FIRST HIGH POWER TESTS OF CLIC PROTOTYPE ACCELERATING STRUCTURES WITH HOM WAVEGUIDE DAMPING

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Abstract

Prototype accelerating structures for the Compact Linear Collider (CLIC) are being developed and high-power tested in collaboration between SLAC, KEK and CERN. Several undamped, low group-velocity and strongly tapered prototypes (of the so-called T18 design) have been operated above 100 MV/m average gradients at a very low breakdown rates. Recently two new structures with the same iris apertures but now including higher order mode damping waveguides in each cell (TD18 design) have been tested at SLAC and KEK. The damped versions could be processed to similar gradients but an increased breakdown rate was observed. The damping waveguides lead to a magnetic field enhancement in the outer diameter of the cells which results in increased pulsed surface heating. The maximum pulsed temperature rise is 80 deg at the design gradient of 100 MV/m compared to only 20 deg for the undamped version. The high-power tests of the two TD18 structures are analyzed with special emphasis to understand if the higher breakdown rate can be explained by pulsed heating or has a different origin.

INTRODUCTION

The CLIC design is aiming for 100 MV/m loaded gradient with an rf pulse length of 240 ns. Due to the large number of structures in each linac a trip rate below $3*10^{-7}$ per meter is required to insure high availability. Such a performance has been demonstrated with undamped prototype structures already [1, 2, 3]. These structures are called T18 because it is a strongly tapered structure with 18 cells [4]. The aperture (radius) reduces from a=4 mm down to 2.7 mm which results in a reduction of group velocity form 2.6 % down to 1 % speed of light. The power, accelerating gradient, surface field and pulsed heating temperature rise for 100 ns pulses is shown in Figure 1 along the structure. However structures suitable for CLIC have to provide strong higher order mode damping in each cell to avoid emittance growth and beam instabilities in the CLIC linac. This is realized for the CLIC structures by four radial damping waveguides in the outer wall of each cell as shown in the picture of a TD18 cell in Figure 2. The waveguides will eventually be equipped with a SiC load at the end of the waveguide to absorb the higher mode power coupled to the waveguide but have been left out for now to concentrate on the high power demonstration of the damping features. We believe the critical issue of these damping features arises from the pulsed surface heating due to an enhancement of the magnetic field at the edges of the waveguide openings towards the cell. The pulsed temperature rise amounts up to 78 deg in these structures for the nominal pulse length of 230 ns. The damped version is called TD18 [4] and its rf parameters along the structure are shown in Figure 1 for comparison. The apertures are identical to those of the undamped version however the waveguide opening results in a reduction of

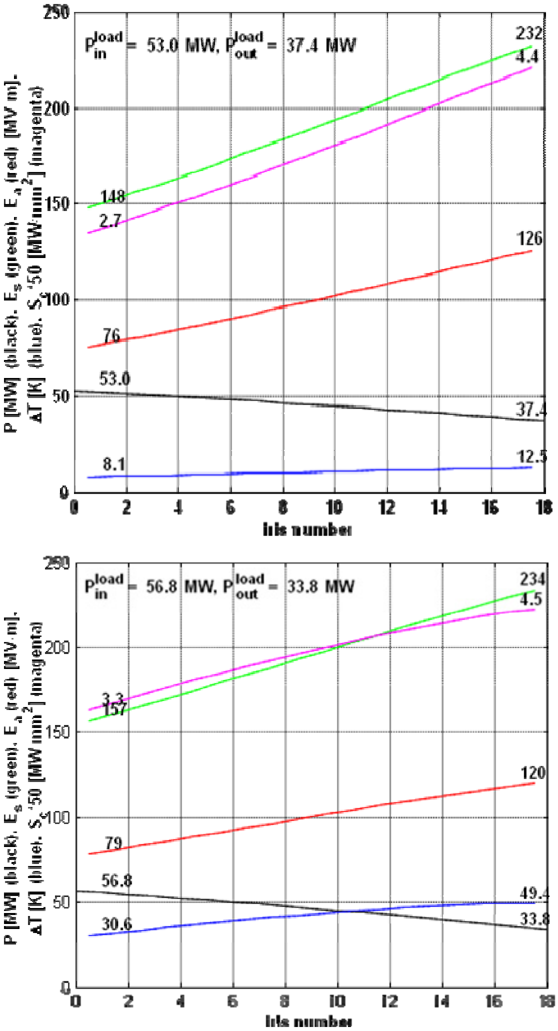

Figure 1: RF parameters along the accelerating structure for an undamped structure T18 (upper plot) and a damped structure TD18 (lower plot). The parameters are for the nominal 100 MV/m gradient and a pulse length of 100 ns.

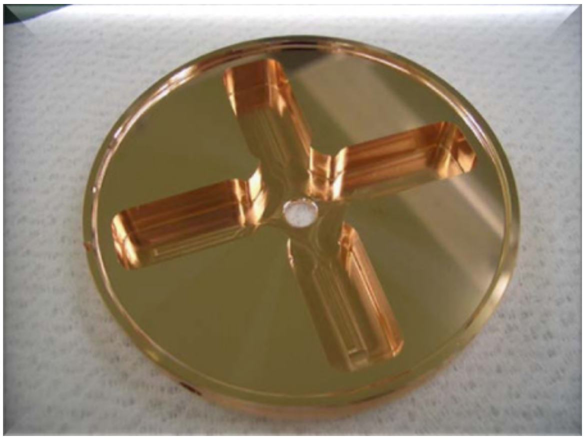

Figure 2: Photo of a damped cell used for the TD18 structures.

the group velocity from 2.3 % to 0.9 % v_g/c. All structures compared here have been made in collaboration between KEK, SLAC and CERN using the same fabrication methods [5]. The cells have been machined by KEK using diamond turning and milling followed by cleaning and etching at SLAC. The disks are then diffusion bonded in a hydrogen furnace and finally the structure is baked in a vacuum furnace. A pair of the damped version has been fabricated and one each was tested in the test facilities at SLAC (NLCTA [6]) and KEK (NEXTEF [7]).

The TD18 structure is important for the CLIC design it is not the base line structure for CLIC which is called TD24 [4] a 24 cell structure with less tapering and reduced surface electrical field and pulse temperature rise. Undamped versions of this structure have been built and will be tested shortly.

HIGH POWER TESTING RESULTS

A total of four T18-type structures have been tested so far but only two have been fully conditioned. The conditioning of two damped versions has been completed. Each facility uses a somewhat different processing protocol and breakdown detection scheme. The results are nevertheless very consistent and seem to be independent of these differences. All structures could be processed to an average unloaded gradient of 100 MV/m at the design pulse length of 230 ns. Different breakdown rates were measured at the end of the processing for these structures. The conditioning took more than 1000 hours, the breakdown rates have been found to continue to improve even after 2500h of processing. The main results are summarized in Figure 3 showing the breakdown probability as a function of unloaded gradient. Due to the strong tapering of the structures (see Figure 1) the fields along the structure would be actually significantly lowered with beam loading in particular towards the end of the structure where the breakdown distribution peaks. Therefore the structures have been tested to the equivalent unloaded gradient. It was found that these curves simply shift down with longer processing time that is why some of them are represented by a single point only. The final results are remarkably similar for different structures of the same type. While the T18's could be operated at around 100 MV/m with the CLIC target trip rate the TD18's shows in average a factor 100 higher breakdown rate and could therefore be operated only at a 10-15 % lower gradient. Furthermore it seems that the TD18(3) tested at SLAC shows a different slope for this kind of measurement. The breakdown location was found to be distributed similar for both types of structures during conditioning. The breakdown probability rises approximately linear towards the end of the structure following the field profile. An exponential dependence as expected from a field emission driven mechanism has not been observed. For the TD18(3) structure the breakdown distribution flattened out over the structure towards the final stage of processing [8]. Dark currents and Fowler-Nordheim field enhancement factors have been found to be similar for both types of structures at the final

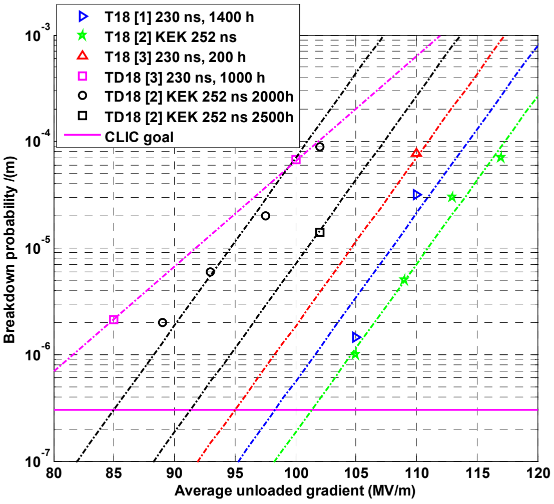

Figure 3: Breakdown rate as a function of gradient for different T18 and TD18 structures. The lines are only added for guiding the eyes and indicating the trends.

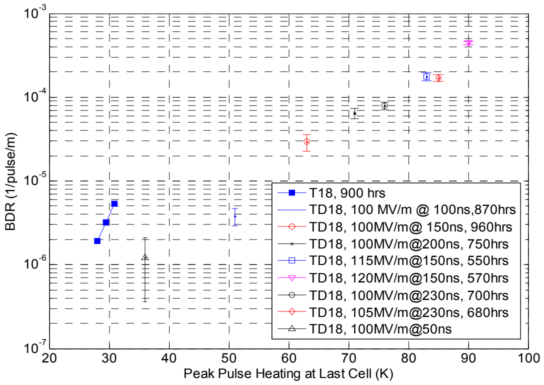

Figure 4: Breakdown probability as a function of pulsed temperature rise in the last cell of T18 and TD18.

conditioning stage. Since the main difference in the rf design are the waveguides and the associated pulsed heating experiments have been carried out in order to try to separate out the effect of the electrical surface field and the magnetic field. Figure 4 shows a series of breakdown rate measurements for different pulsed temperature rise. The maximum temperature rise is located at the corner of the waveguide opening in the last cell of the structures. The data is very well correlated with the temperature but can't be connected to the T18 data at a similar processing state. Further evidence for the influence of the pulsed heating was found in special experiments shaping the rf pulse using the SLED pulse compression system at NLCTA. Like this different pulsed heating temperatures could be realized leaving the gradient and the flat top pulse length unchanged [8]. On the other hand if one seperates the data in Figure 4 and plots the breakdown rate as a function of pulse length for constant gradient one finds the same dependence for T18 and TD18 (see upper plot in Figure 5). If the TD18 for constant pulse length is ploted as a function of the gradient the dependence is similar for different pulse length but the slope is different (see lower plot in Figure 5). However in the SLAC experiment as indicated in Figure 3 the slope of the breakdown probability as a function of gradient is differrent compared to the structure which was tested at KEK. These observations together with the breakdwon distribution which is not strongly peaked at the end of the structure might support a second hypothesis. The cells of T18 are made by turning while the TD18 needs milling for the waveguides. The milled surface actually comes very close to the iris and has a much worse surface finish. The path of the milling tool can be seen in Figure. If the milled surfaces are responsible for the performance difference one could expect a degradation of the breakdown rate equally distributed over the structure which is as well compatible with the data. The tested structures will be cut open and further examined to get more insights in the breakdown mechanism.

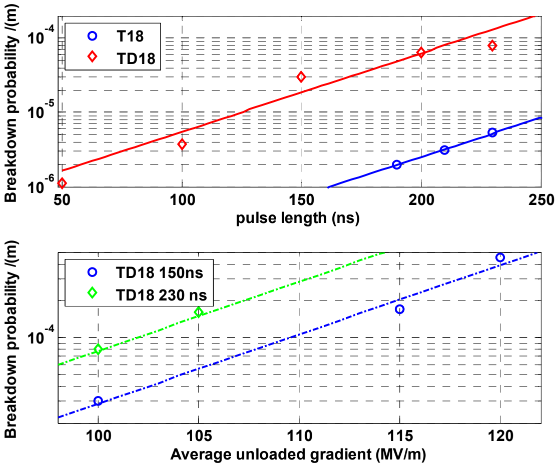

Figure 5: Breakdown rate dependence as a function of pulse length and fixed gradient (upper) and gradient for fixed pulse length (lower) of structures tested at SLAC.

CONCLUSIONS

The high power testing of two TD18-type damped accelerator structures demonstrated that high-gradient operation at the 100 MV/m level is compatible with the strong damping mechanism chosen by the CLIC study.

The structure tested at KEK could be operated for example at a gradient around 90 MV/m with an acceptable breakdown rate. The testing showed nevertheless a significant performance reduction compared to the undamped version. Two possible causes have been identified. Firstly the milling very close to the iris can be avoided by reducing the radius at the outer wall of the cell. The undesired milling surface may be improved by heavy chemical etching with only a small fraction of a micron material removal. Secondly the high pulse temperature rise in this structure was already a concern and a new structure which became the CLIC baseline has been designed with a significant reduction of the magnetic field. This structure called TD24 [4] is much less tapered and has reduced electrical and magnetic surface fields. The maximum pulse heating in the damped version amounts to 40 deg for 100 MV/m loaded gradient. This type of structure is currently fabricated and testing of an undamped version is imminent.

The results presented here are an important milestone towards a structure suitable for CLIC. The next steps will be to test the new structure with reduced pulse heating and to incorporate the SiC absorbers in the mechanical design.

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