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# STATUS OF HIGH POWER TESTS OF NORMAL CONDUCTING SHORT STANDING WAVE STRUCTURES *

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## INTRODUCTION

Our experiments are directed toward the understanding of the physics of rf breakdown in systems that can be used to accelerate electron beams at $\sim 11.4$ GHz [1, 2]. The accelerating structure geometries have apertures, stored energy per cell, and rf pulse duration close to that of the NLC [3, 4] or CLIC [5]. The breakdown rate (breakdown probability) is the main parameter that we use to compare rf breakdown behavior between different structures [6] at a given set of rf pulse parameters (pulse shape and peak power). To date we have tested 34 structures. We consistently found that after initial conditioning, breakdown rate is reproducible for structures of the same geometry and material, and the breakdown rate depends more on the peak magnetic fields than on peak surface electric fields [7]. We tested the structures made from hard copper, soft-copper alloys and hard-copper alloys and reported the results in [8]. Most of structures in our tests were fed axially with rf power, through a removable mode launcher [1]. These tests produced a wealth of experimental data which we now use as a reference for new experiments. One set of such experiments was conducted with structures with non-axial coupling typical of practical accelerating structures [9]. Below we report the results of these experiments and compare them with the data obtained for axially coupled structures The descriptive names of the structures are explained in [8]

## GEOMETRIES

We tested three side-coupled structures. We show their geometries and field distributions for in Fig.1. The structures were designed using the SLAC in-house electromagnetic code Omega3P [11]. The mechanical design was verified using the commercial code HFSS [12]. The geometries of these structures were based on an on-axis-coupled structure with elliptical 2.0 mm thick irises and aperture radius of 3.75 mm. The parameters of this structure can be found in [8]. The main goals of the tests were: quantify the effect of field enhancements due to side-coupling on breakdown rate and to serve as prototypes for practical parallel-coupled structures [13]. All three structures were mechanically designed and then fabricated by the SLAC Klystron Department.

### *Single-feed Structure*

The on-axis field profile in the single-feed structure (1C-SW-A3.75-T2.0-1WR90-Cu, Fig.1a) and b)) is similar to that of the on-axis coupled 1C-SW-A3.75-T2.0-Cu structure: field in the middle cell is double that in the end-cells. Compared with the on-axis coupled structure (for the same accelerating gradient), the fields in the middle cell are perturbed by the rectangular waveguide coupling: the surface magnetic field is higher near the waveguide irises, and peak electric field is higher near the beam aperture. The importance of surface magnetic field on breakdown performance was recognized in our previous experiments [7]. Therefore the shape of the waveguide irises was optimized to make these enhancements as small as practical: the rf magnetic field enhancement is only 20% and electric field 3%. We speculate that since all rf parameters of this structure are close to that of the on-axis-coupled structure, but fields are enhanced due to side-coupling, we will see a clear effect of these enhancements on rf breakdown probability.

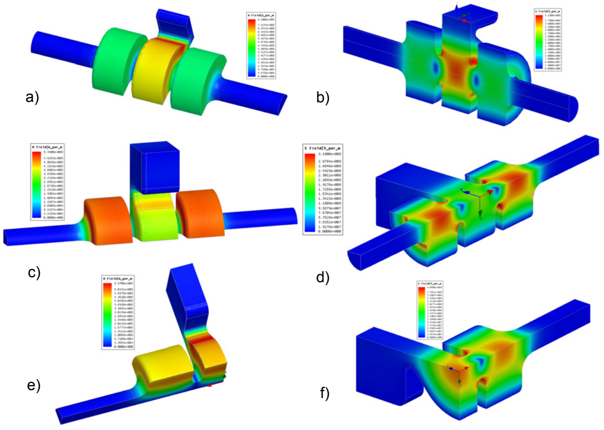

Figure 1: Geometries and fields in three side-coupled structures as simulated by HFSS. The fields are normalized 10 MW of rf losses. Single-feed structure (1WR90-Cu-SLAC-#1): (a) rf magnetic and (b) electric field. Dial-feed structure with reduced coupler fields (2WR90-Cu-SLAC-#1): (c) rf magnetic and (d) electric field. Dial-feed structure with equal on-axis fields in each cell (2WR90-Cu-SLAC-#2): (c) rf magnetic and (d) electric field.

### *Dual-feed Structures*

We designed the symmetrically side-coupled dual-feed structure (3C-SW-A3.75-T2.0-2WR90-Cu, Fig.1e) and f)), based on the on-axis coupled 1C-SW-A3.75-T2.0-Cu structure. The structure irises have the same geometry as for the single-feed structure. There are two features that distinguish this structure from the single-feed structure: symmetric coupling of rf power which eliminates dipole field component; and equal on-axis field in all three cells. We speculate that comparison of the rf breakdown performance of this structure with the single-feed and on-axis-coupled structures will allow us to understand the effect of symmetric coupling and the effect of equal on-axis-fields in each cell. The shape of the waveguide irises was again opti-

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mized to minimize the surface field enhancement (22% rf magnetic and 2% electric) in comparison with the fields in the on-axis coupled structures for the same gradient in the middle cell.

We made two structures of this type. The first one (3C-SW-A3.75-T2.0-2WR90-Cu-SLAC-#1, Fig.1c) and d)) had a manufacturing error, which resulted in reduced coupler fields. In the ”as-designed” structure the highest fields are in the coupler. In the #1 structure the highest fields are in the end-cells. Serendipitously, this error helped us separate the effect of the coupler and the end-cells on the rf breakdown probability.

Experience gained during the production of the structure #1 helped us to produce and tune the second structure (3C-SW-A3.75-T2.0-2WR90-Cu-SLAC-#2, Fig.1e) and f)) with ”as designed” equal-on-axis field in each cell.

## RESULTS

We high-power tested all these structure at the SLAC Klystron Test Laboratory following the procedure developed for the on-axis coupled structures [2]. After the tests, the structures were cut and inspected in the Secondary Electron Microscope (SEM).

### *Single-feed structure*

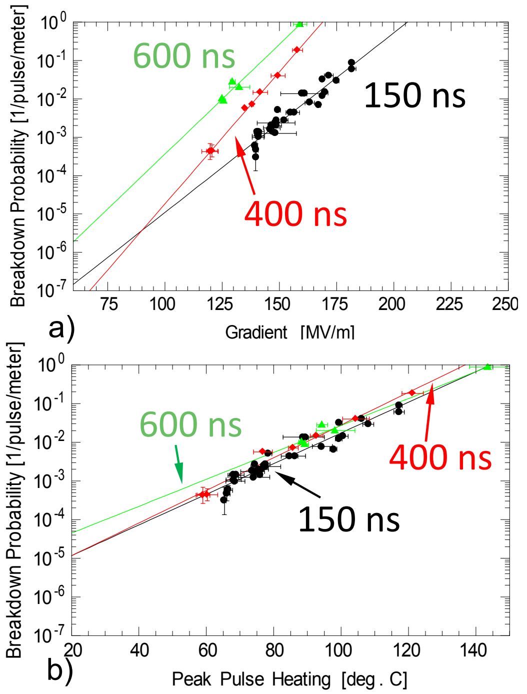

Figure 2: Breakdown rate for different pulse length for the single-feed structure 1WR90-Cu-SLAC-#1 *vs.* a) gradient, and b) pulse heating. Such correlation of the breakdown rate with peak pulse heating is typical for most of the single cell structures. Pulse is shaped to simulate beam loading pulse flat tope noted on the graph.

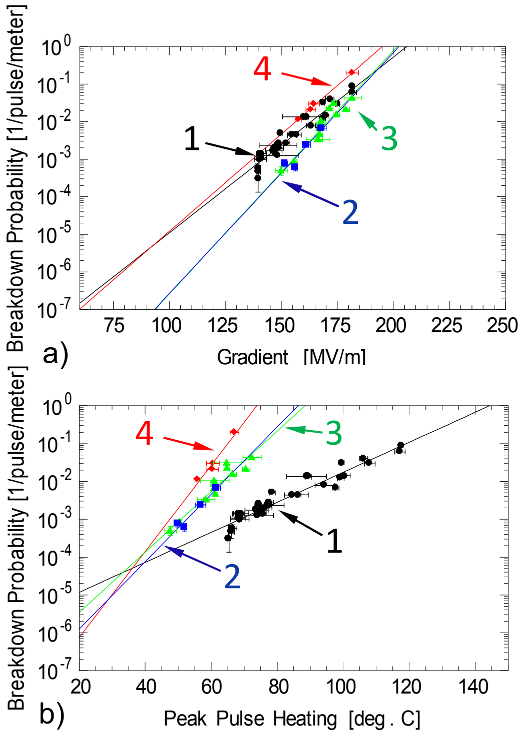

Figure 3: Breakdown rate *vs.* a) gradient and b) peak pulse heating for one single-feed coupled and and three on-axis coupled structures: single-feed structure 1WR90-Cu-SLAC-#1 (1); on-axis coupled Cu-SLAC-#1 (2), 6N-HIP-KEK#1 (3); and 7N-KEK#1 (4). The rf pulse is shaped with flat-top of 150 ns.

The breakdown rate for different pulse lengths on the single-feed structure 1C-SW-A3.75-T2.0-1WR90-Cu-SLAC-#1 is shown in Fig. 2. This rate clearly correlates with the peak pulse heating. Similar correlation is typical for on-axis-coupled structures. When we compare breakdown rate with the rate for several on-axis coupled structures of the same iris geometry at the same pulse length (see Fig. 3), the breakdown rate is practicably the same for the same gradient. Meanwhile the calculated pulse heating (for the same breakdown rate) is higher. We speculate that in this particular geometry, the side coupling does not degrade the rf breakdown performance. This result is consistent with the results obtained with the Photonic-Bandgap-Structure [10], where significant enhancement of peak pulse heating had measurable but weak effect on the rf breakdown rate. SEM inspection of the cut structure showed typical pulse heating damage. The breakdown damage which is more correlated with the peak Poynting vector than with the peak surface electric or magnetic fields (see Fig. 4).

### *Dual-feed Structure*

The tests of the dual-feed structure showed that the rf breakdown rates in #1 and #2 structures are similar but higher than for the on-axis coupled structure (see Fig 5). Knowing the test results of single-feed structure, we expected a similar breakdown rate for the single-feed and dual-feed structure #1 (dual-feed #1 has no coupler-related field enhancements) and higher for #2 (because of higher peak magnetic fields near the coupler iris). Meanwhile

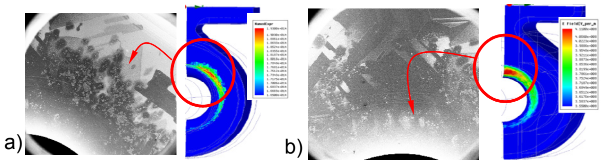

Figure 4: The SEM picture of breakdown damage correlated with (a) peak magnitude of the surface Poynting vector and (b) peak surface electric field. The breakdown damage is correlated more with Poynting vector than with the electric fields. Fields are normalized to 10 MW of lost power. The range on the colored field plots is narrowed to emphasize the location of the peak values.

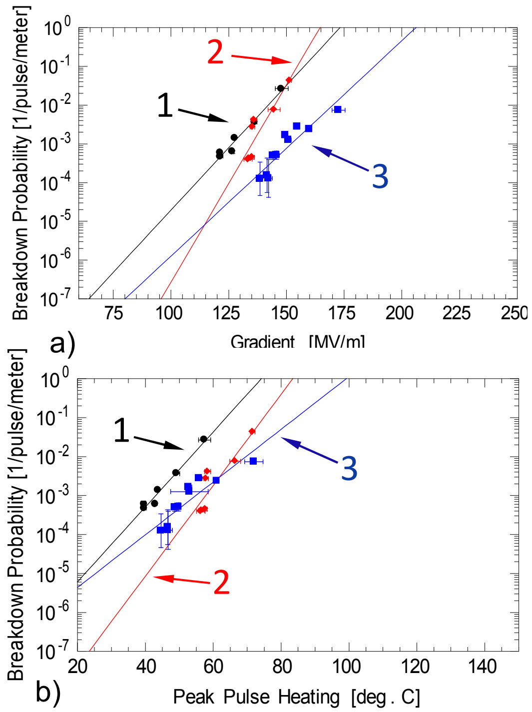

Figure 5: Breakdown rate *vs.* gradient (a) and peak pulse heating (b) for two dial-feed and one on-axis-coupled structures. The structures are: dual-feed 2WR90-Cu-SLAC-#1 (1) and 2WR90-SLAC-#2 (2); on-axis-coupled Cu-SLAC-#1 (3). RF pulse with 200 ns flat-top. There is no obvious correlation of the breakdown rate and peak pulse heating in each structure.

SEM pictures of both structures showed little breakdown damage in the coupler but massive breakdown damage in the end-cells. The SEM pictures for 2WR90-SLAC-#2 are shown on Fig. 6. We did not expect to see such damage in the end-cells of 2WR90-SLAC-#2, because the peak rf electric, the peak rf magnetic, and the peak Poynting vector, are all located in the coupler cell (which shows little breakdown damage).

## SUMMARY

We tested three side coupled structures: one single feed and two double-feed. All structures had different on-axis field profile. The single-feed structure did not show higher rf breakdown rate due to increased magnetic field in the coupler. The breakdown damage in this structure was correlated more with the location of the peak Poyning vector than with the location of the peak electric field. Two dual-feed structures showed moderately higher breakdown rate as compared with both the on-axis coupled structures and the single-feed structure. SEM examination of both structures showed breakdown damage in the end-cells, even for the dual-feed structure #2 with fields higher in coupler cell. We believe that these experiments represent a good test-bed for the subsystems of the full scale parallel coupled structures. The results are promising because they do now show obvious degradation of the breakdown performance due to enhanced magnetic field near the couplers.

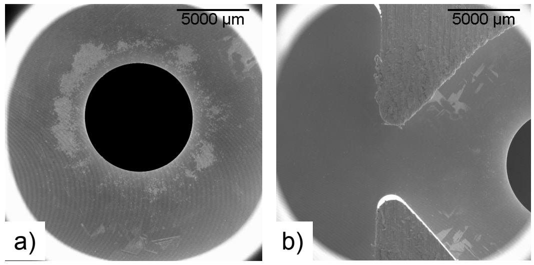

Figure 6: SEM pictures on both sides of the beam iris of the dual-feed structure 2WR90-SLAC-#2: a) end-cell side and b) coupler side. There is little pulse heating damage and intense breakdown damage on the end-cell side of the iris and typical pulse heating damage but no breakdown damage on its coupler side.

## ACKNOWLEDGMENTS

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