

# HIGH POWER TESTS OF 2-PIN WAVEGUIDE STRUCTURES\*

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## Abstract

An X-band two-pin waveguide structure has been built to study the influence of power flow on rf breakdown. Three different sets of pins will be tested at SLAC. These sets were designed to achieve a similar peak surface electric field on one of the pins in each set for different input rf power levels that vary by about an order of magnitude (the other pin is used for matching). Two sets of pins have been tested so far, and the breakdown rate was found to be strongly dependent on the power flow. In this paper, we review the experimental setup, the complete set of results and their implications.

## INTRODUCTION

Although rf breakdown has been studied for many decades, a full understanding of its origins has been elusive. However, it is clear that breakdown depends on more than just the peak electric field. In particular, in this paper we explore how it depends on net rf power flow. Because this is difficult to study in an accelerator structure while holding other factors constant, a 2-pin waveguide structure was designed in which one can obtain the same peak electric field on the pin for different input rf power levels [1]. Two sets of pins have been tested so far, and the breakdown rate has been found to be strongly correlated with the net rf power flow. We'll discuss the experimental results as well as their implications in the paper.

## EXPERIMENT SETUP

The 2-pin waveguide structure, illustrated in Fig. 1a, operates at X-band (11.424 GHz) in a travelling wave mode. The downstream pin is a matching pin; the upstream pin, as seen in Fig. 1b, has a step at the end to enhance the tip surface electric field and make it the likely location of rf breakdown. Both protrude from the centre of a WR90 waveguide broad wall. The rf power is fed from the left side during the experiment.

Three pairs of pins have been manufactured. The upstream pins have different lengths (i.e., different values of  $h$  in Fig. 1a) to achieve the same surface electric field at different values of rf input power. Correspondingly, the downstream ones are customized to match the rf so there is no net reflection back to the source. The rf parameters are listed in Tab. 1. The pins are made of OFE copper without annealing (i.e., hard copper) and undergo the same surface preparation before high power testing, which is SLAC standard UHV cleaning and chemical etching. Scanning electron microscope (SEM) images of the pin tips were taken before and after high power testing to document the breakdown related changes. There were a

small number of etch pits on the surface, which did not appear to affect breakdown results.

Table 1: RF Properties of the Three Sets of Pins for a Maximum Surface Electric Field of 200 MV/m

Set	1	2	3
Power (MW)	4.5	16.7	30.3
$H_{\text{tip}}$ (MA/m)	0.098	0.090	0.082
$H_{\text{max}}$ (MA/m)	0.21	0.19	0.17
$S_{11}$ (dB)	-19.1	-21.5	-27.5

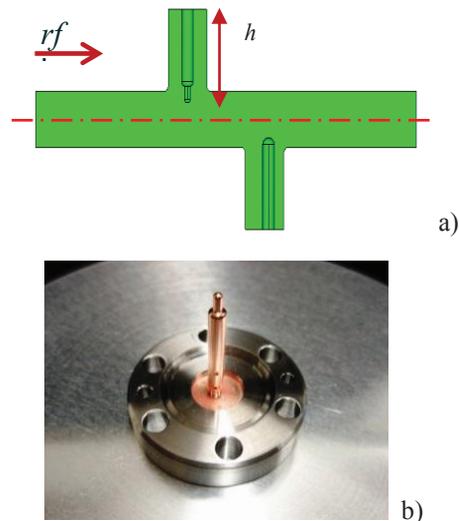


Figure 1: a) Illustration of the travelling-wave 2-pin structure, which consists of a WR90 waveguide and two demountable pins, and b) an upstream pin mounted on a flange before a high power rf test.

## EXPERIMENTAL RESULTS

Two sets of pins have been tested so far. They are sets 1 and 3 as listed in Tab.1. Each set has been tested for about 50 hours using rf pulses with lengths up to 600 ns. The two sets have been tested up to 8 MW and 32 MW respectively.

The test results show a striking difference in the high gradient performance of the two sets. In particular, there is a big difference in the breakdown rate dependence on the peak surface electric field, as shown in Fig. 2, where the rf pulse length was 400 ns. The lines in the figure are power law fits to the data (i.e.,  $E^n$  where  $n \sim 30$ ), which have a dependence similar to that found in X-band accelerator structures [2-3]. For the same breakdown rate, the operational maximum surface field on the high power

\*Work supported by the U.S. Department of Energy Early Career Research Program under contract code LAB 11-572.

pin (set 3) is about 30% lower than that on the low power one (set 1), which only needs 25% of the input power of the high power one, but has 50% higher magnetic field. The pin installation tolerance of 20 microns yields only 3% uncertainty in the surface electric field of the lower power pin and has even less effect on the high power one. Therefore, the different surface field behaviours of the two sets come from their fundamental design difference.

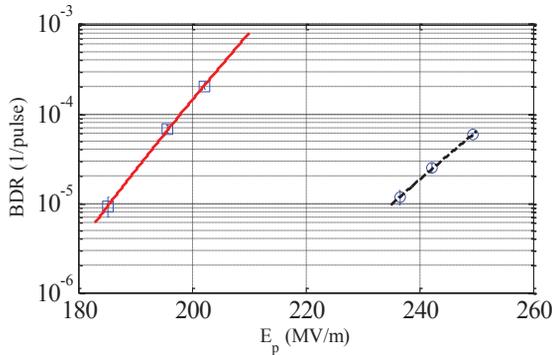


Figure 2: RF breakdown dependence on the maximum surface electric field of the upstream pins, where the square and circle data points are for the high power and low power sets, respectively, and the lines are power law fits to the data.

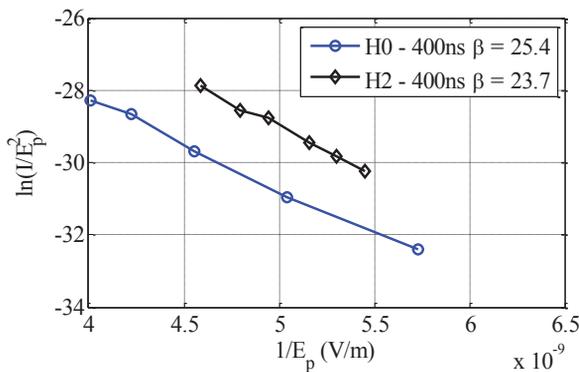


Figure 3: The X-ray intensity divided by peak surface electric field squared (a.u.) versus the inverse peak surface electric field, where the diamond and circle data points are for the high power and low power pins, respectively, with 400 ns pulse lengths.

A photomultiplier tube (PMT) was mounted on the waveguide structure to measure X-ray emission during normal (non-breakdown) operation. The X-ray intensities are plotted in Fig. 3 for the two sets of pins. Assuming the intensity of the PMT reading is proportional to the field emission current, one can obtain the surface electric field enhancement factors (betas) of the pins from the slopes of the resulting curves using the Fowler-Nordheim emission equation. In this case, the betas are 25.4 and 23.7 for the low power and high power sets, respectively.

The SEM images in Fig. 4a and 4b show the surface damage pattern of the upstream pins of the two sets. One can clearly see localized breakdown craters in Fig. 4a (the low power set). However, in Fig. 4b (the high power set), the entire surface has been melted and reshaped by rf breakdown. As expected, SEM images of the downstream matching pins, one of which is shown in Fig. 4c, do not show any breakdown damage. Thus, the breakdowns were confined to the highest surface field regions.

Another test using set 2 has been scheduled. With full testing of the 3 sets, we will obtain a better measure of the breakdown rate dependence on input power for fixed peak surface fields.

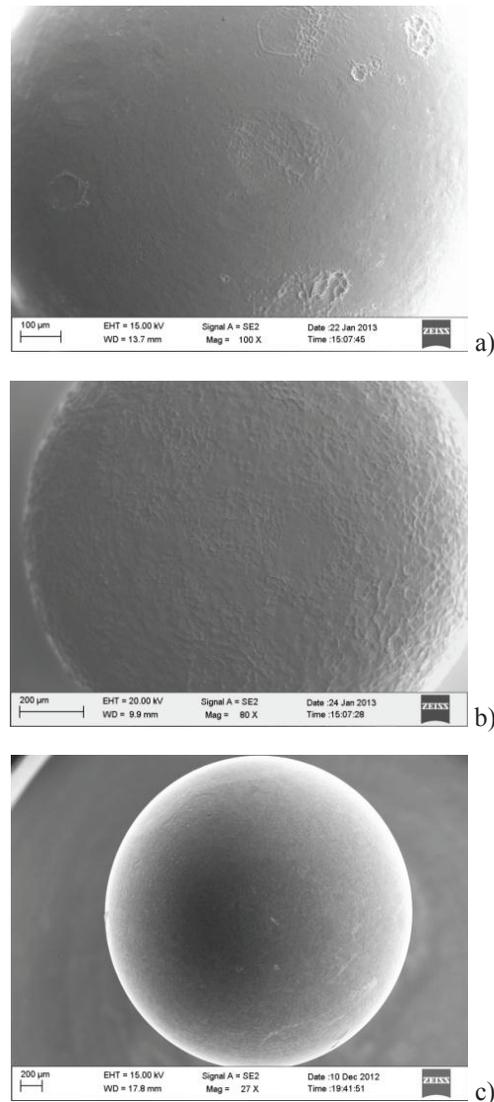


Figure 4: The SEM images of the pin end cap after high power testing a) for the set 1 upstream pin (low power), b) for the set 3 upstream pin (high power) and c) for a matching pin.

## SUMMARY AND DISCUSSION

Two sets of pins have been tested so far. As expected, the rf breakdowns occurred on the upstream, high field pins. Furthermore, the sustainable peak surface electric field depends strongly on the net power flow through the structure. That is, rf breakdown is not only a local phenomenon but depends on the global design of the waveguide structure, just as for accelerator structures [4]. The power flow dependence is also consistent with breakdown measured in X-band waveguides of different group velocities, where however the surface magnetic to electric field ratio varied significantly as well [5].

Generally, a structure with lower power flow tends to have higher sustainable fields (electric and magnetic). This could be explained in terms of the absolute rf energy lost during breakdown being much less for the lower power structures, tending to cause less surface damage and thus produce fewer future breakdown sites. The surface damage patterns in Fig. 4 clearly indicate less damage for the lower power operation.

We have designed another group of pins to factor out the dependence on the rf group velocity. With these pin

sets, the Q's of the 2-pin waveguide structures are very close. These pins are ready for high power testing.

## ACKNOWLEDGMENT

The authors would like to thank Lisa Laurent for taking SEM images of the pins, and Christopher Nantista and Chris Adolphsen for helping to edit this paper.

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