HIGH-GRADIENT TEST OF A TUNGSTEN-IRIS X-BAND ACCELERATOR STRUCTURE AT NLCTA

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Abstract

The CLIC study group at CERN has built two X-band accelerating structures to be tested at SLAC in NLCTA. The structures consist of copper cells with insert irises made out of molybdenum and tungsten, clamped together and installed in a vacuum tank. These structures are exactly scaled versions from structures tested previously at 30 GHz and with short pulses (16 ns) in the CLIC Test Facility at CERN. At 30 GHz these structures reached gradients of 150 MV/m for tungsten and 195 MV/m for molybdenum. These experiments were designed to provide data on the dependence of rf breakdown on pulse length and frequency. This paper reports in particular on the high-gradient test of the tungsten-iris structure. At the shortest possible pulse length of 22 ns a gradient of 125 MV/m was reached at X-band, 20 % lower than the 150 MV/m measured at 30 GHz in the CLIC Test Facility. The pulse length dependence and the dependence of the break down rate as a function of gradient were measured in detail.

The results are compared to data obtained from the molybdenum-iris experiment at X-band which took place earlier as well as to 30 GHz data.

INTRODUCTION

The high-gradient test of an X-band accelerating structure equipped with irises made of tungsten in the Next Linear Collider Test Accelerator (NLCTA) [1] at SLAC, is the second experiment of this kind. An identical structure with molybdenum inserts was tested previously and the results are reported in [2]. This experiment completes a series of high gradient tests using very similar structures with different materials at two different frequencies. The series started with tests at 30 GHz performed in CTF II using identical structures made of copper, tungsten and molybdenum. These experiments achieved record gradients (copper: 110 MV/m, tungsten: 150 MV/m, molybdenum: 195 MV/m) at the short pulse length of 16 ns available in CTF II [3]. Inspired from this success the structure was scaled to X-band to be tested in NLCTA to provide data at a longer pulse length and insight into frequency dependence of rf breakdown. The design principle can be seen in figure 1, a washer like iris is inserted into a copper disk forming together one cell of the accelerator with the new material in the region of high electrical surface fields and copper in the region of high magnetic fields. These cells are then simply clamped together and installed in a vacuum tank for high power testing. A reasonably good electrical contact is established by clamping the softer copper onto the much harder tungsten. The first X-band structure was built with molybdenum irises. As reported in [2] the result from CTF II could not be confirmed. Furthermore the structure conditioned very slowly and reached a peak gradient of 85 MV/m at 30 ns after 700 hours of processing.

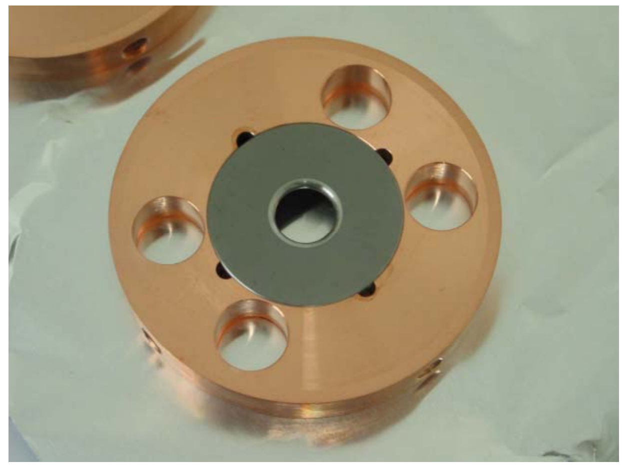

Figure 1: Tungsten-iris inserted into a copper disk forming together a cell of the rf structure. The beam aperture is 9.2 mm.

The second structure equipped with tungsten inserts is otherwise identical to the molybdenum version. The parameters are summarized in table 1. The irises were made out of the same high purity (99.95%) tungsten as for the 30 GHz version using the same supplier. The structure was assembled at CERN and shipped under vacuum to SLAC where it was installed into the NLCTA beam line without an in situ bake out.

Table 1: Structure Parameters

Frequency	11.424 GHz
Number of cells	30+2 matching cells
Phase advance per cell	$2\pi/3$
Beam aperture	9.19 mm (constant)
Group velocity, v_g/c	4.6 %
Fill time	20 ns
E surface / E axis	2.2
Input Power for 100 MV/m Peak Gradient (first cell)	175 MW

EXPERIMENTAL RESULTS

The tungsten-iris structure was high-power tested for a total of almost 800 hours. The initial conditioning took about 450 hours and the rest of the time was used for measuring breakdown rates and pulse length dependence. The structure was conditioned at 60 Hz using the automated rf conditioning system developed for NLC. The structure was conditioned with rf pulses up to 260 MW of X-band power ranging in pulse length from 22 to 200 ns. The conditioning procedure was very similar to the previously tested molybdenum structure, details can be found in [2]. The conditioning history is shown in figure 2. The gradient on the vertical axis is the accelerating field in the first cell of the constant impedance structure.

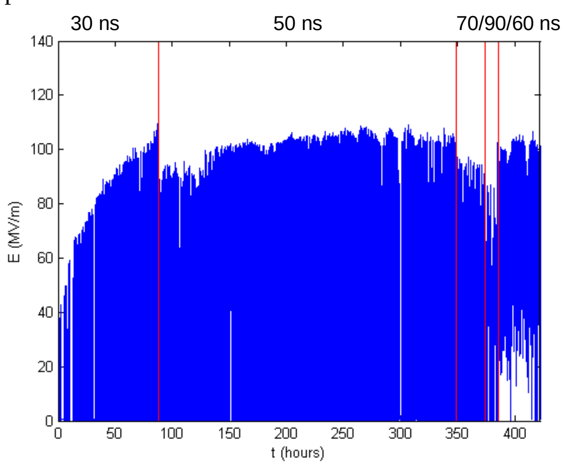

Figure 2: Conditioning history of the tungsten-iris structure in NLCTA.

The structure conditioned reasonably fast with short pulses of 30 ns but the conditioning slowed down considerably while extending the pulse length. Breakdowns were fairly uniformly distributed over the length of the structure according to timing analysis of the rf pulses, which is somewhat surprising for the constant impedance structure with about 40% surface field variation over the length of the structure. The pulse length dependence at a constant trip rate was studied in detail revealing a stronger dependence than that measured previously with the molybdenum structure or with NLC-type copper structures [4]. The maximum surface field obtained as a function of pulse length is compared in figure 3 for the clamped tungsten and molybdenum structure and the fully brazed NLC structures. While the copper and molybdenum structure show a reduction of the obtainable surface field proportional to $E_s \sim \tau^{-1/6}$ the tungsten structure shows quarter-root ($E_s \sim \tau^{-1/4}$) dependence fitting the full pulse length range. The data would be as well consistent with the $\tau^{-1/6}$ behaviour and a step at 30 ns. The results obtained at 30 GHz for the different materials are also included as single points at 16 ns. The results fit very well for copper indicating no significant frequency dependence. They are also

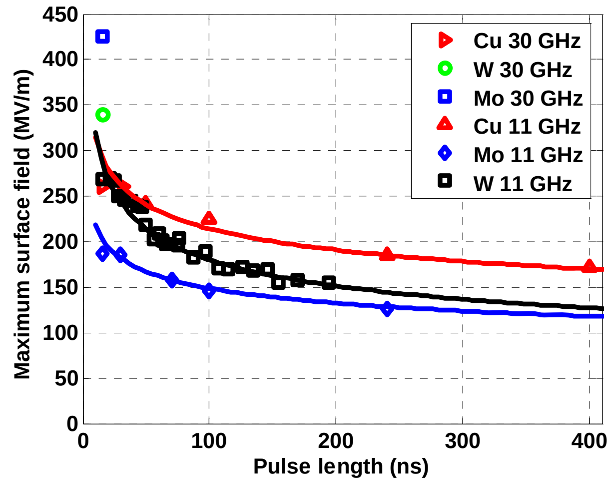

Figure 3: Pulse length dependence of the maximal surface field for different structures.

consistent for tungsten where at 11 GHz a gradient of 125 MV/m was achieved at a pulse length of 22 ns. This gradient corresponds to the limit of the available rf power (~260 MW) in the test station in NLCTA. The result for Molybdenum on the other hand falls significantly short of what was achieved at 30 GHz.

A comparison of the breakdown probability as a function of accelerating gradient is shown in figure 4 for different structures. It is eye catching that the slopes for copper are roughly twice as steep as for refractory metals independent of the frequency. If this is a material property or due to construction or preparation techniques is an important question to answer. For a linear collider a breakdown probability below 10^{-6} is needed therefore the useable gradient for the time being is still better for copper than for molybdenum or tungsten. The curve for copper at 11 GHz uses a single measured data point at 50 ns from a NLC prototype accelerator and a slope indicated by the line measured in detail at 400 ns [4].

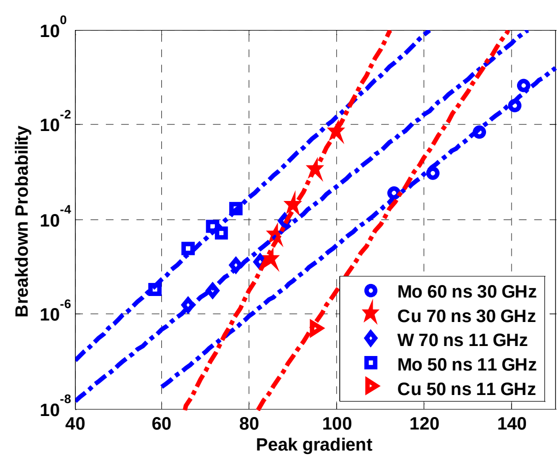

Figure 4: Break down probability as a function of gradient, for different structures.

CONCLUSIONS

The high power test of the tungsten-iris structure at X-band didn't show a performance as spectacular as at 30 GHz. The gradient achieved is only slightly higher at short pulse than for comparable NLC-type structures made out of copper. In addition at acceptable breakdown rates the gradient is lower and the pulse length dependence less favourable for the tungsten structure compared to copper. The obtained results are nevertheless consistent with those achieved at 30 GHz taking into account the maximum power available at short pulses. Extrapolating to 16 ns using the measured pulse length dependence results in a gradient of 135 MV/m which is within 10 % of the 150 MV/m achieved with tungsten at 30 GHz.

Post mortem analysis of the tungsten irises, made at SLAC, revealed pictures similar to the 30 GHz version (see figure 5.). The first high gradient iris (iris 2) has clear traces of heavy conditioning and local melting. The signature of heavy conditioning diminishes as one goes along the structure. On iris 15 for example the machining marks still dominate the SEM picture. The first iris is a matching iris with a bigger diameter and a much lower surface field therefore the amount of local melting is much less than on iris 2. The results of the post mortem inspection indicate that most of the breakdowns occurred in the first third of the structure which is contradictory to the online determination of the breakdown location using the rf signals. Carbon and aluminium particles were found on the surfaces which could remain from the polishing process applied to machine the tungsten irises to the required precision. It is possible that these particles are sources of breakdowns although there are no obvious visible correlations. Micro cracks were observed as well on the conditioned surface confirming the observations on tungsten at 30 GHz at CERN.

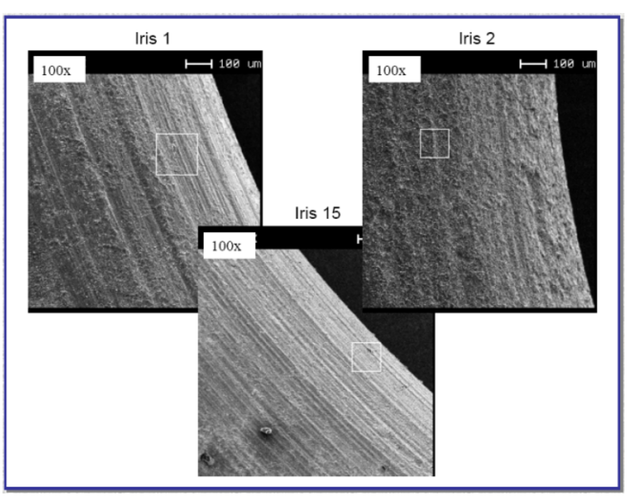

Figure 5: SEM pictures from the coupling iris (Iris 1) the first high gradient Iris (Iris 2) and an iris from the middle of the accelerator.

The fact that results are consistent for copper and tungsten when comparing 11GHz and 30 GHz at short pulse length suggests that the inconsistently bad result for molybdenum is not systematic. It is therefore likely that something went wrong during the construction and preparation of the molybdenum structure. The molybdenum structure was sent to SLAC under vacuum but arrived vented. Therefore a hot nitrogen bake was performed in situ after installation to improve the vacuum. The tungsten structure arrived still under vacuum and was tested without any bake out. It could be that this difference is responsible for the very different performance.

It turns out that refractory metals can be conditioned to high gradients even in excess of copper results but need much more conditioning time and have a higher breakdown rate compared to traditional copper structures. If it turns out that the shallower slope is a property of refractory metals, then it might be that one can't capitalize on the higher gradient achievable during conditioning. Therefore it is important to find out if the different slopes are a characteristic of the bulk material or due to surface preparation or assembly technique. An origin for the different slope could be the clamping technique used to build the structure. Discolouring was found around the clamped joints during the post mortem analysis

Experiments to answer these questions are already under way at CERN and SLAC. SLAC launched a campaign to prepare "copper like" surfaces for tungsten and molybdenum and test their high gradient behaviour. The CLIC group is currently testing a new structure design (HDS [5]) which has no clamped contact in areas with rf currents. This new type of structure will be tested with different materials at 30 GHz at CERN using CTF3 as well as scaled versions at 11 GHz in NLCTA at SLAC continuing the fruitful collaboration on these high gradient issues.

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