SLAC HIGH GRADIENT TESTING OF A KEK X-BAND ACCELERATOR STRUCTURE*

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Abstract

The high accelerating gradients required for future linear colliders demands a better study of field emission and RF breakdown in accelerator structures. Changes in structure geometry, vacuum pumping, fabrication methods, and surface finish can all potentially impact the conditioning process, dark current emission, and peak RF power handling capability. Recent tests at SLAC of KEK's "M2" travelling wave x-band accelerator section provides an opportunity to investigate some of these effects by comparing its performance to previously high power tested structures at SLAC [1,2]. In addition to studying ultimate power limitations, this test also demonstrates the use of computer automated conditioning to reach practical, achievable gradients.

1 ACCELERATOR STRUCTURE

The design parameters of the M2 accelerating section are outlined in Table 1. The structure cells were manufactured by diamond turn machining, assembled in a clean room, and diffusion bonded. Complete details of the fabrication process are described in the KEK JLC Design Report [3]. For comparison, an earlier tested 1.8m SLAC x-band section (DS1) was built with conventional machining, assembled with little control over cleanliness, and brazed using standard techniques.

Table 1: M2 Design Parameters.

Structure Type	Detuned
Length	1.31m
Cell Number	150
Phase Advance/Cell	$2\pi/3$
Iris Aperture Diameter	5.35–3.67 mm
Cavity Diameter	22.5–21.3 mm
Disk Thickness	0.966–2.39 mm
Group Velocity	1.03*c*–0.020*c*
Filling Time (measured)	113 ns
Attenuation Parameter	0.609
Shunt Impedance R0	79 MΩ/m
Average Q	6300
Peak Power for 73 MV/m	130 MW
E_{surf}/E_{acc}	2.15

Just prior to high power testing, the structure was baked at 250°C for 2 days. It had been stored under vacuum of 10^{-9} torr for approximately 24 months after a wakefield ASSET [4] test conducted at SLAC in Aug. 1996.

2 TEST FACILITY

Two 50 MW x-band klystrons operating at 11.424 GHz and 1 μs pulse width combine in a magic tee to feed a SLED-II pulse compression system. The output 150 ns rf pulse then feeds the accelerator structure test area (ASTA). All system components before the accelerator structure were previously tested to more than 300 MW at this pulse width at a repetition rate of 60 Hz [5]. At this power, the average accelerating field in the M2 structure would be well over 100 MV/m.

Pairs of vacuum pumps located near the input and output couplers monitor gas activity. Since there is no pumping in the structure cells, these pumps, along with the beam line pump, supply the limited pumping speed for the bulk of the structure.

SLED and structure input powers are measured with a HP peak power meter. A crystal detector measuring reflected power is interlocked to remove triggers to the low-level drive of the klystrons for reflected peak power exceeding 5 MW. This interlock is meant to protect the klystron windows but it also prevents large gas bursts in the accelerator structure caused by multiple arcing.

One downstream faraday cup measures dark current and another off-axis faraday cup measures the dark current energy spectrum using a spectrometer. Radiation levels are monitored with 3 scintillators along the structure and a calibrated radiation meter measures contact levels at the input or output ends.

3 EXPERIMENTAL RESULTS

3.1 Conditioning Summary

Over the several week test, the high voltage running time meter logged more than 560 hours of which an estimated 440 hours can be considered as actively processing. At the 60 Hz repetition rate, this time gives approximately 1×10^8 total pulses—a factor of 4–5 greater number of pulses than in previous structure tests at SLAC.

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A PC system running LabVIEW handled the majority of processing by adjusting power levels based on structure vacuum and reflected arc interlock trips. Details of the algorithm are beyond the scope of this paper but the overall strategy for conditioning remained consistent between operator and computer control. The first 100 hours were mainly processed by hand to the 60 MV/m level. During this time, as indicated in Fig. 1, the SLED compression was not phased for maximal gain in order to allow average power heating to help outgas the structure.

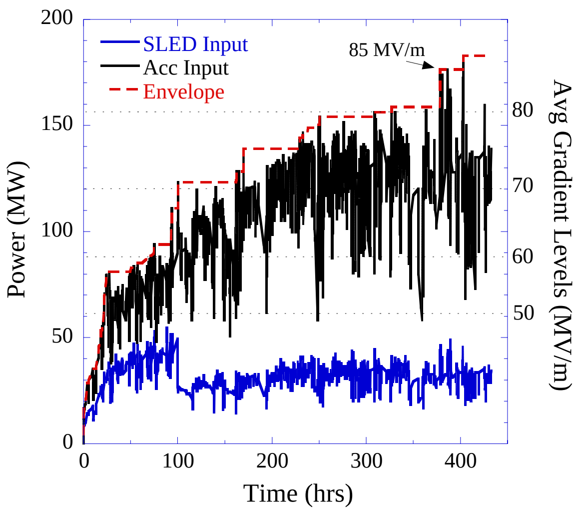

Figure 1: M2 active processing history.

Even at a conservative pace, only 20 hours were required to reach 50 MV/m average gradient and the structure suffered only a handful of reflected power trips due to rf breakdown. At higher powers, once arcing started, gas bursts and vacuum recovery limited progress. After the first 150–200 hours, gas activity associated with breakdown became quite negligible and only reflected trips prevented advancement. Although progress slowed dramatically, continued processing still seemed to increase achievable peak power. Reversing the axes of the previous plot reveals an exponential behaviour.

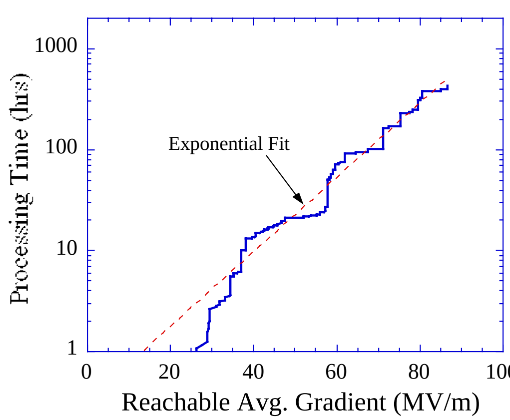

Figure 2: Time required to reach desired gradient using monotonic envelope from Fig. 1.

3.2 High Gradient Performance

At the end of testing, average gradients reached 85 MV/m and was sustainable for ~10 seconds before arcing. At 75 MV/m, however, the structure ran for one hour without any arc trips. Previous tests of SLAC's 1.8m DS1 structure reached gradients of only 68 MV/m and were limited by available power. Both structures showed similar patterns in processing difficulty, dark current emission, and dark current energy spectrum. Figure 3 compares the two structure's peak dark current readings from the downstream faraday cup. To evaluate the real difference between the two curves, corrections must be made for structure length, iris size, and cut-off hole size. Estimating these corrections, the structures may be within a factor of 2, with the leftover difference most likely attributable to cleanliness.

The dark current measured at a particular gradient did not steadily improve during processing as was witnessed in the DS1 tests. The M2, however, was constantly being pushed to reach higher power. Also note that the M2 dark current appears to deviate from expected values at very high gradients.

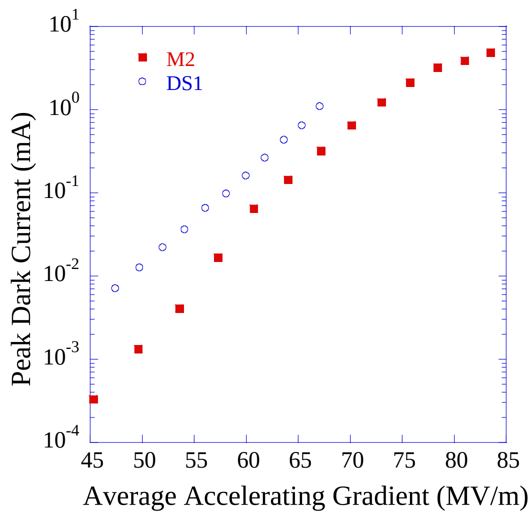

Figure 3: M2 and DS1 dark current comparison.

3.3 Visual Inspection

A conservative estimate of 3000 arcs occurred at average gradients over 50 MV/m. Once the high power test finished, the structure was visually inspected with a boroscope to evaluate the extent of damage to the cells.

Figure 4 compares sections of input and output cell irises. The output end showed no discernible damage to the cells; the copper still had a polished surface with grain boundaries easily identified. In marked contrast, the input cells were heavily damaged (but only the first 30 cells could be viewed); the cell irises were completely pitted with no signs of the original machined surface finish remaining. Both ends of the structure reached equivalent average gradients, but the dynamics of rf breakdown seem to protect the downstream cells from arcing at the expense of cells upstream.

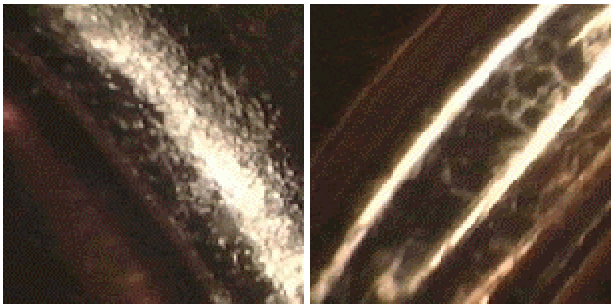

Figure 4: Typical cell irises near input (left) and output (right) of structure.

3.4 RF Evaluation

Degradation in rf performance was evaluated by bead-pull measurements [6] before and after high power testing. Figure 5 plots the integrated phase error of the accelerating mode as a function of position along the structure. The most dramatic changes occurred at the beginning cells in agreement with the visual evidence.

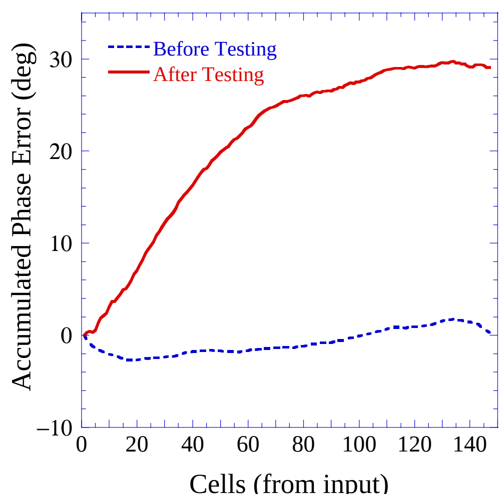

Figure 5: Accumulated phase advance error measured as a function of distance along structure.

Figure 6 uses the group velocity along the structure to plot the associated change of frequency in each cell. Cell to cell variation is due to uncertainties in measurement but an average of 1 MHz shift over the entire structure results in the observed 30° total phase shift. The change in frequency is equivalent to a copper layer of several microns being removed from the iris surface. The exact nature of the frequency shift is still being investigated.

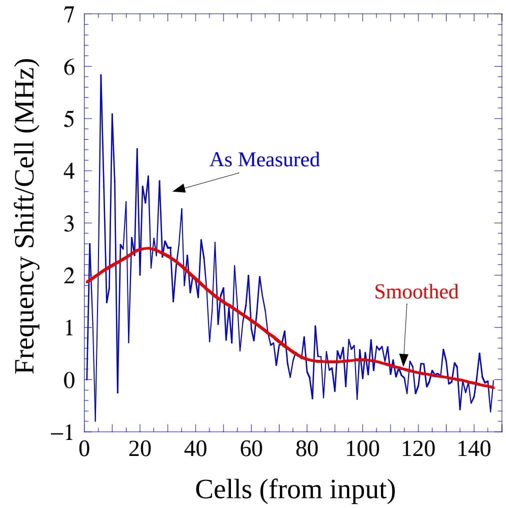

Figure 6: Frequency shift per cell as a function of position along structure.

4 SUMMARY

The M2 structure test achieved several milestones: with the aid of computer assisted processing, the total number of integrated pulses in conditioning approached $1x10^8$; stable and achievable gradients of 75 MV/m were demonstrated in a usable accelerator structure; and the effects of intensive conditioning were easily seen and quantified. As a result, tests at SLAC are underway to better understand arc formation and the mechanism of rf breakdown, particularly in long structures.

5 REFERENCES

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