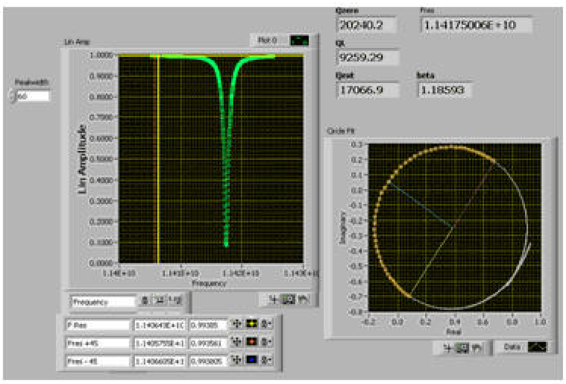

Figure 4: Cold Test measurements – TE_{011} mode

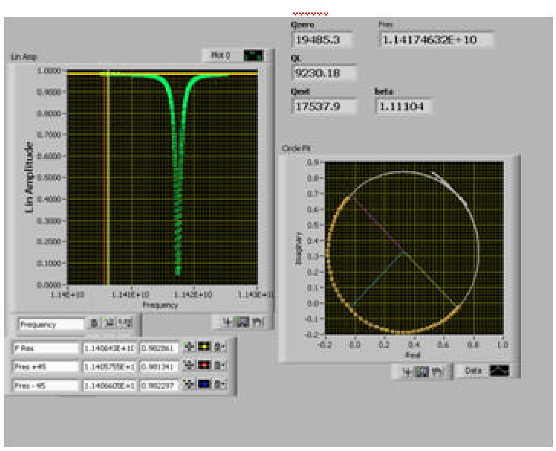

Figure 5: Cold Test measurements – TM_{020} mode

EXPECTED HIGH POWER OPERATION

The standard for comparing various structure performances at high power operation has generally been to compare them for 10 MW power loss and/or 100MV/m accelerating field operation. Thus we calculated the RF electric and magnetic fields normalized to these values and the results for 10MW power loss are shown in Figs. 6 and 7.

At 10 MW power loss, the peak on-axis electric field due to the TM_{020} accelerating mode is 380 MV/m however a more relevant figure is the average gradient in the accelerating cell, which is 121.8 MV/m at 10 MW

Table 1: Basic Parameters of the X-band Dual Mode Structure: Simulation and Measurement Comparison

Parameter	Simulation	Meas. @ Rm T
f_{TE011} - GHz	11.42419	11.42175
f_{TM020} - GHz	11.42413	11.42419
Qo_{TE011}	19754	20240
Qo_{TM020}	19292	19485
$S11_{TE011}$-dB (fraction)	-22 (0.078)	-22 (0.08)
$S11_{TM020}$-dB (fraction)	-25 (0.056)	-25 (0.05)
β_{TE01}	1.17	1.18
β_{TM01}	1.11	1.11
Shunt Imp. - MΩ/m	29.4	-

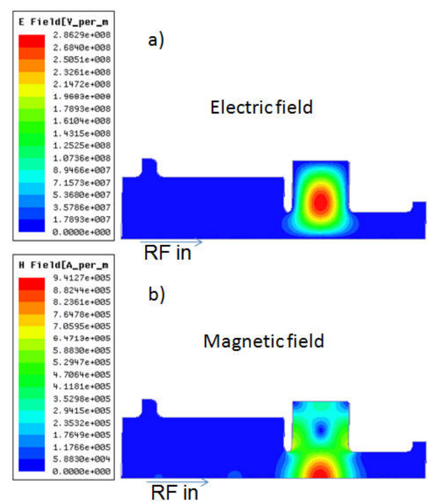

Figure 6: TE_{011} electric and magnetic fields normalised to 10MW power loss. a) electric, b) magnetic

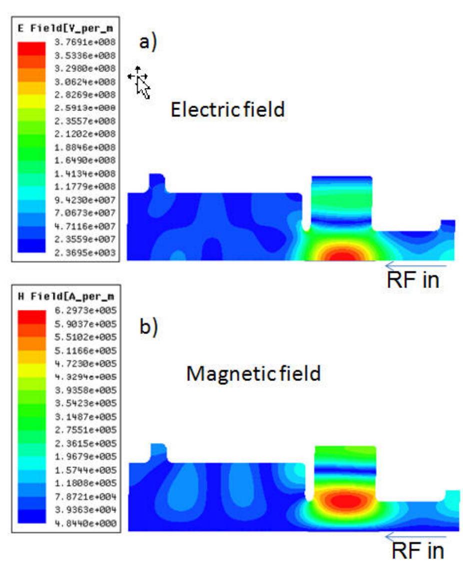

Figure 7: TM_{020} electric and magnetic fields normalised to 10MW power loss. a) electric, b) magnetic

power loss. As important for the high power breakdown rate studies are the peak fields on the surface. Fig. 8 shows the TE_{011} and TM_{020} magnetic fields on the surface normalized to 10 MW power loss. Fig. 8 also shows the TM_{020} electric field which is of interest because it is the mode that accelerates the electrons. These fields are comparable to the peak fields in the various structures being studied during the high power RF breakdown rate experiments.

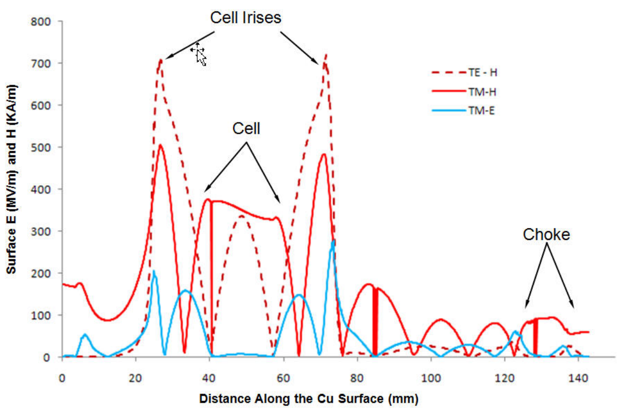

Figure 8: TE_{011} and TM_{020} surface magnetic and electric fields normalised to 10MW power loss

Table 2 shows the cavity parameters as relevant to an electron travelling at the speed of light through the structure on the crest of the accelerating standing wave TM_{020} electric field. Once more, these values are very comparable to the structures undergoing high power RF tests for Breakdown rate studies.

Currently the X-band dual-mode accelerating structure is being installed on the beam line at the Accelerator Structure Test Area at SLAC. High power tests are expected to begin in September of 2011.

SUMMARY

An X-band dual-mode accelerating structure has been designed to study the effects of the electric and magnetic fields separately from each other. This structure is very close in geometry and performance to the single cell standing wave accelerating structures being tested for high power operation and breakdown rates with the advantage of allowing us to isolate breakdowns due to magnetic or electric fields on the surface of the structure. Simulated cavity parameters are in remarkable agreement with the same parameters measured in cold tests. High power tests will be conducted in the Fall of 2011.

Table 2: Cavity Parameters for Accelerating the Speed-of-Light Particles – TM_{020} mode.

Parameter	**10 MW Power Loss**	**100 MV/m Acceleration**
Ave on-axis Acc. MV/m	121	100
Accel. Across Cav. MeV	2.41	1.98
Max. Surface E MV/m	278	229
Max. Surface H kA/m	506	426
Stored Energy Jouls	2.69	1.81
Power Loss MW	10.00	6.74

ACKNOWLEDGEMENTS

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