

HIGH-GRADIENT BREAKDOWN STUDIES OF X-BAND CHOKE-MODE STRUCTURES*

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Abstract

As an alternative design for Compact Linear Collider (CLIC) main accelerating structures, X-band choke-mode damped structures had been studied for several years. However, the performance of choke-mode cavity under high power is still in lack of research. Two standing-wave single-cell choke-mode damped accelerating structures working at 11.424 GHz and one reference structure without choke were designed, manufactured, low-power measured, and tuned by accelerator group at Tsinghua University. High-power test had been done on them to study the breakdown phenomenon in high gradient and how the choke affects high-gradient properties. A max gradient of 75 MV/m were achieved by the choke-mode structure and the choke breakdown limited further increasing of the gradient. Inner surface inspection of the choke-mode structures indicates that the axial part of the choke limits the performance of the structure. Based on this observation, three new choke-mode structures were designed and being manufactured.

INTRODUCTION

One of the highest priorities for the Compact Linear Collider (CLIC) collaboration has been the development of high-gradient accelerating structures for the CLIC main linac [1]. Transverse wakefield created by the beam in the structure needs to be suppressed to avoid beam instability. The CLIC-G design, with waveguide damping, is the baseline for the CLIC main linac [2, 3]. Alternatives, choke-mode damped structure, had also being investigated for several years. Tsinghua University has been collaborating with CERN and KEK to assess the feasibility of X-band high-gradient choke-mode accelerating structures [4–6]. Three X-band single-cell standing-wave structures including two choke-mode structures and one reference structure without choke were designed, fabricated, assembled, and tuned by Tsinghua University. The high-power test, aiming at studying the high-gradient properties of X-band choke-mode structure, were conducted in New X-band Test Facility (Nextef) at KEK [7]. One of the choke-mode structures was cut into three pieces for inner surface observation after the high-power test. A new set of three new choke-mode structures were designed and manufactured based on the experimental results and the

post-mortem observations. Below we report the main results of the test and the observations from the post-mortem. Information of the new choke-mode structures is also presented.

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 [8]. Geometry of the choke-mode structure is shown in Fig. 1. The names of the single-cell structures are derived from the manufacturer's name plus structure's type and key geometry. An example of a single-cell structure name is: THU-CHK-D1.26-G1.68. Here THU is the manufacturer and CHK is the structure's type. D1.26 is the d23 dimension in mm and G1.68 is the d1 dimension in mm, as shown in Fig. 1. Three single-cell structures including THU-CHK-D1.26-G1.68, THU-CHK-D1.26-G2.1, and THU-REF¹ were designed, fabricated, assembled, and tuned at Tsinghua University. The details of RF design and mechanical design can be found in [6].

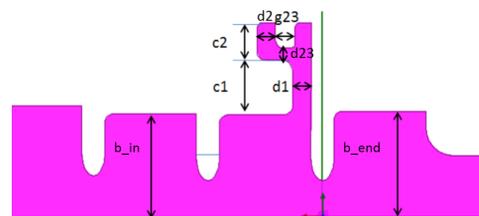


Figure 1: Choke-mode structure geometry.

The individual parts of the single-cell structures were diffusion bonded in a hydrogen furnace at Tsinghua University. Operating frequency was tuned to 11.424 GHz at the working temperature of 30 °C which is the standard cooling water temperature at Nextef. Vacuum baking was performed at 500 °C for five days. The structures were kept under vacuum after baking by sealing with a valve and were shipped to KEK under vacuum.

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¹ Note the nomenclature here is different from that in [6]. Dimension of d23 shown in Fig. 1 is added in the structure's name.

HIGH-POWER TEST

High-power test was conducted after the structure was installed in Shield-B [7] of Nextef at KEK. THU-CHK-D1.26-G1.68 was first tested followed by THU-CHK-D1.26-G2.1 and THU-REF. Nextef was founded in 2006 as a re-assembled facility of Global Linear Collider Test Accelerator (GLCTA) [9, 10] and provides up to 100 MW for X-band accelerating structure studies. Shield-B is aiming at basic high-gradient study by testing single-cell structures [11]. Details of the test-stand and experimental setup can be found in [12].

EXPERIMENTAL RESULTS

The summary of the conditioning history of THU-CHK-D1.26-G1.68 is shown in Fig. 2. The blue, green and red points represent the accelerating gradient (E_{acc}), the pulse width of rf power, and the accumulated number of breakdowns, as a function of elapsed hours respectively. The E_{acc} value was recorded at every interlock event. The dots that fall below the envelope of E_{acc} correspond to interlocks occurring during the power ramping stage after previous breakdown. Rf power could not be further increased after 100 hours in 100 ns pulse width operation due to continuous breakdowns. Same phenomenon happened at longer pulse width operation. The maximum gradient obtained in the test was 75 MV/m as shown in Fig. 2. Similar phenomenon happened in the operation of THU-CHK-D1.26-G2.1 at 60 MV/m, while THU-REF could operate at 120 MV/m. The conditioning histories of THU-CHK-D1.26-G2.1 and THU-REF are still under analysing.

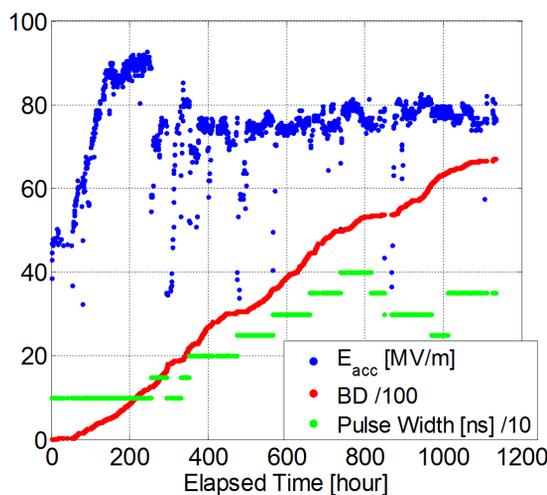


Figure 2: High-gradient testing history of THU-CHK-D1.26-G1.68. The blue dots are the E_{acc} [MV/m], the green dots are the pulse width [ns] divided by ten and the red dots are breakdown number divided by 100.

Two types of breakdowns, which were accompanied with and without current flash, were observed in the high-power test, as shown in Fig. 3. Breakdowns were accompanied with

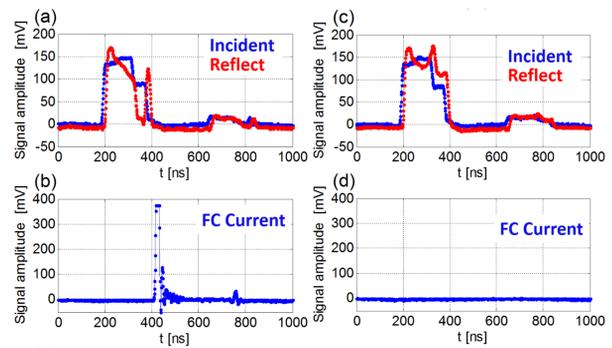


Figure 3: Examples of two types of breakdowns. (a) and (b) are incident and reflection waves and Faraday cup signal of the breakdown accompanied with current flash. (c) and (d) are the signals of the breakdown accompanied without current flash.

the current flash into the Faraday cup during the initial ramping stage of the conditioning. After initial ramping, few current flash breakdowns were observed in the detected events. As the Faraday cups were located at the end of the pipe axis, the electrons emitted from the choke breakdown area were not easily collected. It was speculated that breakdowns with current flash occurred in the cylinder cavity while breakdowns without current flash occurred in the choke. Frequent breakdowns in the choke during the high-gradient test were assumed to be the main limitation of obtaining higher gradient as shown in Fig. 2. This speculation was verified in the post-mortem observation. This will be discussed in the next section.

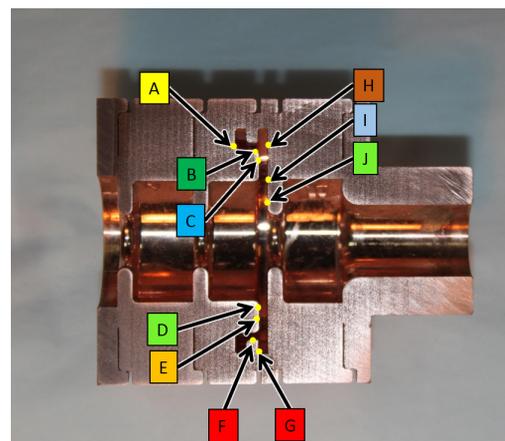


Figure 4: Inner surface inspecting points of THU-CHK-D1.26-G1.68.

POST-MORTEM OBSERVATION

THU-CHK-D1.26-G1.68 was cut after the high-gradient test was finished. The structure was cut along radial direction twice, allowing microscopy imaging of the choke surface which was speculated as frequent breakdown sites. The surfaces of the irises and cylinder cavity are very clean while the surfaces of the choke groove are very rough with naked

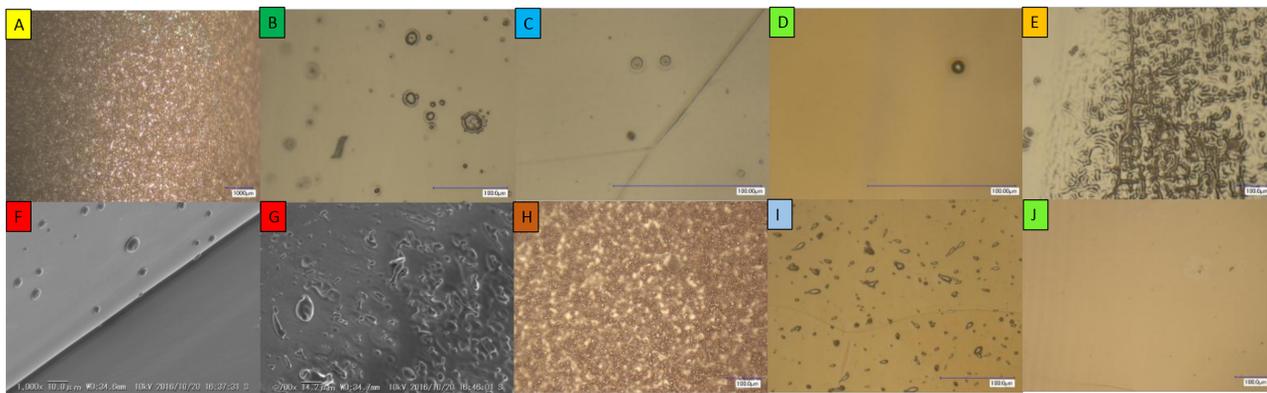


Figure 5: Results of the inner surface inspections.

eye observation. The structure was then examined with a microscope. The microscopy's model is KEYENCE VE-8800. Ten points were chosen for inner surface inspections as shown in Fig. 4.

The inner surface observation results are shown in Fig. 5. The areas of cylinder cavity and irises were clean as shown in point D and J, indicating that few breakdowns occurred in these areas. Microscopy imaging of point B, E, F, G, H, and I showed damage such as "craters", small "protrusions", and "speckles". Point B and F showed significantly more damage than the other points. The damage at point E, G, H and I was speculated as melting copper sputtered from the choke area. Therefore, d23 area shown in Fig. 1 had a high breakdown rate. The breakdown happened in the choke is speculated as "two-surface" breakdown for the damaged surface. "Two-surface" breakdown is that electrons from a field emitter, or an evolving arc, hit another surface in a concentrated spot because that surface is not very far away. This spot, which gets hit, becomes hot and active and shoots electrons and/or ions back at the original spot.

NEW CHOKE-MODE STRUCTURES

Based on the observation of post-mortem, three new choke-mode structures were designed. As breakdowns occurred frequently in d23 area in high gradient, electric field at d23 area (E_{d23}) was reduced and dimension of d23 was increased in the optimization. The information of the choke-mode structures is shown in Table 1. New structures are under fabrication for the high-gradient test.

Table 1: Choke-mode Structures

Structure	d23 (mm)	d1 (mm)	E_{d23}/E_{acc}
THU-CHK-D1.26-G1.68	1.26	1.68	1.57
D1.26-G2.1	1.26	2.1	1.88
D1.89-G2.1	1.89	2.1	1.36
D2.21-G2.1	2.21	2.1	1.30
D1.88-G2.5	1.88	2.5	1.50

CONCLUSION

Two standing-wave single-cell choke-mode damped structures and one reference structure have been successfully designed, fabricated, and tuned at Tsinghua University. High-power test was conducted in Nextef at KEK. The test demonstrated that the present choke-mode structure can operate at a highest gradient of 75 MV/m, while the reference structure can operate at 120 MV/m. Two types of breakdowns, which were accompanied with and without current flash, were observed in the test. The former one was speculated to be the breakdown occurred in the iris and cylinder cavity area while the latter one was speculated to be located in the choke. Post-mortem of THU-CHK-D1.26-G1.68 verified this speculation and indicated that d23 area of the choke is the critical limitation of obtaining higher gradient. The present d23 with dimension of 1.26 mm will cause continuous breakdowns around 75 MV/m. Three new choke-mode structures were designed and being fabricated based on this observation. They will be high-power tested and compared to study the performance of choke in high gradient.

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