STUDY OF RF BREAKDOWN IN NORMAL CONDUCTING CRYOGENIC STRUCTURE *

V. A. Dolgashev, S. G. Tantawi, D. Martin, J. Lewandowski, S. Weathersby, A.D. Yeremian,
SLAC, Menlo Park, CA, 94025, USA

Abstract

RF Breakdown experiments on short 11.424 GHz accelerating structures at SLAC have shown that properties of rf breakdown probability are reproducible for structures of the same geometry. At a given rf power and pulse shape, the rf breakdown triggers continuously and independently at a constant average rate. Hypotheses describing the properties of the rf breakdown probabilities involve defects of the metal crystal lattice that move under forces caused by rf electric and magnetic fields. This crystal defect dynamics depends on the temperature of the structure. To study the dependence we designed and built an experimental setup that includes a cryogenically cooled single-cell, standing-wave accelerating structure. This structure will be high-power tested at the SLAC Accelerator Structure Test Area (ASTA).

INTRODUCTION

We continue experiments 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 39 structures. 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. Experiments with the copper structure described in this paper will study the behavior of rf breakdown while the material properties of copper, such as thermal and electrical conductivity, yield stress, *etcetera*, change at cryogenic temperatures.

MOTIVATION

In our experiments with single-cell standing wave (SW) 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]. Recent studies show that the breakdown rate correlates with peak pulse surface heating and peak Poynting vector, although the exact mechanism determining the breakdown rate is unclear [8]. One of the current hypotheses explains the statistical behavior of rf breakdown in X-band accelerating structures by generation and movement of dislocations under stresses created by rf magnetic and electric fields [9, 10]. This dislocation movement should dramatically change under cryogenic temperatures and this should be reflected in the statistical behaviour of the breakdown rate. To study this change we designed and built an experimental setup that includes a cryogenically cooled copper single-cell-SW accelerating structure. The solid model of the cryostat, SW structure and the feeding rf waveguides is shown on Fig. 1. The mode launcher is connected to 0.9 inch diameter circular waveguide (2) at the bottom of the cryostat. The TM_{01} waveguide mode created by the mode launcher flows through two choke joints (3) toward the SW structure (1). The structure is separated from the rest of the cryostat by heat shield (5) and cooled by cold head (4).

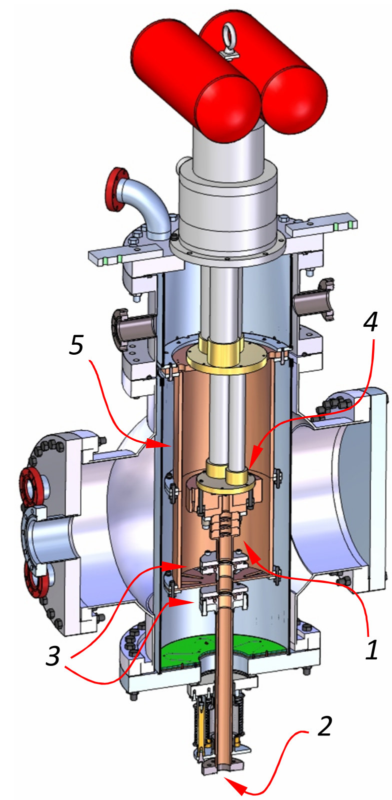

Figure 1: Solid model of the cryostat with SW structure: 1 - SW structure; 2 - input waveguide; 3 - rf chokes; 4 - cold plate; 5 - heat shield.

DESIGN CONSIDERATIONS

We plan to test the single-cell SW structure at temperatures from $\sim$30 K to 300 K. The structure will be placed

* This work was supported by the U.S. Department of Energy contract DE-AC02-76SF00515.

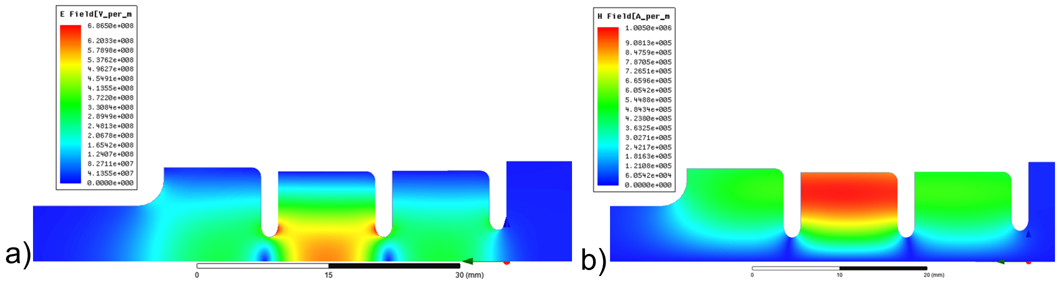

Figure 2: Geometry and fields cryo single-cells standing wave structure: (a) rf electric and (b) magnetic field. The fields are normalised to 10 MW of lost power at 96 K.

into the cryostat and powered by a SLAC X-band 50 MW XL-4 klystron. The operating temperature will depend on cooling capacity of the cryo-cooler and the average power lost in the structure. For the same gradient and pulse shape, the average power is proportional to pulse-repetition rate. We plan to adjust the repetition rate to keep the structure at the desired temperature.

Single Cell Standing Wave Structure

In order to reduce heat load on the cryo-cooler, we based geometry of the structure on highest-shunt-impedance and smallest aperture structure out of those tested at room temperature [7]. The structure is made of three cells with the highest fields in the middle cell (same as the room temperature structures [11]). The parameters of the periodic cell with the same iris dimensions as this high-field cell are listed in Table 1.

Table 1: Parameters of periodic structure at 96 K and 100 MV/m accelerating gradient.

Stored energy [J]	0.153
Q-value [10^3]	19.1
Shunt impedance [MOhm/m]	228.62
H_{max} [MA/m]	0.290
E_{max} [MV/m]	203.1
Losses in a cell [MW]	0.5737
a [mm]	2.75
a/λ	0.105
$H_{max}Z_0/E_{acc}$	1.093
t [mm]	2
Iris ellipticity	1.385

For the rf design of the standing wave structure we used copper conductivity and expansion coefficient determined in our previous cryo experiments done at 11.4 GHz [12]. Q-value data from [12] could be fited to a simple function $Qo(T) = 20834 + 8.5 \cdot 10^6/T$, where T is temperature in Kelvin. Using this function we defined a temperature range for the experiment. We designed the structure to be critically coupled at 96 K. At temperatures below 43 K and same input power the structure will have fields up to 22% higher than at 96 K (assuming that the field profile do not change at these temperatures). The structure will be over-coupled with $\sim \beta = 2$ at temperature below 40 K. At room temperature the structure will be under-coupled with $\beta = 0.45$ and with 60% fields of the 96 K case. Since the structure needs only 3.7 MW at 96 K to reach 200 MV/m gradient, the available klystron power is sufficient to study the whole temperature range.

The structure was designed with the 2D finite element code SLANS [13] and verified with HFSS [14]. The main structure parameters are listed in Table 2. Surface electric and magnetic fields are shown on Fig. 2. At room temperature the structure will have π mode resonant frequency at 11.394 GHz. The structure was mechanically designed and then fabricated by the SLAC RF Accelerator Research and Engineering Division. The SW structure for this experiment is made using the same procedure as previous room temperature structures.

Table 2: Parameters of cryo single cell standing wave structure normalised to 10 MW of lost power at 96 K as calculated by SLANS.

Stored energy [J]	2.78
Q-value [10^3]	19.89
H_{max} [MA/m]	0.990
E_{max} [MV/m]	679.2

Waveguide

One issue in the design of the cryostat was thermal isolation of the cold structure from the room temperature input waveguide. In our previous cryo high power rf tests of different materials the thermal isolation was achieved by using TE_{01} mode in the input waveguide [12]. Since TE_{01} mode has no axial currents, the waveguide system can have gaps (width of which change during cool-down) while rf integrity is preserved. For the cryo test of this accelerating SW structure we used a solution employing rf chokes in the waveguide carrying TM_{01} mode. These chokes were developed as a replacement for a flange whose rf current continuity depended on a metal-to-metal contact [15, 16]. The chokes (3) are shown on Fig. 1 and Fig. 3. The chokes interrupt the thermal path from SW structure to room temperature mode launcher while retaining rf integrity of the waveguide system. To preserve rf properties of the choke

ISBN 978-3-95450-115-1

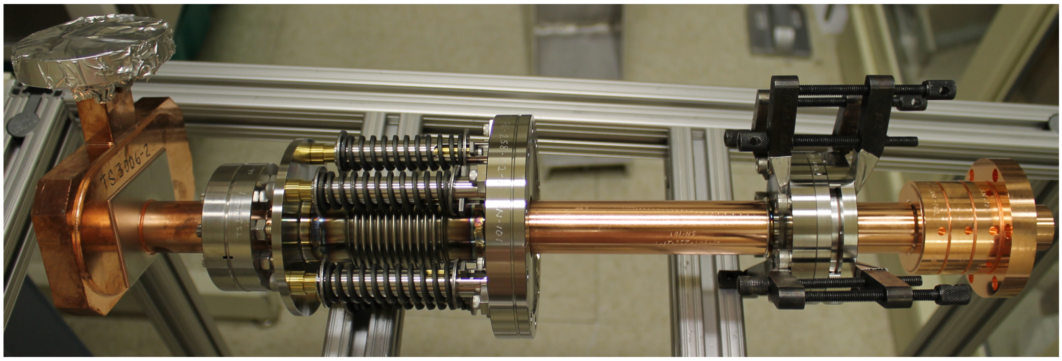

Figure 4: Cryo single-cell-SW structure prepared for bead-pull measurements. From left to right: TM_{01} mode launcher, spring assembly to maintain gap in rf chokes, rf choke, SW structure. To simplify the measurements, second choke is not installed.

during cool-down, the axial gap of the choke is set by stainless steel balls and maintained by applying mechanical spring force from the bottom of the cryostat (see the springs on Fig. 1 and Fig. 4).

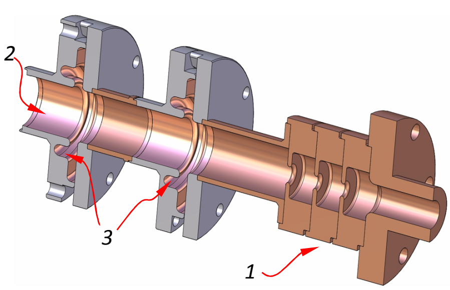

Figure 3: Solid model of SW structure (1) with input circular waveguide (2) and rf chokes (3).

SUMMARY

We designed and manufactured a system for study of the basic physics of rf breakdown in cryo-cooled normal conducting accelerating structures. We plan to start the high power test of the first structure in summer 2012. The tests will be conducted at SLAC Accelerator Structure Test Area.

ACKNOWLEDGMENTS

The mechanical and thermal design, manufacturing and assembly of the SW structure and cryostat are done at the SLAC, with great help from Chuck Yoneda, Andrew Haase, and the staff of the SLAC RF Accelerator Research and Engineering Division.

REFERENCES

[1] V.A. Dolgashev et al. SLAC-PUB-11707, Proc. of PAC 2005, Knoxville, Tennessee, 595-599 (2005).

[2] V.A. Dolgashev et al., Proc. of LINAC10, Tsukuba, Japan, 1043-1047 (2010).

[3] J. W. Wang, High Energy Phys. Nucl. Phys. **30**, 11 (2006).

[4] V.A. Dolgashev et al., Poc. of PAC03, Portland, Oregon, 1264-1266 (2003).

[5] Poc. of "The X-Band Acc. Str. Design and Test-Program Workshop," CERN, Geneva, Switzerland, June 2007.

[6] V.A. Dolgashev et al., SLAC-PUB-12956, PAC07, Albuquerque, New Mexico, 25-29 June 2007, pp 2430-2432.

[7] V.A. Dolgashev et al., Appl. Phys. Let. 97, 171501 (2010).

[8] V.A.Dolgashev et al., MOPC071, Proccedings of IPAC11, IPAC2011, San Sebastin, Spain, pp. 241-243.

[9] F. Djurabekova et al., Presentation at International Workshop on Breakdown Science and High Gradient Technology, KEK, Tsukiba, April 2012, http://indico.cern.ch/conferenceDisplay.py?confId=165513.

[10] A. Pohjonen et al., Jour. Appl. Phys. 110, 023509 (2011).

[11] V.A. Dolgashev et al., Proc. of IPAC 2010, Kyoto, Japan, 3810-3812 (2010).

[12] J. Guo et al., WPEEC073, Proccedings of IPAC10, Kyoto, Japan, 2010, pp. 3049-3051.

[13] D. G. Myakishev et al., Proceedings of IEEE PAC01, 1991, San Francisco, Ca, pp.3002-3004.

[14] http://www.ansoft.com/products/hf/hfss/

[15] A.D. Yeremian et al., THPEA065, Proceedings of IPAC10, Kyoto, Japan, pp. 3822-3824.

[16] A.D. Yeremian et al., 2009, SLAC-TN-09-003.