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PROGRESS IN UNDERSTANDING BREAKDOWN CHARACTERISTICS OF X-BAND CHOKE-MODE STRUCTURES*

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Abstract

As one of the higher-order-mode (HOM) damping structures, X-band choke-mode accelerating structures had been studied for several years. However, the breakdown characteristics of the X-band choke are still unknown. Five different single-cell choke-mode accelerating structures and one reference structure were designed, fabricated and high-gradient tested to study the related RF breakdown characteristics. The absence of field emission current flash was proposed to be the sign of breakdowns occurring inside the choke, this was verified by the post-mortem observation. Evaluation of the breakdown rate revealed that there is memory effect with pulse width and electric field. The breakdown rate in a single RF pulse did not have the 5th order pulse width and 30th order electric field dependency predicted by the empirical formula.

INTRODUCTION

Tsinghua University has been collaborating with CERN and KEK to assess the feasibility of X-band high-gradient choke-mode accelerating structures [1–3]. However, the breakdown characteristics of the X-band choke are still unknown. Five X-band single-cell standing-wave structures were designed, fabricated, assembled, and tuned by Tsinghua University [4]. The high-gradient tests were conducted in New X-band Test Facility (Nextef) at KEK to study the related breakdown phenomenon [5].

Two of the choke-mode structures was cut into three pieces for inner surface observations after the high-gradient tests. The main results of the observations from the post-mortem were reported below. The breakdowning timing of the structures was also studied.

OVERVIEW OF THE SINGLE-CELL STRUCTURES

The single-cell standing-wave structure consists of three parts: the input coupler cell, the high-gradient middle cell(s), and the end cell [6]. Five single-cell structures including THU-CHK-D1.26-G1.68, THU-CHK-D1.26-G2.1, THU-CHK-D1.89-G2.1, THU-CHK-D2.21-G2.1, and THU-REF were designed, fabricated, assembled, and tuned at Tsinghua University. The fabrication and test flow can be found in [4]. The details of RF design and mechanical design can be found in [7].

HIGH-GRADIENT TEST

High-gradient test was conducted after the structure was installed in Shield-B [4, 8] of Nextef at KEK. Shield-B is aiming at basic high-gradient study by testing single-cell structures [9].

EXPERIMENTAL RESULTS

The summary of the conditioning history of THU-CHK-D1.26-G1.68 is shown in Fig. 1. Two types of breakdowns, which were accompanied with and without current flash, were observed in the high-gradient test [4]. The blue, red and cyan points represented the accelerating gradient (E_{acc}), the accumulated number of breakdowns, and the accumulated number of breakdowns with current flash, as a function of number of pulses respectively. The E_{acc} value was recorded at every interlock event. Few breakdown events accompanied with current flash were observed after the initial ramping stage. It was speculated that breakdowns with current flash occurred in the cylinder cavity while breakdowns without current flash occurred in the choke.

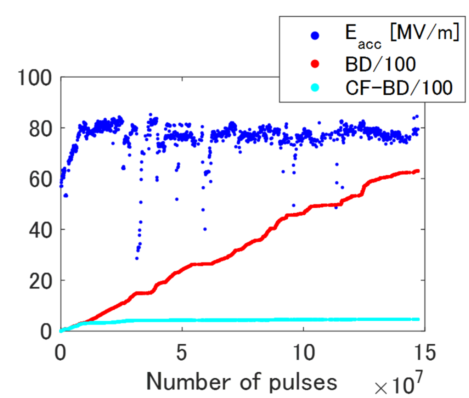

Figure 1: High-gradient history of THU-CHK-D1.26-G1.68. The blue dots are the E_{acc} [MV/m], the red dots are the breakdown number divided by 100, and the cyan dots are the current flash breakdown number divided by 100.

The summary of the conditioning history of THU-CHK-D1.89-G2.1 is shown in Fig. 2. Differing from THU-CHK-D1.26-G1.68, breakdown events with current flash

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were observed during the whole high-gradient test of THU-CHK-D1.89-G2.1. It was speculated that the high-gradient performance of THU-CHK-D1.89-G2.1 was limited by the breakdowns occurred in the choke area and the cylinder cavity area. This speculation was verified in the post-mortem observation. This will be discussed in the next section.

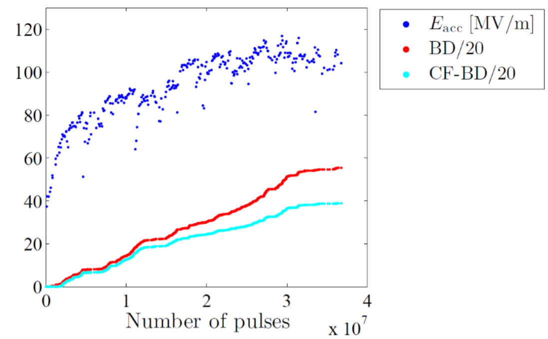

Figure 2: High-gradient history of THU-CHK-D1.89-G2.1. The blue dots are the E_{acc} [MV/m], the red dots are the breakdown number divided by 100, and the cyan dots are the current flash breakdown number divided by 100.

POST-MORTEM OBSERVATION

THU-CHK-D1.26-G1.68 and THU-CHK-D1.89-G2.1 were cut to observe the inner surfaces after the high-gradient tests were finished. Both of the structures were cut twice by following the procedures introduced in [4]. A microscopy whose model is KEYENCE VE-8800 was used to examine the structures. Several points were chosen for inner surface inspections of THU-CHK-D1.26-G1.68. The post-mortem observation indicated that choke area had a high breakdown rate [4].

Twelve points were chosen for inner surface inspections of THU-CHK-D1.89-G2.1 as show in Fig. 3. The inner surface observation results are shown in Fig. 4. Microscopy imaging of point B, C, E, H, and J showed damage. Both choke area and iris area were damaged. Therefore, breakdowns in the choke and iris limited the high-gradient performance of the strcuture. The speculation conducted by the high-gradient history was verified by the post-mortem observation. The absence of field emission current flash was the sign of breakdowns occurring inside the choke.

BREAKDOWN TIMING STUDY

Breakdown timing is defined as the rising time of the reflection wave as shown in Fig. 5.

Breakdown timing of THU-REF at 200 ns operation is shown in Fig. 6. The breakdown timing of normal breakdown (NL-BD) ramped from 60 ns to 100 ns and had a uniform distribution from 100 ns to the end of the pulse. If there is no memory effect with the electric field, a huge increasing of breakdown rate should be observed in the first 100 ns of the pulse which is the filling stage of the structure based on the empirical formula [5]. However, only a slow

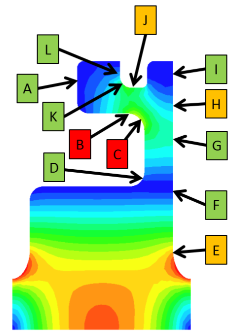

Figure 3: Inner surface inspecting points of THU-CHK-D1.89-G2.1. Background is the electric field of the structure.

ramping was observed in the initial stage in Fig. 5. We also did not see the quick ramping of breakdown rate in the second step of the pulse. The breakdown rate in a single RF pulse did not have the 5th order pulse width and 30th order electric field dependency predicted by the empirical formula. The breakdown timing of following-pulse breakdown (FP-BD) ramped in the first 100 ns and decreased after 100 ns. This was the same as what we observed in the traveling-wave structures [5].

CONCLUSION

Four standing-wave single-cell choke-mode structures and one reference structure have been successfully designed, fabricated, and tuned at Tsinghua University. High-gradient tests were conducted in Nextef at KEK. The absence of field emission current flash was the sign of breakdowns occurring inside the choke. The breakdown rate in a single RF pulse did not have the 5th order pulse width and 30th order electric field dependency predicted by the empirical formula.

ACKNOWLEDGEMENT

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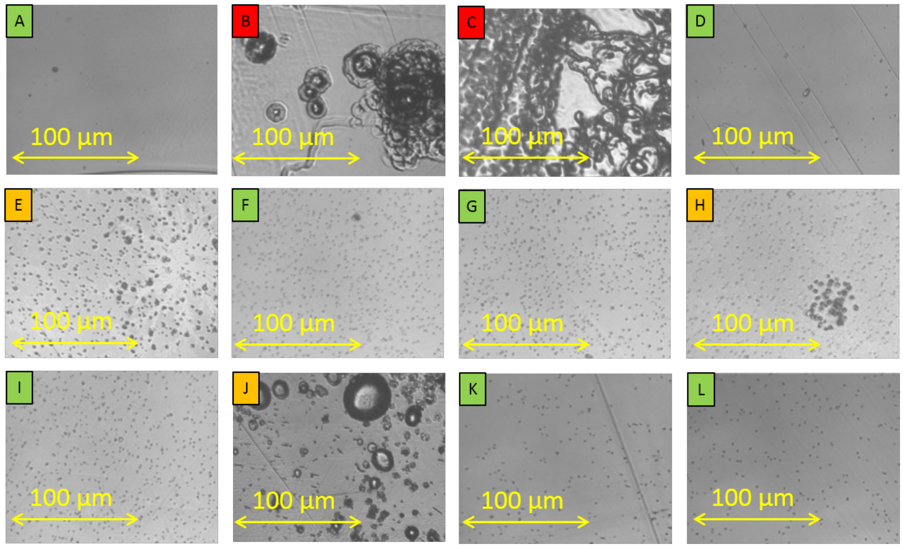

Figure 4: Inner surface inspection results of THU-CHK-D1.89-G2.1.

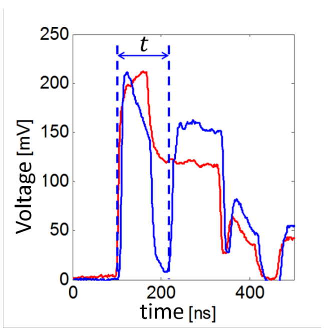

Figure 5: Breakdown timing. Red line is the input and blue line is the reflection. t is the rising time of the reflection wave.

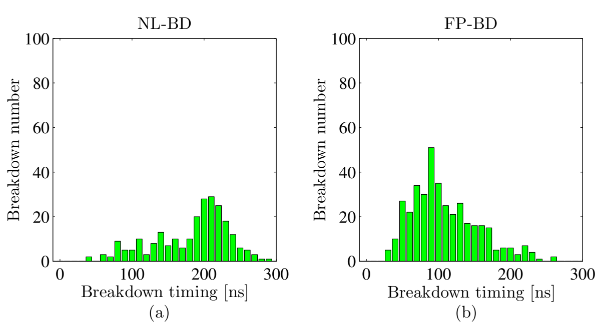

Figure 6: Breakdown timing of THU-REF at 200 ns operation. (a) is the breakdown timing distribution of normal breakdowns; (b) is the breakdown timing distribution of following-pulse breakdowns.

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