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HIGH POWER TEST OF AN X-BAND SLOTTED-IRIS ACCELERATOR STRUCTURE AT NLCTA

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The CLIC study group at CERN has built two X-band HDS (Hybrid Damped Structure) accelerating structures for high-power testing in NLCTA at SLAC. These accelerating structures are novel with respect to their rf-design and their fabrication technique. The eleven-cell constant impedance structures, one made out of copper and one out of molybdenum, are assembled from clamped high-speed milled quadrants. They feature the same heavy higher-order-mode damping as nominal CLIC structures achieved by slotted irises and radial damping waveguides for each cell. The X-band accelerators are exactly scaled versions of structures tested at 30 GHz in the CLIC test facility, CTF3.
The results of the X-band tests are presented and compared to those at 30 GHz to determine frequency scaling, and are compared to the extensive copper data from the NLC structure development program to determine material dependence and make a basic validation of the HDS design.

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The CLIC study group at CERN has built two X-band HDS (Hybrid Damped Structure) accelerating structures for high-power testing in NLCTA at SLAC. These accelerating structures are novel with respect to their rf-design and their fabrication technique. The eleven-cell constant impedance structures, one made out of copper and one out of molybdenum, are assembled from clamped high-speed milled quadrants. They feature the same heavy higher-order-mode damping as nominal CLIC structures achieved by slotted irises and radial damping waveguides for each cell. The X-band accelerators are exactly scaled versions of structures tested at 30 GHz in the CLIC test facility, CTF3.

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INTRODUCTION

The Hybrid Damped Structure (HDS) provides higher order mode damping by combination of four radial waveguides with slots up to the iris tip in each cell [1]. This heavy damping is desired for CLIC to enable very short bunch spacing and therefore a reduced rf pulse length. This slotted iris design at 30 GHz was not possible to implement within the classical disk technology for structure fabrication due to the very narrow slots. A new approach was developed in which an accelerating structure is formed by four high-speed milled bars which are than clamped together. Another novel feature of this structure is a very short phase advance (60 degrees) per cell. This choice makes the slot damping more effective and lowers the electrical surface field. The ratio of surface field to accelerating field is only 1.6 for this structure (versus 2.1 typically). Originally this structure was designed for CLIC rf parameters at 30 GHz, which have been, an accelerating gradient of 150 MV/m and a pulse length of 70 ns. A HDS-type structure with 60 cells and a constant gradient design has been tested at 30 GHz at CERN in the CLIC Test Facility [2]. The X-band versions reported on here were designed to get data on frequency scaling, material dependence and to benchmark the new technology against the classical technology used by NLC prototype structures [3, 4]. Two structures have been built at CERN one made of Copper and one made of Molybdenum using an exact scaled geometry from 30 GHz (last cell of HDS60). The main parameters of this structure are summarized in table 1. The assembled Molybdenum structure can be seen in figure 1. The assembled structure equipped with input and output waveguides and a cooling circuit was installed in a vacuum tank for the high power test. The water fittings have been vacuum-brazed into the quadrants therefore both structures have been heated up to 830 °C. Recently the CLIC study changed its frequency to 12 GHz and the loaded accelerating gradient to 100 MV/m [5]. These changes made this experiment even more relevant for CLIC but the emphasis remained on comparing scaled structures and materials rather than achieving the new CLIC design gradient.

Table 1: HDX11 Structure Parameters

Frequency	11.424 GHz
Number of cells	11+2 matching cells
Phase advance per cell, l_{cell}	60 deg, 4.37 mm
Beam aperture	8.4 mm (constant)
Group velocity, v_g/c	5.1 %
Fill time	4 ns
E surface / E axis	1.6
Input Power for 100 MV/m Peak Gradient (first cell)	164 MW

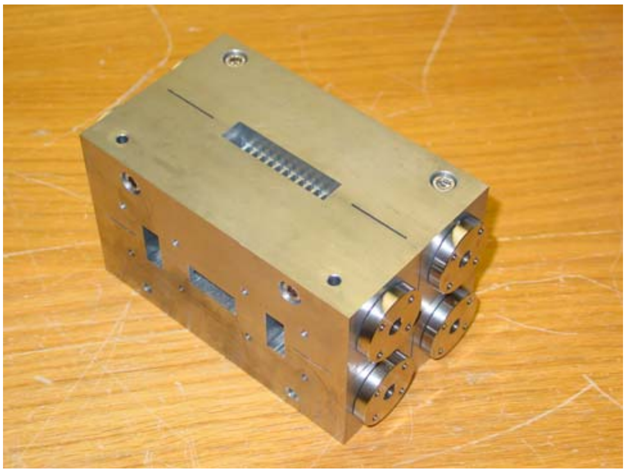

Figure 1: Photo of the assembled accelerating structure (HDX11mo) made out of 4 Molybdenum quadrants. Visible are the input and output coupler waveguides as well as the flanges to connect the water cooling pipes.

EXPERIMENTAL RESULTS

Both structures have been high-power tested at SLAC in NLCTA [6]. The test stand used, consists of two klystrons and a SLED pulse compressor providing up to 300 MW of rf power for a pulse length up to 240 ns. The conditioning is done by a sophisticated control system which was developed for the NLC prototype accelerating structures. The data acquisition and control software is able to determine the energy balance (Pin –Pout) for each rf pulse at 60 Hz. A breakdown is than defined by a certain missing energy threshold. The conditioning is stopped for each breakdown detected and subsequently the power is ramped back in amplitude and pulse length in a parameterized way. The copper version was high power tested for a total of 600 h and accumulated about 20,000 breakdowns during the testing. The structure was removed from its vacuum tank and replaced by the Molybdenum version which has been tested for 500 h accumulating 11,500 breakdowns so far. The conditioning started at a pulse length of 40 ns and focused afterwards on 70 ns due to the old CLIC parameters and in order to compare with the results obtained at 30 GHz at the same pulse length. The conditioning history of the Molybdenum version up to date is shown in figure 2.

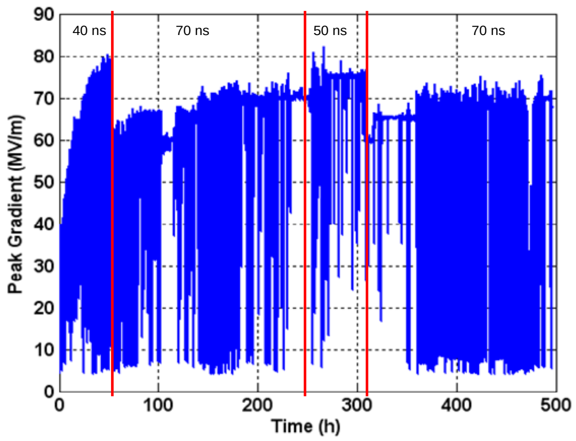

Figure 2: Conditioning history of HDX11 molybdenum structure.

After initial conditioning (the first 50-100h) breakdown-rate measurements at different gradients have been performed. The initial conditioning of the Copper version was faster (15h to 80 MV/m at 40 ns) compared to the Molybdenum version (50h to 80 MV/m at 40 ns).

A large scale accelerator like CLIC requires an extremely high reliability for all components. The trip rate for the accelerating structures has to be below 1 in a million pulses. A summary of the breakdown rate measurements is shown in figure 3. The breakdown probability as a function of the accelerating gradient in the first cell is plotted for both x-band structures and the 30 GHz version (HDS60 tested form the back end). A straight line was fitted through the data to guide the eye. The performances of exactly scaled structures at 30 GHz and 11.4 GHz are very similar. The Molybdenum version shows a slightly

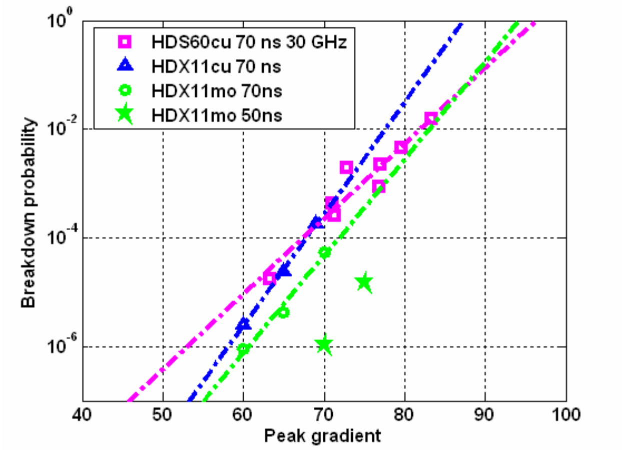

Figure 2: Break down rates as a function of the peak accelerating gradient for different structures and pulse length. The results of the x-band structures made out of copper and molybdenum are compared to a scaled version at 30 GHz made out of copper (HDS60cu).

better performance in terms of breakdown rate than the Copper one. For comparison, recent measurements of NLC prototype structures in this pulse length range demonstrated over 100 MV/m average gradient with a breakdown rate of 10^{-6}. At 30 GHz a comparable round structure made by brazing disks achieved 80 MV/m at 70 ns and 10^{-6} breakdown rate. It is also worth mentioning that the slope of the breakdown probability versus gradient is very similar, independent of frequency and material.

The Copper structure has been disassembled and inspected after high power testing using an optical microscope and an SEM. The post mortem inspection revealed erosion due to rf breakdown predominately on the region of high electrical surface field in the first half of the structure. The erosion is significantly less towards the end of the structure even though there is only 5 % field attenuation along the structure. The radial damping slots did not seem to be a main source of trouble, but numerous breakdown sites were detected along them even at a large radial distance away from the tip of the irises. It turned out that the milled surfaces are much rougher than typical turned ones and that some breakdown areas seemed to be correlated with machining marks. A SEM image of the first two irises is shown in figure 4. One can clearly see the erosion along a vertical line which happens to be the transition from the flat part of the iris to the curvature of the crest. The material erosion however did not lead to a measurable change in S-parameters of the structure.

DISCUSION

Two HDS-type structures have been successfully high-power tested at x-band, their performance however was consistently worse compared to more traditional structures. From the point of view of the rf design they are novel with respect to their very short phase advance,

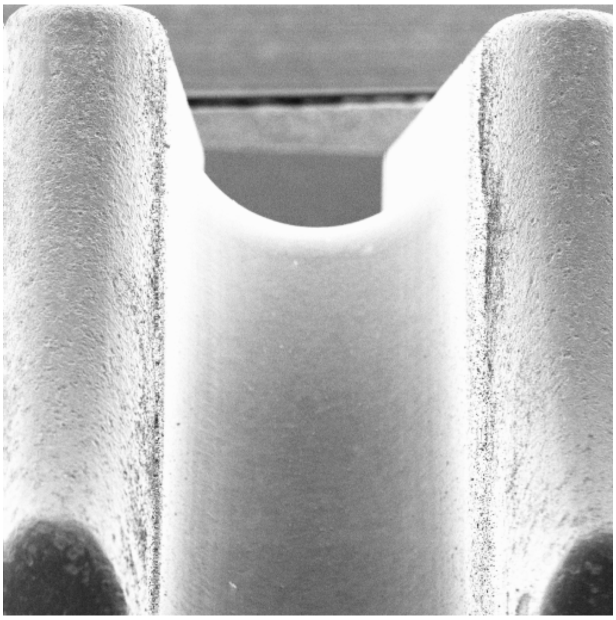

Figure 4: SEM picture of the first and second iris after high power testing. The iris spacing is 4.37 mm.

and the slotted iris damping. In addition the fabrication technology consists of clamping together four 3d-milled quadrants compared to the traditional method of high temperature brazing of turned disks. In principle each of the mentioned differences could account for the performance deficit. The post mortem inspection indicated that the surface roughness obtained by high-speed milling might need improvement. Also, it showed the copper grain sizes to be much smaller than in NLC structures due to the lower braze temperature. The damping slots did not seem to be responsible for the reduced performance. The quadrants underwent a high temperature brazing cycle to braze in the water fittings. Vacuum brazed structures made out of turned disk using the same brazing cycle performed better at 30 GHz than the corresponding HDS design. We currently do not have short phase advance round structure data. Experiments to probe these differences are planned or already under way.

The experiments with HDS-type structures at 30 GHz and 11.4 GHz show a remarkably similar performance in terms of break down rate at a certain gradient and pulse length. This is also supported by results from round structures with clamped irises. These results indicate that the high-gradient performance for exactly scaled structures is independent of frequency.

Surprisingly the structures made out of different materials ended up being very close both in the final performance at a fixed gradient and pulse length as well as in their behaviour as a function of gradient. Earlier experiments at 30 GHz with round structures using clamped irises made out of Molybdenum and Tungsten showed substantially higher gradients at a high breakdown rate [7]. The breakdown rate versus gradient on the other hand had a much shallower slope giving a comparable performance to Copper in the 10^{-6} probability range. High power tests with scaled clamped-iris structures at x-band confirmed the shallow slope but not the superior gradient in the frequent breakdown regime [8, 9]. The new results suggest that in the low breakdown rate regime, the final performance of accelerating structures made out of refractory metals is not superior to Copper. The shallower slope measured with clamped-iris structures are most likely related to the specific fabrication technology. The question of whether refractory metals can support higher gradients remains unclear. The experiment confirmed previous observations that structures made out of refractory metals need significantly longer to condition than Copper structures. More results obtained with HDS-type structure made out of different materials at 30 GHz can be found in [2].

It turns out that the fabrication method is critical for the final performance. The new methods were used to allow operation with different materials and to achieve heavy HOM damping. To do so using the traditional technology of brazing disks is very challenging at 30 GHz. At 12 GHz this is easier due to the larger size. Further experiments are planned or already under way to compare structures made out of different materials and with different fabrication technologies to clarify the remaining questions.

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