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# CLIC HIGH-GRADIENT TEST RESULTS

H. H. Braun, S. Döbert, I. Syratchev, M. Taborelli, I. Wilson, W. Wuensch

*Abstract*

The CLIC (Compact Linear Collider) high-gradient RF structure testing program has been carried out in order to gain insight into the physical processes involved in RF breakdown, determine the mechanisms that limit gradient and produce damage so that technical concepts can be developed which allow higher accelerating gradients. Two main paths towards higher gradients have emerged from this program, and the performances of two new structures which incorporate them are presented.

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The CLIC (Compact Linear Collider) high-gradient RF structure testing program has been carried out in order to gain insight into the physical processes involved in RF breakdown, determine the mechanisms that limit gradient and produce damage so that technical concepts can be developed which allow higher accelerating gradients. Two main paths towards higher gradients have emerged from this program, and the performances of two new structures which incorporate them are presented.

## 1 INTRODUCTION

CLIC main-linac accelerating structures [1] are specified to operate at a frequency of 30 GHz, a loaded accelerating gradient of 150 MV/m and a pulse length of 130 ns. A demonstration that such a gradient at this pulse length is possible in a multi-cell structure has already been made with a 11.4 GHz accelerating structure in 1994 [2,3]. This structure however, had a smaller iris aperture, a/?=0.11, than those envisaged for CLIC, and it was conditioned very carefully. Subsequent tests of prototype CLIC structures in CTF II (CLIC Test Facility 2), gave gradients of only about 70 MV/m and significant damage was observed [4]. A picture of the damage to an input coupling iris is shown in Figure 1.

The difficulties encountered in the 30 GHz tests has lead to a substantial effort to address breakdown and damage issues. A compelling picture of RF breakdown has emerged from the studies [5,6] and two paths for increased performance have been identified. The first is that accelerating gradient can be improved by designing for reduced surface electric field. The second is that an arc-resistant material be used instead of copper in the areas of a structure where damage occurs [7]. The arc resistance of a material is a well established concept at DC, and is a consequence of a high melting point and a low vapour pressure. A number of refractory metals are arc resistant, but tungsten, with a DC conductivity only three times worse than copper, is the most obvious candidate.

The program of testing to demonstrate the validity of these two ideas is described in this report. The program consisted of two parts. In the first part, described in section 2, a series of simple and rapid tests were made by re-using a copper constant impedance structure and replacing only the damaged iris of the input coupler with a new iris. Each new iris to be tested was clamped between the coupler and the structure, giving mechanical integrity and an RF contact. Vacuum was provided by placing the clamped assembly inside a vacuum tank. In these tests only relative material properties could be tested since the geometry of the structure was unchanged. Achievable gradients were also limited because the rest of the structure was in copper. However, maintaining the single feed coupler guaranteed that the potential for damage to the new irises under test remained very high.

The second part of the testing program, described in section 3, consisted of producing two entirely new 30-cell structures with reduced surface electric field geometry. The geometries of the structures were the same but one was made entirely of copper and in the other, all irises were made of tungsten. The first objective was to demonstrate an improved accelerating gradient due to the RF design change. The second objective was to provide a direct comparison of achievable gradient between tungsten and copper.

All tests were made in CTF II and the results reported here were all produced using 16 ns RF pulses, unless noted otherwise. To improve turn-around time, no in-situ bakeouts were made. All structures were conditioned in the same way, by raising power to maintain controlled levels of emitted breakdown electron currents, vacuum activity and missing RF energy. The calibrations of field levels were always confirmed by measurement of the acceleration of a 0.5 nC probe beam.

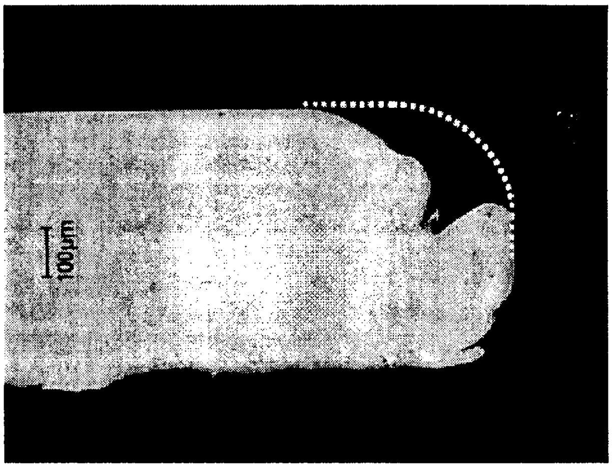


Figure 1: Cross section of damage to input coupler iris. The dotted line represents the geometry the iris had before RF processing. The rough surface on the bottom of the iris was caused by cutting the iris from the structure.

## 2 SINGLE-IRIS TESTS

The RF parameters of the single-feed constant impedance structure are summarized in Table 1. The parameters were unchanged when the irises were replaced. A ground tungsten, an electro-polished tungsten, a tungsten-copper composite and an OFHC copper iris were tested. The conditioning curves for each of the irises are shown in Figure 2.

From the conditioning curves it is clear that the tungsten and the tungsten/copper irises provide an improved gradient. A study of the consequences of conditioning on the copper and the tungsten irises is shown in Figure 3. The copper iris shows the same damage pattern as the copper iris of the original coupler, Figure 1. The peak surface electric field of the copper iris with damage was estimated to be nearly 40% higher than that of the original undamaged geometry. The tungsten iris shows no change to its geometry. An SEM (Scanning Electron Microscope) analysis showed that the tungsten iris has been sprayed with copper from the surrounding structure. Microscopic zones of melted tungsten are also visible, but these zones appear to be benign and a normal consequence of conditioning. From these tests it was not possible to conclude whether the tungsten went to a higher gradient because the surface is capable of supporting a higher gradient, or whether the tungsten went to a higher gradient because it maintained its shape.

Table 1: Single-feed constant impedance accelerating structure. $E_{peak}$ refers to the peak surface electric field (on the first iris) and $\langle E_{acc} \rangle$ refers to the average accelerating gradient of the structure.

| | |
|---|---|
| Frequency | 29.985 GHz |
| Phase advance | 2p/3 |
| Number of cells | 84 + 2 coupling |
| Iris diameter | 4.0 mm |
| Iris thickness | 0.55 mm |
| $v_g/c$ (measured and calculated) | 0.082 |
| Measured $Q$ | 4200 |
| $E_{peak}/\langle E_{acc} \rangle$ | 4.4 |
| Power for $E_{acc}$ = 100MV/m | 63 MW |

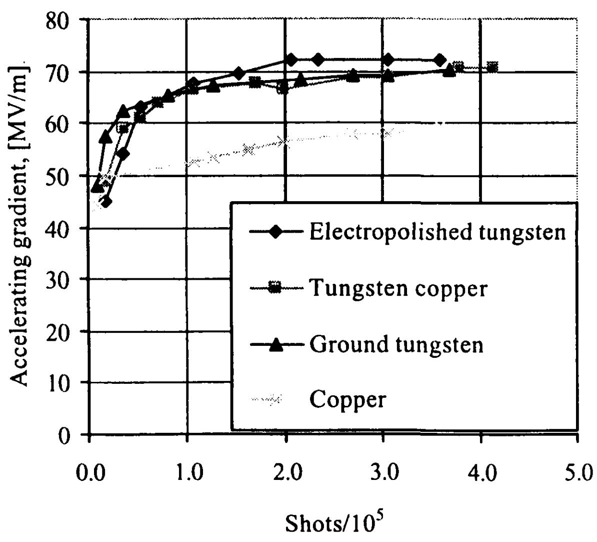


Figure 2: Conditioning histories of four clamped irises.

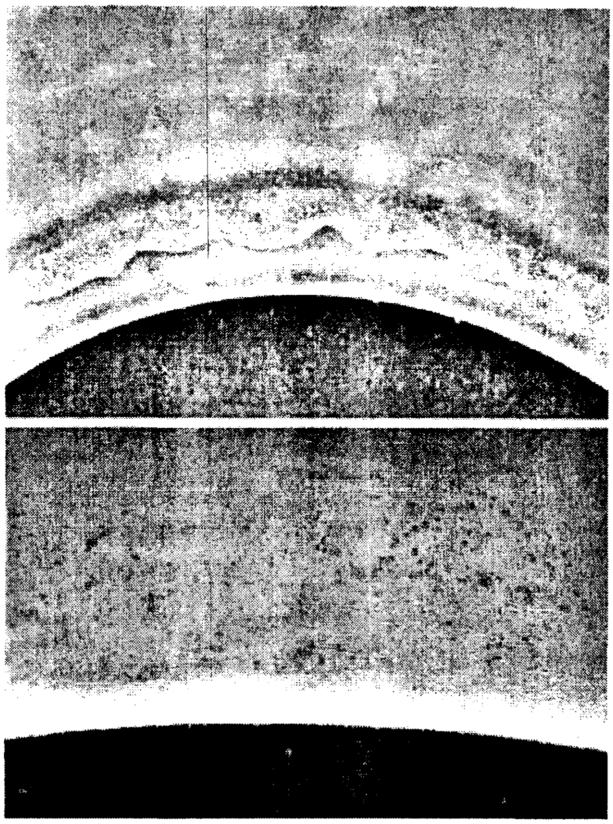

Figure 3: SEM images of the copper (upper) and tungsten (lower) irises. The tungsten image was taken at a higher magnification – the radii are the same.

## 3 FULL-STRUCTURE TESTS

The surface electric field in the cells of the new 30-cell structures was reduced, compared to the geometry of the structure used in the previous test, by reducing the iris aperture and increasing the iris thickness. The surface field enhancement in the coupler was reduced by adopting a 'mode launcher' coupler [8]. The RF properties of the structures are summarized in Table 2.

The tungsten-iris structure was composed of copper disks, which formed the cavity cell walls, and tungsten irises, which were placed in counter-bores in the copper disks. These parts are shown in figure 4. The whole structure was assembled by clamping. The all-copper structure was made from diamond turned disks and assembled by vacuum brazing, although the couplers were clamped on. Both structures were tested inside a vacuum tank and each structure was mounted on a vacuum cover plate to reduce turn-around time between experiments to about an hour. The tungsten-iris structure mounted on its cover plate is shown in figure 5.

The conditioning curves of the two new structures, along with the copper data from the previous test, is shown in Figure 6. The first feature to emphasize is the average accelerating gradient improved from 60 MV/m to 102 MV/m from RF design changes alone. A further improvement to 125 MV/m was obtained by the tungsten.

The accelerating gradient in the first cell was 152 MV/m for the tungsten-iris structure and 114 MV/m for the copper structure. A visual inspection of both structures confirmed that the geometry of the tungsten irises was unchanged while the first iris with the highest surface fields of the all copper structure was eroded. A detailed analysis of the geometric and surface changes of the two structures will be made at a later date.

Table 2: RF properties of tungsten-iris and copper structures.

| | |
|---|---|
| Frequency | 29.985 GHz |
| Phase advance | 2p/3 |
| Number of cells | 30 + 2 matching |
| Iris diameter, thickness | 3.5, 0.85 mm |
| $v_g/c$ (measured and calculated) | 0.046 |
| Measured $Q$ (W) | 1820 |
| Measured $Q$ (Cu) | 3400 |
| $E_{peak}/<E_{acc}>$ (W) | 2.7 |
| $E_{peak}/E_{acc}>$ (Cu) | 2.5 |
| Power for $E_{acc}$ = 100 MV/m (W) | 42 MW |
| Power for $E_{acc}$ = 100 MV/m (Cu) | 35 MW |

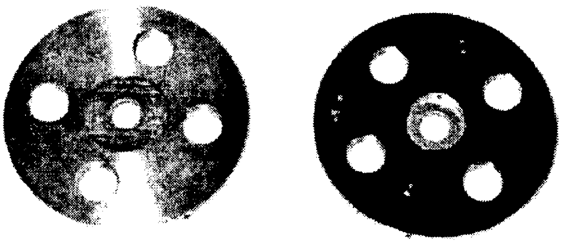

Figure 4: Tungsten irises in copper cells of tungsten-iris structure.

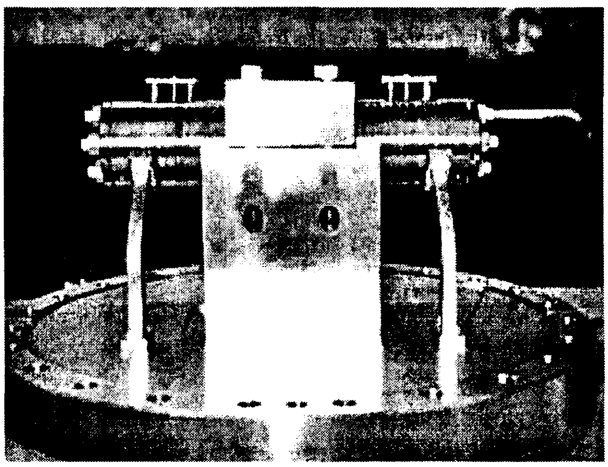

Figure 5: Tungsten iris structure mounted on the vacuum tank cover-plate. The structure is held and cooled by the copper block in the middle of the structure.

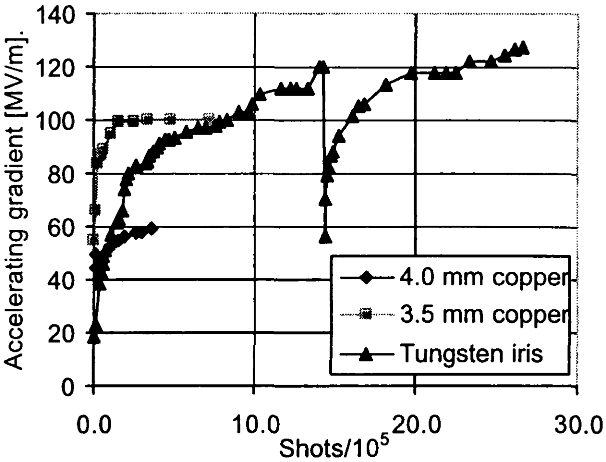


Figure 6: Conditioning histories of the tungsten and copper structures. The break in the tungsten curve occurred after the vacuum was broken for visual inspection.

To investigate pulse length dependence, the RF pulse length was reduced to 8 ns, which corresponds to the filling time of the structure. The beneficial effect of the reduced pulse length allowed a direct measurement, using the tungsten-iris structure, of a 16.2 MeV energy gain of a 0.5 nC electron bunch. This corresponds an average accelerating gradient of 152 MV/m and a gradient in the first cell of 184 MV/m.

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