CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC-NOTE-698

A HIGH-GRADIENT TEST OF A 30GHZ COPPER ACCELERATING STRUCTURE

R. Corsini, S. Döbert, R. Fandos, A. Grudiev, E. Jensen, T. Ramsvik, J. Rodriguez, J. Sladen, I. Syratchev, M. Taborelli, F. Tecker, P. Urschütz, I. Wilson, W. Wuensch
CERN, Geneva, Switzerland

O. Mete
University of Ankara, Turkey

Abstract

The CLIC study is investigating a number of different materials at different frequencies in order to find ways to increase achievable accelerating gradient and to understand what are the important parameters for high-gradient operation. So far a series of rf tests have been made with a set of identical-geometry 30 GHz and X-band structures in copper, tungsten and molybdenum. A new test of a 30 GHz copper accelerating structure has been completed in CTF3 with pulse lengths up to 70 ns. The new results are presented and compared to the previous structures to determine dependencies of quantities such accelerating gradient, material, frequency, pulse length, conditioning rate, breakdown rate and surface damage.

Presented at LINAC06, Knoxville, TN, US, August 21-25, 2006

Geneva, Switzerland
November 2006

A HIGH-GRADIENT TEST OF A 30 GHZ COPPER ACCELERATING STRUCTURE

R. Corsini, S. Döbert, R. Fandos, A. Grudiev, E. Jensen, T. Ramsvik, J. Rodriguez, J. Sladen, I. Syratchev, M. Taborelli, F. Tecker, P. Urschütz, I. Wilson, W. Wuensch, CERN, Geneva, Switzerland
Ö. Mete University of Ankara, Turkey.

Abstract

The CLIC study is investigating a number of different materials at different frequencies in order to find ways to increase achievable accelerating gradient and to understand what are the important parameters for high-gradient operation. So far a series of rf tests have been made with a set of identical-geometry 30 GHz and X-band structures in copper, tungsten and molybdenum. A new test of a 30 GHz copper accelerating structure has been completed in CTF3 with pulse lengths up to 70 ns. The new results are presented and compared to the previous structures to determine dependencies of quantities such accelerating gradient, material, frequency, pulse length, conditioning rate, breakdown rate and surface damage.

INTRODUCTION

The CLIC study has been investigating different materials through both rf and dc-spark tests in an effort to determine if alternative materials to copper can be found which will allow higher accelerating gradients [1, 2].

The initial part of this study consisted of testing a set of three identical-geometry 30 GHz structures with Cu, W and Mo irises in the CLIC Test Facility II (CTF2) [1]. The Cu structure was meant to be used as a reference to which the results of the other materials would be compared. Pulse lengths in CTF2 were limited to 16 ns for the W and Mo structures while pulses as long as 32 ns were used for the Cu one.

Figure 1: Picture of the 30 GHz copper structure while low power rf measurements were being performed.

A new test stand at CTF3 [5] allows testing up to and beyond the current CLIC pulse length of 70 ns. It was first used to investigate a 30 GHz Mo-iris structure (new but identical to the one previously tested in CTF2) [6]. The test of a second structure, also identical to the Cu one tested in CTF2, has also been completed. The main results are reported in this paper.

Relevant rf parameters of this structure are listed in Table 1. Fig. 1 shows a picture of the structure while low power rf measurements were being performed. It is clamped to the cooling block and attached to the cover plate of the vacuum tank where it was tested. The cells of the structure are brazed together and the couplers are clamped between the structure and stainless steel rings. This is an important difference with respect to the Mo and W-iris structures where also the cells are clamped altogether.

Frequency	29.984 GHz
Number of cells	30
Phase advance	$2\pi/3$
Beam aperture	3.5 mm
Group velocity	4.6% of c
Fill time	8.3 ns
E_{SURF} / E_{ACC}	2.2
Power needed for E_{ACC} = 150 MV/m	54 MW

Table 1: Main structure parameters.

Two other (geometrical-identical but scaled to 11 GHz) W and Mo-iris structures have also been tested at NLCTA [3, 4] in an effort to understand the possible frequency dependence of the gradient achieved.

The 30 GHz RF power used to test the structures is produced when an electron beam is decelerated using a Power Extracting and Transfer Structure (PETS) in CTF3. Part of the kinetic energy of the beam is transformed into 30 GHz rf power. The amount of rf power going into the structure under test can be regulated using a variable power splitter. The pulse length can also be modified by changing the length of the electron pulse passing through the PETS. Several directional couplers are used to pick up the rf signals used to characterize the rf pulses. Faraday cups located up and down stream of the structure collect the electron burst that makes it through the irises of the structure when a breakdown occurs. That current together with the measured reflected power and the transmitted power (or lack of transmitted power) was used to determine whether or not the structure was able to hold the gradient produced by the rf pulse. Refer to [5] and [6] for more details on the experimental setup.

EXPERIMENTAL RESULTS

Conditioning and testing history of the structure

A total of 400 hours were used to condition and study the performance of the structure. Out of all that time, just a small portion of it (a few hours) was used for conditioning. Most of the time was used to measure breakdown rates.

The repetition frequency was 10 Hz. But, that together with the 400 hours do not directly translate into the total number of pulses used since a good portion of the time was spent evacuating the gas released when a breakdown occurred. Dead times caused by external factors like maintenance and shutdowns of CTF3 have also been removed from the data.

Four magnitudes are shown in fig. 2: the pulse energy, the peak pulse power, the pulse length and the average gradient over 70 ns in the first cell (40 ns during the last 25 hours).

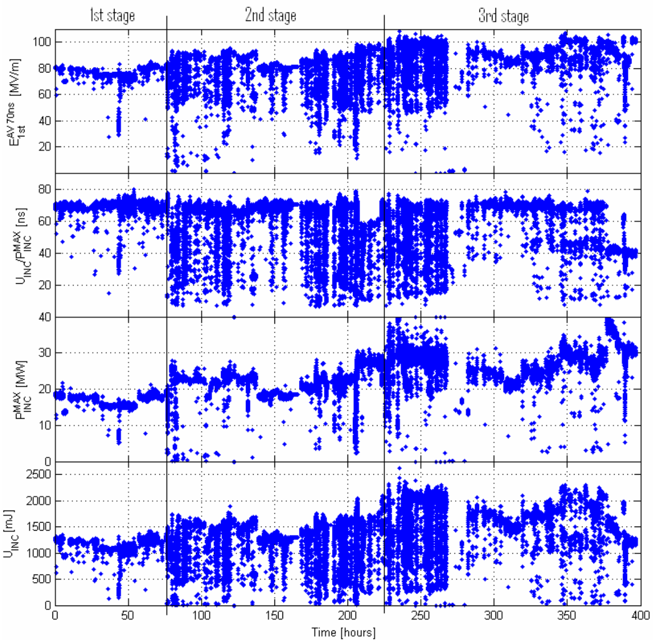

Figure 2: Conditioning and testing history of the structure. From top to bottom are: average accelerating gradient in the first cell, pulse length (computed as the pulse energy divided by the incident peak power), peak incident power and pulse energy. The structure was vented and visually inspected at the end of each conditioning stage.

Damaging the structure before measuring the breakdown rate dependence with gradient was a special concern. For that reason, the structure was conditioned in three stages: up to 80, 90 and 100 MV/m. After reaching those gradients, the breakdown rate was measured and the structure was visually inspected using an endoscope. Even though the structure was exposed to air during the few hours the inspection lasted, it quickly recovered to the last gradient achieved.

These inspections showed that the surface of the first few irises had clearly been affected by the conditioning process. The surface roughness increased after each conditioning stage and multiple spots could be observed where the breakdowns occurred. At the same time, it was not obvious whether or not changes in the geometry of the cells had occurred. These changes were clearly visible in the Cu structure tested in CTF2 [7]. Detailed inspection of the irises, using a scanning electron microscope, will be carried out in the near future in an effort to better quantify the damage.

Conditioning gradients slightly above 100 MV/m for 70 ns pulses and 110 MV/m for 40 ns pulses were achieved. These gradients are consistent with the 110 MV/m achieved for 32 ns long pulses in CTF2. It also confirms the weak pulse length dependence measured in CTF2 [1]. These numbers can also be compared to the 140 MV/m for 70 ns pulses for the Mo-iris tested in CTF3 [6], the 193 MV/m at 16 ns for the Mo-iris tested in CTF2 and, the 150 MV/m at 16 ns for the W-iris also tested in CTF2 [1].

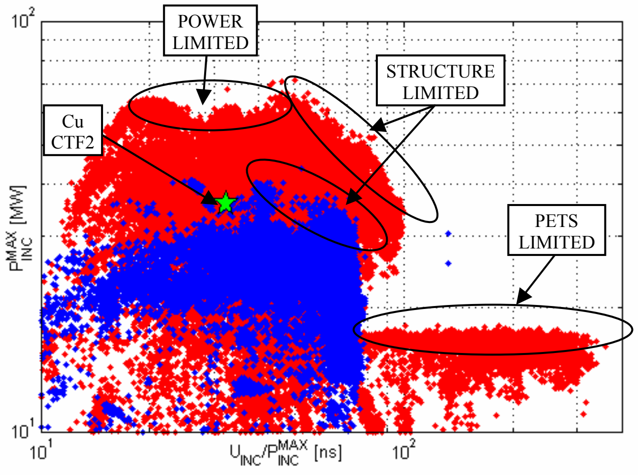

Figure 3: Peak power vs. pulse length. The blue points were reached with the Cu structure and the red points by the Mo-iris structure tested earlier in CTF3. The green star shows the best point achieved by an identical Cu structure tested in CTF2.

The input power versus pulse length for the entirety of stable rf pulses observed during the conditioning process is plotted in fig. 3 in blue. The data is compared to the achieved performance of the Mo-iris structure previously tested in CTF3 (in red). The green star shows the highest peak power / pulse length reached with a similar structure in CTF2.

It should be mentioned that some of this diagram was not covered because of reasons different than the structures performances: limitations in power available, breakdowns in the PETS and limited time for experiments.

Breakdown Rate

All the gradients quoted in the previous sections are for the conditioning limit of the structure. The breakdown probability at this limit is very high but it is reduced when the gradient is lowered.

The exact breakdown probability for CLIC structures has not yet been calculated since there is still some uncertainty about the exact machine layout and parameters like the transverse kick the main beam would receive when a breakdown occurs. Nevertheless, it is expected to be of the order of 10^{-6} based on approximate calculations with reasonable assumptions.

The breakdown probability as a function of gradient has been measured after each conditioning stage in order to determine how much the gradient would need to be reduced to be able to operate the structure with the required breakdown rate.

The results are shown in fig. 4. The three set of blue points correspond to the Cu structure after it was conditioned to 80, 90 and 100 MV/m. The three red sets correspond to different pulse lengths for the Mo-iris structure tested in CTF3.

The data has been fitted with lines that give constant pulse dependence for all breakdown probabilities – which means that the slopes are inversely proportional to the gradient at a fixed breakdown probability. This same inverse proportionality fits well with data of the X-band Mo-iris structure [3].

Backing off around 25 % would be necessary to operate the copper structure at 10^{-6} breakdown rate. The slope of these lines is similar to the one measured in other copper structures tested at the NLCTA despite of the difference in frequency [8]. In the other hand, it is significantly larger than the one measured for Mo-iris structures. The origin of this difference is not clear yet. Some possible explanations are that it is due to the clamping of the irises in the Mo structure, the surface state created during the conditioning process or that it is intrinsic to the material. If the latter was true, it could mean that even if Mo-iris structures could potentially reach higher accelerating gradients, it would not be much better than copper in an accelerator with the breakdown requirements of CLIC. Different test will be performed in the near future to understand these issues better.

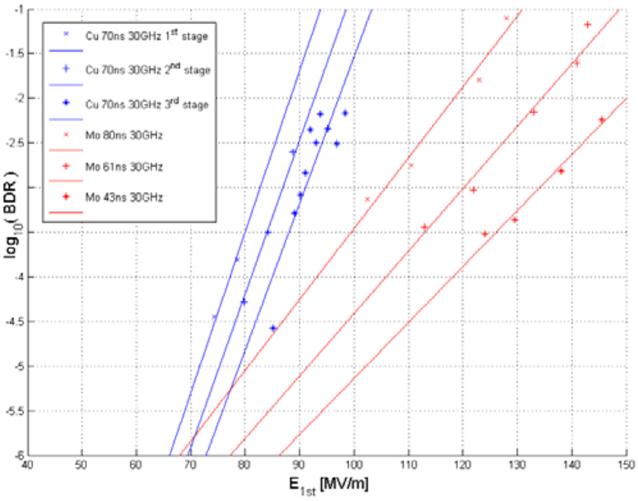

Figure 4: Breakdown probability as a function of the accelerating gradient in the first cell for different structures.

REFERENCES

[1] W. Wuensch et al., “A Demonstration of High Gradient Acceleration”, PAC 2003.

[2] T. Ramsvik et al., “Investigations of DC Breakdown Fields”, EPAC 2006.

[3] W. Wuensch et al., “A High-Power Test of an X-Band Molybdenum-Iris Structure”, LINAC 2004.

[4] S. Döbert et al., “High-Gradient Test of a Tungsten-Iris X-Band Accelerator Structure at NLCTA”, these proceedings.

[5] C. Achard et al., “30 GHz Power Production in CTF3”, PAC 2005.

[6] W. Wuensch et al., “A High-gradient Test of a 30 GHz Molybdenum-iris Structure”, EPAC 2006.

[7] H. Braun et al., “CLIC High-gradient Test Results”, LINAC 2002.

[8] S. Döbert et al., “High Gradient Performance of NLC/GLC X-Band Accelerating Structures”, PAC 2005