HIGH-GRADIENT PERFORMANCE OF X-BAND CHOKE-MODE STRUCTURES*

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Abstract

The choke-mode accelerating structure is one of the higher-order-mode (HOM) damping structures. It has the advantage of relatively simple fabrication and low surface magnetic field. C-band choke-mode accelerating structures have been successfully applied in multibunch XFEL. However, the X-band choke-mode study remains in the theoretical design stage. The high-gradient performance of the choke is still unknown. Five different single-cell choke-mode accelerating structures were designed, fabricated and high-gradient tested to study the related RF breakdown characteristics. It was observed that high electric field and small choke dimension caused serious breakdowns in the choke which was the main limitation of the high-gradient performance. The Choke-mode accelerating structures reached 130 MV/m by decreasing the electric field and increasing the choke gap. A new quantity was proposed to give the high-gradient performance limit of choke-mode accelerating structures due to RF breakdown. The new quantity was obtained from the summary of the high-gradient experiments and could be used to guide high-gradient choke-mode accelerating structure design.

INTRODUCTION

As one of the HOM damping structures, choke-mode accelerating structure has the advantage of relatively simple fabrication and low surface magnetic field. However, the high-gradient performance of the X-band choke is still unknown. Four different single-cell choke-mode accelerating structures and one reference structure were designed, fabricated, assembled, and tuned by Tsinghua University [1]. The high-gradient 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 [2]. The high-gradient performance of different chokes were compared to study how choke dimension affect the breakdown phenomenon in the structure. A new quantity was proposed to give the high-gradient performance limitation of choke-mode accelerating structures due to RF breakdown.

DESIGN 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 [3]. 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. Geometry of the choke-mode structure is shown in Fig. 1. The name derivation of the single-cell structures can be found in [1]. General information is shown in Table 1. R_E is the max surface electric field divided by accelerating electric field (E_{acc}) for the middle cell. R_p is the maximum surface electric field at the input of 1 MW. The fabrication and test flow can be found in [1].
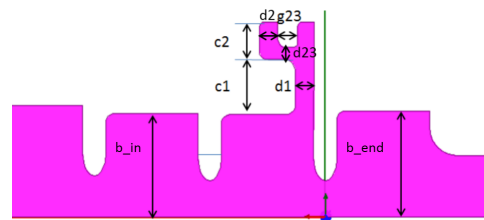

Figure 1: Choke-mode structure geometry.

HIGH-GRADIENT TEST

High-gradient test was conducted after the structure was installed in Shield-B [1, 2] of Nextef at KEK. Shield-B is aiming at basic high-gradient study by testing single-cell structures [4].

HIGH-GRADIENT PERFORMANCE

The summary of the conditioning history of the single-cell structures is shown in Fig. 2. The green, red, blue, cyan, and magenta points represent the accelerating gradient (E_{acc}) of THU-REF, THU-CHK-D1.26-G1.68, THU-K-D1.26-G2.1, THU-CHK-D1.89-G2.1, and THU-CHK-D2.21-G2.1. The E_{acc} value was recorded at every interlock event. Information of the maximum gradient obtained in the test was shown in Table 2. E_{choke} is the maximum surface electric field in the choke area. E_{surf} is the maximum surface electric field. THU-REF reached a highest accelerating

Table 1: Information of the Choke-Mode Structures

THU-	d23 [mm]	d1 [mm]	R_E	R_p [MV/(m $\sqrt{\text{MW}}$)]	Q_0
REF	-	-	2.05	130	9010
CHK-D1.26-G1.68	1.26	1.68	2.10	109	7519
CHK-D1.26-G2.1	1.26	2.10	2.05	104	7247
CHK-D1.89-G2.1	1.89	2.10	2.04	110	8006
CHK-D2.21-G2.1	2.21	2.10	2.06	112	8210

gradient of 145 MV/m which validated Tsinghua X-band single-cell structure manufacturing technology. Both THU-CHK-D1.89-G2.1 and THU-CHK-D2.21-G2.1 reached over 100 MV/m in a short time. These two structures' high-gradient performances were better than the structures with the choke gap of 1.26 mm (THU-CHK-D1.26-G1.68 and THU-CHK-D1.26-G2.1). This revealed that breakdown rate can be reduced by increasing the choke gap size and decreasing the electric field in the choke area.
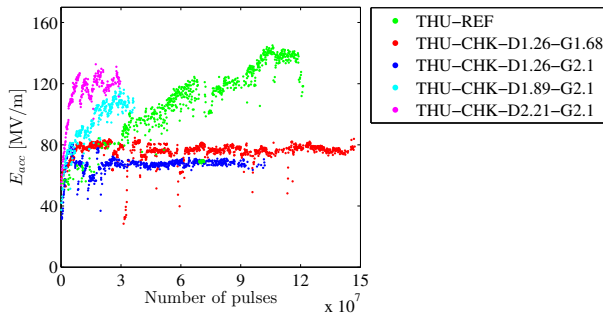

Figure 2: High-gradient testing history of single-cell structures. The green, red, blue, cyan, and magenta points represent the E_{acc} of THU-REF, THU-CHK-D1.26-G1.68, THU-CHK-D1.26-G2.1, THU-CHK-D1.89-G2.1, and THU-CHK-D2.21-G2.1 with respect to the numbe of pulses.

NEW QUANTITY OF CHOKE

Breakdown rate measurements were conducted in the final stage of the high-gradient tests for each structure as shown in Table 3.

Breakdown rate (BDR) is strongly dependent on E_{acc} and rf pulse width. The dependencies that have been observed in many CLIC prototype structures are reported in [5,6] and can be approximated with the following relation:

$$\frac{\text{BDR}}{E_{acc}{}^{30} \cdot \tau^5} = \text{constant} . \qquad (1)$$

Then we can define normalized accelerating gradient (G) as below:

$$G = \frac{E_{acc} \cdot \tau^{1/6}}{\text{BDR}^{1/30}} , \qquad (2)$$

G represents the high-gradient performance of the accelerating structure during the stable operation stage. G depends on both E_{choke}/E_{surf} and choke dimension (d23). A new quantity named CHK was proposed to as shown below:

$$G = (\frac{E_{choke}}{E_{surf}})^\alpha \times d23^\beta \times \gamma . \qquad (3)$$

We can fit α, β, and γ in Eq. (4) by applying the high-gradient test results. Fitting results indicated that $\alpha = -0.83$, $\beta = -0.61$, and $\gamma = 339$:

$$G = (\frac{E_{choke}}{E_{surf}})^{-0.83} \times d23^{-0.61} \times 339 . \qquad (4)$$

Fitting results were shown in Fig. 3. The new quantity named CHK could be used to guide high-gradient choke-mode accelerating structure design.
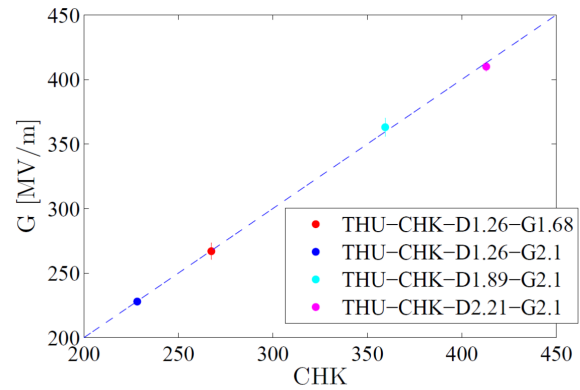

Figure 3: New quantity fitting. The red, blue, cyan, and magenta points represent the THU-CHK-D1.26-G1.68, THU-K-D1.26-G2.1, THU-CHK-D1.89-G2.1, and THU-CHK-D2.21-G2.1.

CONCLUSION

Four 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. High electric field and small choke dimension would cause serious breakdowns in the choke. It was the main limitation of the high-gradient performance. THU-CHK-D2.21-G2.1 reached 130 MV/m by decreasing the electric field and increasing the choke gap size. A new quantity was proposed to give the high-gradient performance limit of choke-mode accelerating structures due to RF breakdown. It could be used to guide high-gradient choke-mode accelerating structure design.

Table 2: Choke High-Gradient Performance Comparison

THU-CHK	E_{acc}^{max} [MV/m]	E_{choke}^{max} [MV/m]	$E_{\mathrm{choke}}/E_{\mathrm{surf}}$
D1.26-G1.68	85	134	0.76
D1.26-G2.1	71	135	0.92
D1.89-G2.1	117	175	0.73
D2.21-G2.1	131	185	0.69

Table 3: Breakdown Rate Measurements of the Single-Cell Structures

THU-CHK	E_{acc} [MV/m]	Number of pulses	Number of breakdowns	Pulse width [ns]
D1.26-G1.68	77.3	8.93×10^5	2	300
D1.26-G2.1	67.1	4.19×10^6	16	300
D1.89-G2.1	105	6.14×10^5	3	350
D2.21-G2.1	121	2.17×10^6	15	350

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