

TOWARD HIGH-POWER HIGH-GRADIENT TESTING OF MM-WAVE STANDING-WAVE ACCELERATING STRUCTURES*

E. A. Nanni[†], V. A. Dolgashev, A. Haase, J. Neilson,

S. Tantawi, SLAC National Accelerator Laboratory, Menlo Park, USA

S. Jawla, S. C. Schaub, R. J. Temkin, Massachusetts Institute of Technology, Cambridge, USA

B. Spataro INFN-LNF, Frascati, Rome, Italy

Abstract

We present preliminary testing results for single-cell accelerating structures intended for high-gradient testing at 110 GHz. The purpose of this work is to study the basic physics of ultrahigh vacuum RF breakdown in high-gradient RF accelerators. The accelerating structures consist of π -mode standing-wave cavities fed with the TM_{01} circular waveguide mode. We fabricated two structures one in copper and the other in CuAg alloy. Cold RF tests with quasi-optical excitation confirm the design RF performance of the structures. The structures will be powered with a MW gyrotron oscillator that produces microsecond pulses. One megawatt of RF power from the gyrotron may allow us to reach a peak accelerating gradient of 400 MeV/m.

INTRODUCTION

The high-gradient performance of accelerating structures is important for the selection of an accelerator's operational frequency. RF breakdown is one of the major phenomena that limits the achievable gradient in accelerating structures. Extensive studies on RF breakdown in copper accelerating structures [1] have been performed at frequencies as high as 11-12 GHz [2-6], 17 GHz [7] and 30 GHz [8-10].

The statistical behavior of RF breakdown became apparent during NLC/GLC work [2, 4, 11, 12]. After many pulses at the same RF power and pulse shape, for most accelerating structures the breakdown rate approached a steady state or is slowly decreasing. It is now common practice to measure and use the breakdown probability to quantify the high-gradient performance of accelerating structures.

Recently, we have expanded our experiments on the basic physics of ultrahigh vacuum RF breakdown to the mm-wave range with beam-driven accelerators at FACET [13, 14]. In this paper, we continue this study [15] using a 110 GHz MW pulsed gyrotron oscillator [16] as the RF power source. We are aiming to achieve accelerating gradients well beyond 100 MeV/m and plan to measure RF breakdown statistics.

ACCELERATING STRUCTURE ASSEMBLY

We have completed the fabrication of the structures for the high power experiment and are performing preliminary testing. The structure is powered from the gyrotron via a

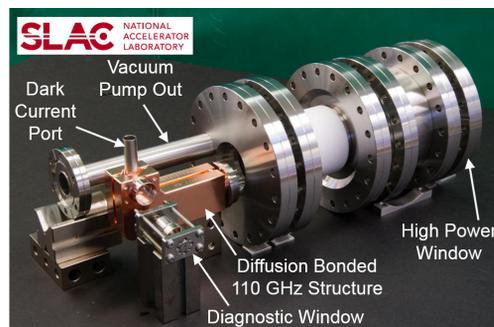


Figure 1: Components for the high power test assembly prior to final fabrication. The diffusion bonded copper accelerating structure is shown in the foreground. The high power pulse enters from the right through a window (not visible). The diagnostic port allows for calibrated transmission data which provides an accurate measurement of the fields in the structure.

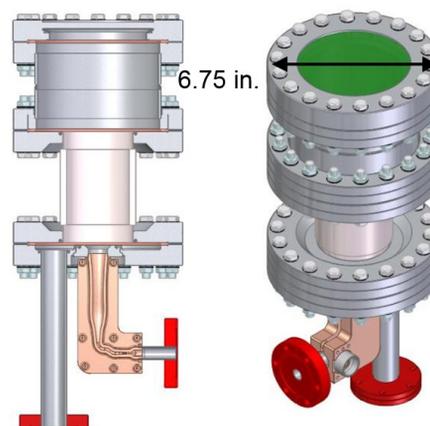


Figure 2: A solid model of the high power test assembly shown in Fig. 1 with a cut-away view (left) and a rotated view (right). The high power pulse enters from the window at the top of the figure (shown in green for visibility). The Gaussian beam is being focused to a waist located at the final aperture of the copper horn. The Gaussian beam is converted into the TM_{01} mode before being coupled into the structure.

quasi-optical transport in air with Gaussian optics. The structure assembly and solid models are shown in Fig. 1 and Fig. 2.

Details of the mode converter and the electric field distribution are shown in Fig. 3. First, the Gaussian mode is focused onto the aperture of a smooth-walled horn with

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[†] nanni@slac.stanford.edu

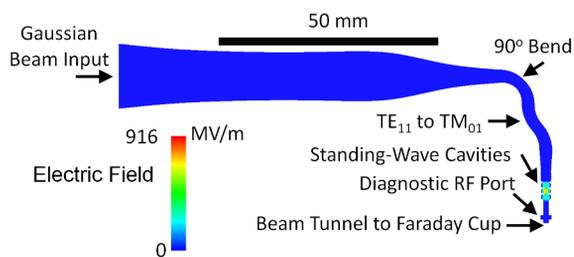


Figure 3: Model of the assembly consisting of the mode converter and the standing-wave accelerating structure A0.286-T0.2-Cu. We show the magnitude of the electric field on the symmetry plane using HFSS [17]. The field is normalized for 1 MW in the input Gaussian beam.

4.6 mm beam waist. The horn converts the Gaussian mode into the TE_{11} mode of a circular waveguide with $\sim 99\%$ conversion efficiency. Following the Gaussian converter is a TE_{11} to TM_{01} mode converter, which includes a 90 degree bend. The mode converter has a 97% power conversion efficiency and a bandwidth exceeding 2 GHz. The parameters of the mode converter exceed the requirements for this experiment since its bandwidth is larger than the tunable frequency range of the gyrotron oscillator.

ACCELERATING STRUCTURE PERFORMANCE

We have designed and built standing-wave accelerating structures with cavity geometries that allow for direct comparison with experiments at 11.424 GHz [3], where accelerating cavities with a/λ ratios of 0.105, 0.143 and 0.215 were extensively studied. Here a is the radius of the iris aperture and λ is the operational wavelength. Structures with a larger a/λ have a higher peak surface electric field for the same accelerating gradient. For our first experiments we are utilizing cavities with the a/λ ratio of 0.105.

Table 1: RF parameters of the 110 GHz single-cell accelerating structure. Fields are normalized to 1 MW of dissipated RF power. Accelerating gradient is defined as the peak surface electric field divided by K_e which was determined for the periodic solution [15].

Name	Unit	A0.286-T0.2-Cu
a/λ		0.105
Iris Aperture Radius, a	[mm]	0.286
Iris Thickness, t	[mm]	0.2
Iris Ellipticity		1
Accel. Gradient, E_{acc}	[MeV/m]	404
Max. Surf. Elec. Field, E_{max}	[MV/m]	916
Max. Surf. Mag. Field, H_{max}	[MA/m]	1.13
$H_{max}Z_0/E_{acc}$		1.04
$K_e = E_{max}/E_{acc-periodic}$		2.27
Peak Pulsed Heating	[°C]	156
(20 ns Square Input Pulse)		

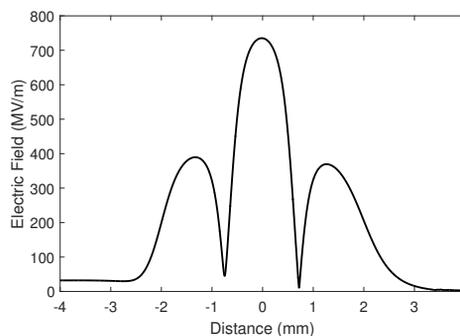


Figure 4: On-axis electric field for three cavities with an a/λ of 0.105 assuming 1 MW of dissipated RF power in the structure.

We presented the detailed design of the 110 GHz structures in [15]. These structures have three cells, with the on-axis electric field in the central cell twice as high as in the adjacent cells. This was done to ensure that most of the breakdowns are in the central cell. The two end cells create fields that mimic the fields in a multi-cell standing wave structure. The on-axis electric field is shown in Fig. 4. The accelerating structure is fed through a 1.187 mm radius TM_{01} cylindrical waveguide. The beam pipe radius is 0.660 mm radius so the TM_{01} mode is below cutoff. The RF parameters are given in Table 1. The parameters were normalized for 1 MW of dissipated RF power.

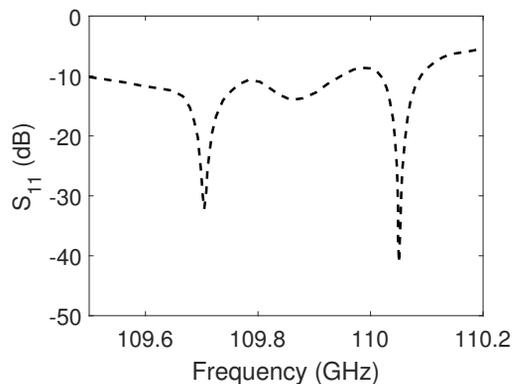


Figure 5: Measured S_{11} for the Gaussian beam mode converter and the high-power accelerating structure.

Two high power RF structures from Fig. 1 were fabricated in both copper (Cu) and copper-silver (CuAg). The devices were designed to be fabricated from pair of mirror image blocks each containing a 180 degree segment of all the RF elements. The first two devices were fabricated at SLAC by diffusion bonding together a pair of blocks/slabs that were machined at EDM Department, Inc. After diffusion bonding the measured π -mode frequency of the clamped structures is 110.1 GHz for Cu and 110.4 GHz for CuAg. We performed S-parameter measurements of the diffusion bonded assembly, with the S_{11} vs. frequency shown for the Cu structure in Fig. 5. The three visible resonances on the trace are the 0, $\pi/2$ and π mode from left to right. We measured a loaded Q factor of 1600 for Cu and 1200 for CuAg structures. These are in good agreement with the expected loaded Q factor

of 1800. The spacing of the 0 and π modes does not match the design due to variations in cell coupling, however it is acceptable and will not impact the high power test. In the future we plan to fabricate circuits using brazing and other methods.

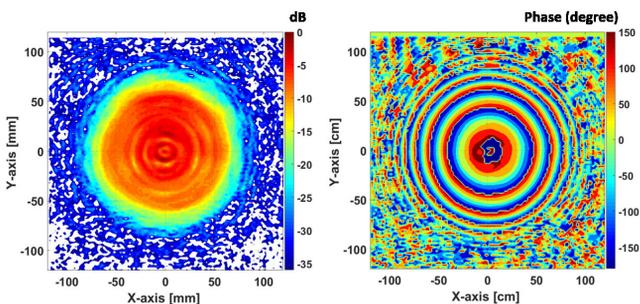


Figure 6: Intensity (left) and phase (right) measured at 343 mm from horn aperture using a fundamental rectangular waveguide probe and a vector network analyzer. The horn is excited by coupling power in through the RF diagnostic port and coupling to the cavities.

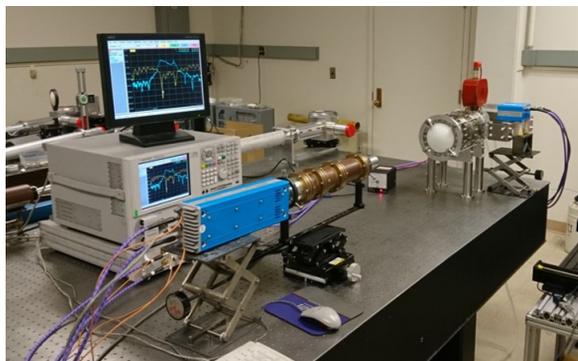


Figure 7: Cold-test setup for quasi-optical coupling excitation of the accelerating structure. The Gaussian beam launcher is located in the foreground. The structure is located on the right in the background.

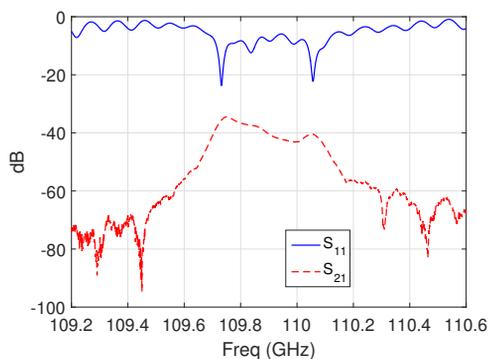


Figure 8: S-parameters from the cold-test setup for quasi-optical coupling in Fig. 7. The π -mode resonance at 110 GHz has a S_{11} of -23 dB which will provide excellent coupling of the gyrotron power. The -40 dB coupling for the transmitted signal through the diagnostic port is in excellent agreement with the design.

QUASI-OPTICAL COLD-TEST MEASUREMENTS

To design the quasi-optical transport and prepare for high power testing, cold-test measurements were performed with a vector network analyzer. The initial measurements utilized the diagnostic port for transmitting power into the structure and subsequently the horn. The radiated field amplitude and phase were measured in the far-field as shown in Fig. 6. These measurements demonstrate the horn couples strongly to a Gaussian beam. The measured radiation pattern was used to aid in the design of the lens for coupling power into the structure.

To couple a free-space collimated beam into the structure, a polyethylene lens was fabricated, mounted immediately prior to the high power window and tested. A Gaussian beam launcher, designed to produce the same beam as the gyrotron, was utilized during the cold-test. The quasi-optical test setup is shown in Fig. 7. The complete S-parameters for the structure are shown in Fig. 8 with efficient coupling at 110.1 GHz for the π -mode.

CONCLUSION

We have presented preliminary experimental results for single-cell accelerating structures designed for high-gradient testing at 110 GHz using a gyrotron as the RF power source. Cold tests indicate that the desired RF parameters could be achieved. With 1 MW these structures may reach peak accelerating gradients of 400 MeV/m.

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