RECENT PROGRESS IN R&D OF ADVANCED ROOM TEMPERATURE ACCELERATOR STRUCTURES*

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Abstract

The NLC and JLC groups face two major challenges in designing X-Band accelerator structures for an electron-positron linear collider. The first is to demonstrate stable, long-term operation at a 70 MV/m gradient, which is required to keep the machine cost low, and the second is to strongly suppress the structure long-range wakefield, which is required to achieve high luminosity. During the past 2 years, the major emphasis has been on proving high gradient operation, although dipole wakefield suppression studies are continuing.

This paper describes high gradient test results from a series of prototype TW and SW structures being developed for the NLC/JLC. Schemes for damping and detuning the dipole modes of these structures are also presented.

1 INTRODUCTION

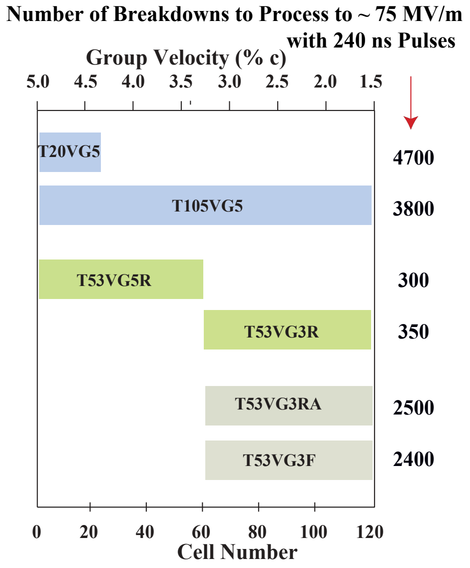
Early high gradient tests of X-Band structures at SLAC demonstrated reasonably stable operation at accelerator gradients in excess of 100 MV/m, and surface electric fields more than twice this value [1]. Because high power sources were not available at the time, short, low group velocity ($v_g/c \sim 0.03$) structures were used. In contrast, the structure initially chosen for the NLC/JLC was 1.8 m long in order to be efficient and to reduce the cost of couplers and high power waveguide. The group velocity at the upstream end of this structure was necessarily high ($v_g = 0.12$ c) and decreased toward the downstream end ($v_g = 0.03$ c) to achieve constant gradient. These structures showed significant damage when operated at 50 MV/m, almost exclusively near their upstream end [2]. Motivated by these observations, a series of structures (T-Series) were built with varying length and group velocity to study how these variables affect high gradient performance (the peak surface fields along the structures were kept constant). These structures are described in Section 2.

One of the most striking results from the high gradient operation of these structures was that the input and output couplers broke down 1 to 2 orders of magnitude more often than the other cells. A discussion of the probable cause and proposed solutions is presented in Section 3. Although the performance of the non-coupler cells was close to meeting NLC/JLC requirements, the iris radii of the 'T' structures are too small from a wakefield perspective. To achieve low group velocity with acceptable iris radii, structures with a 150 degrees phase advance per cell (H-Type) have been built. Their design is described in Section 4. Dipole wakefield suppression has been studied for these structures, as well as for SW structures, which may be a viable candidate for the NLC/JLC. These studies are discussed in Section 5. Finally, a series of SW structures have been built and high power tested. The results are presented in Section 6.

2 T-SERIES STRUCTURES

The six structures in the T-Series were built with different lengths and initial group velocities. The methods of cell manufacturing and cleaning for these structures also differed. For three of the structures, the cells were fabricated using poly-crystal diamond turning by a vendor near SLAC, and three were made at KEK using single-crystal diamond turning. Before assembly, the KEK cells underwent little (0.3 μm) or no etching as part of their cleaning procedure, while the SLAC cells were more deeply etched (either 1.5 or 3.0 μm). After assembly, all structures went through a pre-processing procedure that included 'wet' and 'dry' hydrogen firing at 950 °C, a two-week vacuum furnace bake-out at 650 °C, and a one-week in-situ bake-out at 220 °C. The program of high gradient tests took place at the NLCTA, which delivered a total 3000 hours of high-power rf at 60 Hz during this period.

Table 1. T-Series Structures



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The rf processing of the T-Series structures started at a higher gradient (55-65 MV/m) than that (35-45 MV/m) for the earlier, 1.8 m structures. In addition, much less damage was observed in these structures at gradients above 70 MV/m (the nominal NLC/JLC unloaded gradient) than in the 1.8 m structures at gradients of 50-70 MV/m.

After processing to 80-85 MV/m, the breakdown rate at 70 MV/m was dominated by events in input and output couplers. The rf signature of these events was different from those in the body and was similar structure-to-structure.

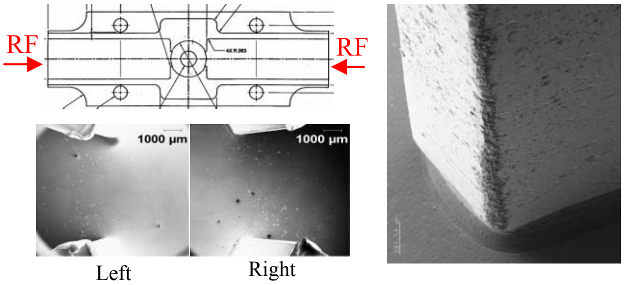
The breakdown rates in the body of the structures (i.e., excluding the couplers) at 70 MV/m gradient are close to acceptable for the NLC/JLC. For the three 53 cm, 0.03 c initial group velocity structures that were run at the NLC/JLC design pulse width of 400 ns, the breakdown rates were < 0.1, 0.2 and 0.3 per hour, respectively, while the goal is < 0.1 per hour.

The breakdown related damage was measured by the change in the rf phase advance profile along the structures. In a test where a 53 cm, 0.03 c initial group velocity structure was run in parallel with a 53 cm, 0.05 c initial group velocity structure, the phase shift per breakdown was five times higher in the higher group velocity structure. The increase in damage with group velocity was also seen in a 105 cm structure whose upstream and downstream halves share the same cell designs with the 53 cm, 0.05 c and 0.03 c structures, respectively. The phase shift profile along in 105 cm structure is similar to that expected from individual profiles measured for the 53 cm structures, suggesting that the damage is a local phenomena and so does not depend on structure length. Finally, the net phase change in the body of the 53 cm, 0.03 c structure after 1200 hours of operation, including processing, was only 0.5 degrees.

Although better handling and pre-processing procedures were adopted for the T-Series structures, a large variation in the initial processing rates was still observed. Of the three pairs tested, one pair processed about 10 times faster than other two in terms of the number of breakdowns required to reach a gradient of about 75 MV/m. The processing rate was similar for each structure in a pair, regardless of group velocity, length, and method of cell manufacturing and cleaning. This suggests that whatever changes occurred to affect the processing rate happened when the structure pairs were together. Surface analyses of the irises are being done to look for clues as to the cause of these differences.

3 PULSE HEATING

An autopsy of the input coupler of one of the structures revealed severe damage and some melting on the edges of the waveguide openings to the cell, and extensive pitting near these edges and on the coupler iris. The waveguide edges see large rf currents that are a strong function of their sharpness, and the associated pulse heating can be significant. By design, the edges in the T-Series structures were sharper (76-µm radius) than those in the 1.8-m structures (500-µm radius). The predicted pulse heating for the T-Series structures is 130-170 °C, well below the copper melting point, but high enough to produce stress-induced cracking, which can enhance heating [3].



Left Right

Figure 1: Damaged input coupler of a 0.03 c structure

Acoustic monitors have localized the thermal energy deposited from coupler breakdowns [4]. All of the coupler arcs appear to occur near the four edges damaged by pulse heating. The arcs may be caused by the copper debris observed adjacent to the damaged edges, although this does not explain the severe pitting on the coupler irises.

Several coupler designs with much lower pulse heating have been proposed. They are illustrated in Figure 2 with the field patterns shown in two cases. Type (a) is a traditional coupler with a 3 mm full radius at the edges of the coupling irises. The temperature increase due to pulse heating is less than 50 °C for a 70 MV/m gradient and 400 ns pulses. Type (b) and (c) use rectangular TE to circular TM mode converters with different matching designs. Type (d) has an rf choke in order to increase acceleration in the coupler cavity. The pulse heating for (b), (c) and (d) is negligible.

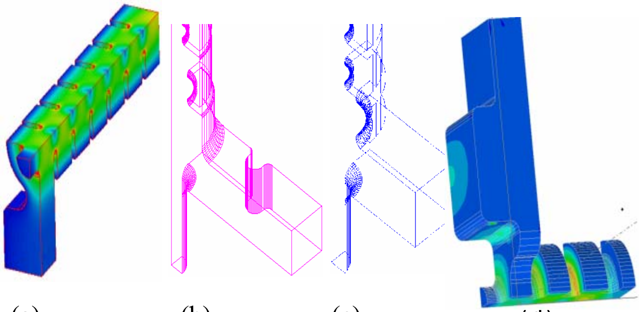

(a) (b) (c) (d)

Figure 2. Several couplers with low pulse heating.

Test structures with type (a) and (b) couplers are being fabricated. The connection between breakdown and pulse heating should become clearer when tests of these structures begin in September, 2002.

4 HIGH PHASE ADVANCE STRUCTURES

Although the results from the T-Series structures are encouraging, their average cell iris radii are too small to meet NLC/JLC short-range wakefield requirements. To increase the iris size while maintaining a low group velocity, a structure design with thicker irises and a higher phase advance per cell (150º instead of 120º) design has been adopted [5]. Two of these structures (H-Type) have been built, one 60 cm long with an initial group velocity of 0.03 c, and the other 90 cm long with an initial group velocity of 0.05 c. The structures have been installed in NLCTA and now are under high power test. During the next year, several more H-Type structures will be tested, culminating in one that is fully damped and detuned for wakefield suppression. The renewed awareness of pulse heating has also led to design changes in the manifold slots for damped structures. Figure 3 shows the new accelerator cup design for the H-Type Damped Detuned Structure (HDDS).

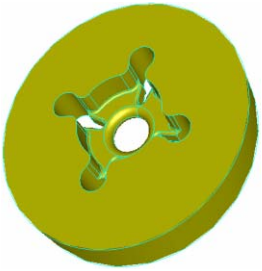


Figure 3. HDDS cup with pie-shaped dipole mode coupling slots. The temperature rise due to RF pulse heating is reduced from 70^0C to about 25^0C by rounding the slot edges with a 0.5-mm radius on the disk and a 2-mm radius at the cell radius.

5 WAKEFIELD IN H-TYPE STRUCTURES

The long range-wakefields in the H-Type structures will be suppressed in a manner similar to that developed for the 1.8 m structures. That is, the cell frequencies will be detuned and the wakefield damped by coupling out the dipole mode energy via four manifolds that run along the structure [6]. The cell dipole mode frequencies have been computed using a program that maximizes the destructive interference among the mode fields [7]. To obtain acceptable wakefields, the frequencies for three 60 cm structures were interleaved to effectively create a 1.8 m detuned structure. The resulting wakefield from the first dipole band is shown in Figure 4.

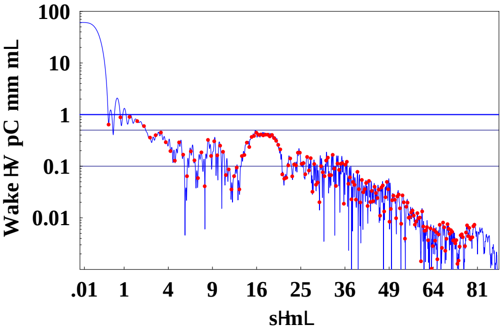


Figure 4. Envelope of optimized wakefield for HDDS with 3-fold interleaving. The frequency spread of the dipole modes has a sigma of 7.7%.

The wakefield at the first trailing bunch (42cm from the first bunch) is a strong indicator of the size of resonant beam growth. For this reason, the wakefield was minimized at this location. The third dipole band must also be detuned for these structures. The iris thicknesses will be carefully tailored for this purpose. To verify the wakefield suppression, a wakefield measurement scheme using a coaxial wire is being developed at SLAC (see Figure 5) [8].

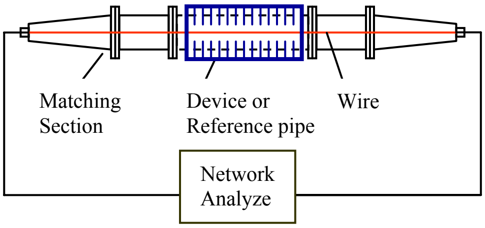


Figure 5. Wire system for wakefield measurements.

6 STANDING WAVE OPTION

Another approach being explored for achieving higher gradients is to use short SW structures that require much lower peak power than the TW structures. The SW structures tested so far are 20 cm long, contain 15 cells and have a coupling beta of one or two. They are operated in pairs, which allows the power reflected from them during their approximately 100 ns fill/discharge periods to be routed to loads.

Three such pairs have been tested during the past year. One pair performed well at the NLC/JLC loaded gradient of 55 MV/m and flattop pulse width of 270 ns (unlike the SW structures, the SW structures do not need to operate above the NLC/JLC loaded gradient).After processing, the average breakdown rate for this pair at 55 MV/m was about 0.1 per hour per structure during a several hundred hour period, which is about a factor of two higher than desired for these short structures. No discernable shift in frequency (< 100 kHz) was measured in either structure after 600 hours of operation.

From measurements made during operation and after removal from NLCTA, it appears that most of the breakdowns occurred in the coupler cells of the SW structures. For NLC/JLC running conditions, the pulse heating for the best performing pair was estimated to be 40 °C, while that for the other two pairs was 60 °C and 150 °C. In the next pair of structures to be tested, a coupler with a lower temperature rise (< 20 °C) will be used, and choke mode cells will be included to test their high gradient properties in preparation for use to damp wakefields.

For the SW structures, the three lowest dipole bands are equally strong and must all be suppressed. In design simulations, these modes have been successfully damped by attaching two higher order mode couplers and by carefully shaping the dipole frequency profile.

7 REFERENCES

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