COMPARISON OF HIGH GRADIENT PERFORMANCE IN VARYING CAVITY GEOMETRIES

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Abstract

Five types of CLIC prototype TW accelerator structures were high-gradient tested at KEK, up to 100 MV/m level. The ramping speed of each processing and the resultant breakdown rate were compared among them. From this comparison, it was found that the ramping speed of the structures with opening ports for HOM damping with magnetic coupling became slow and the resultant breakdown rate became high. This indicates the role of the magnetic field on vacuum breakdowns in copper structure at the region around 100 MV/m. In this paper, we review such processing characteristics and the final high gradient performance of the recent structures. One of the structures showed frequent breakdowns in two particular regions of the structure, indicating a mechanism reflecting not only the geometry or material characteristics but the local features acquired after completion or even during the running.

INTRODUCTION

Significant progress over the past few years has been made towards demonstrating the feasibility of one of the most crucial RF performance specification of CLIC [1] – an acceleration gradient of 100 MV/m with the nominal pulse width of 240 ns (flat top of 156 ns) and a breakdown rate of a few 10^{-7} /pulse/m. To optimize the structure parameters, results from previous high gradient experiments were used as a guide along with such parameters as 'Sc' to design a structure that should perform well at high gradients and be CLIC compatible [2].

Since 2007, an international collaboration on high gradient X-band accelerator structure development has been mainly lead by CERN, SLAC and KEK [3]. One of the undamped structures showed in 2011 an extremely good performance meeting the CLIC breakdown rate (BDR) requirement with ever decreasing BDR in the continuing operation [4]. The focus since then has been the experimental study of structures with the heavy damping features needed for CLIC. In the present paper, the test results from Nextef [5] of KEK in recent two years are presented.

Before going into the detailed description, the symbols in the structure code name are described. Typical example such as TD24R05 come from T=travelling wave, D=damped, 24=number of cells and additional R05=corner radius of 0.5mm.

One of the most concerns in the design of the damped structure is the reduction of surface magnetic field, H_s, which leads to the surface temperature rise within a pulse. Actually the TD18 structure tested at SLAC showed clear increase of BDR as the temperature rise [6]. Then we speculate that the high H_s may lead to the breakdown trigger. The 24-cell structures are designed to reduce the H_s comparing to those of 18-cell one [7]. Since the performance of undamped T24 structure was found extremely good, we assumed the improved performance of related damped structure, TD24.

In the present paper are reviewed the recent results since last conference [8] of these 24-cell damped structures, where the H_s was reduced than TD18.

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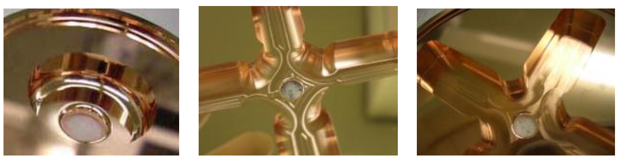
ACCELERATOR STRUCTURE DESIGN AND PREPARATION

Design

The structures discussed in the present paper are the 24-cell structures. The H_s of TD24 was reduced comparing to the TD18 by changing the accelerator mode parameters while that of TD24R05 was further reduced than TD24 by reducing the corner radius of 3mm down to 0.5mm [7]. These cell shapes are shown in the picture of Fig. 1.

Table 1. Accelerator gradient and surface temperature rise in a pulse along the structure in the operation of unloaded gradient of 100 MV/m.

Structure	TD18	TD24	TD24R05
E_{acc} [MV/m]	79 ~ 120	94 ~ 102	94 ~ 102
ΔT [C]	29 ~ 47	25 ~ 21	21 ~ 19



T24 TD24 TD24R05

Figure 1: CLIC prototype structure cells.

Preparation of structures

The techniques used to fabricate the structures are the same as developed for the GLC/NLC structures in the early 2000's [9, 10]. These include machining the parts with the combination of milling and diamond turning, diffusion bonding the cells in a hydrogen furnace and a final 650 degC vacuum bake for ten days.

Recently one possible problem was discussed related to the spark-like markings which were acquired through the high power processing [11]. It might be related to a high current running through the gap of micron order in one of the cell corners, possibly formed due to the imperfect diffusion bonding. To suppress this possibility, the cell flatness was carefully checked and confirmed that the inner area of the flat surface to be bonded is high comparing the outer area, which may lead to the less gap formation where the high current passes. In practice, the surface flatness is specified that the cell flatness should be less than 0.5 micron when sandwiched by two optical-quality flats and the inner area should be higher, though the actual inspection by laser interferometer is inspected by eye.

Experimental setup preparation

The structures were vacuum-leak checked and nitrogen gas purged at SLAC in a reasonably clean environment. At KEK, these were firstly checked in S_{ij} and dressed up for installation. These were all done in the clean room.

The high test was performed at Nextef of KEK [5]. It should be mentioned that the setup was carefully purged by nitrogen gas during any replacement, such as the structure exchange. However, as seen in the Fig. 2, the area is located in a somewhat dirty concrete vault and the outside of the components were covered with much of dust.

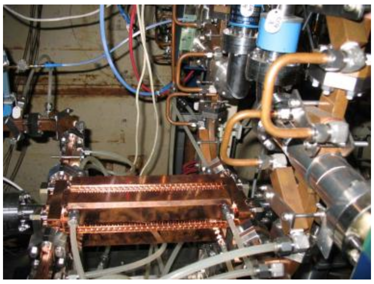


Figure 2: Nextef setup in reality.

RF PROCESSING RESULTS

Initial processing rate

The processing was performed semi-automatically by a control program, starting with a short pulse width such as 50 nsec. After reaching the top power level, it increased the width stepwise by 50-100nsec jump. When we observe a vacuum pressure increase typically in early stage of the processing by more than several 10^{-6} Pa, the program slows down or stops ramping of power level. When a big breakdown happens, it stops the next pulse and restart from somewhat lower power level after waiting for a few tens of seconds. The breakdown is identified by an abrupt burst of the Faraday cup current, either upstream or downstream and mostly both, in addition to the big reflection in RF power.

The observed ramping speed in early stage of the processing of recent tested structures is shown in Fig. 3 as a function of running time. It was found that the undamped structures showed much faster ramping comparing to the damped structures. The ramping speeds of both damped structures, TD24#4 and TD24R05#2, were similar and these were much faster than TD18#2, whose H_s is much higher, indicating the importance of low H_s.

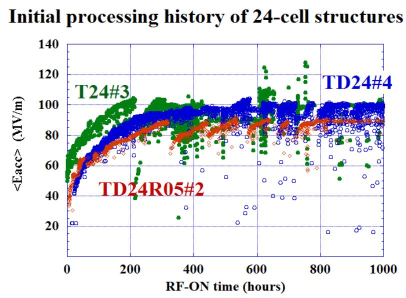


Figure 3: Comparison of initial ramping speed.

Breakdown rate evolution

The comparison of breakdown rates (BDR) vs. time for the recent structures is shown in Fig. 4. The reduction of BDR of T24#3 was fastest. The BDR of TD24#4 was higher and its reduction speed was slower than T24#3. The BDR of TD24R05#2 was even higher than TD24#4 and the reduction vs. time was much less. It may reflect the appearance of hot spot at 1500 hours of operation described in the next paragraph.

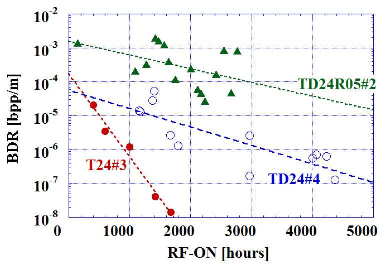


Figure 4: Comparison of BDR evolution versus time.

Breakdown location

BD location can be identified from the timing of the abrupt increase of the reflection pulse and the fall of the transmitted pulse.

After reaching to 90 MV/m with 252nsec pulse in the TD24R05#2, the structure was conditioned with the longer pulse width at around 1700 hours. As shown in Fig. 5, frequent breakdowns appeared at the downstream of the structure after the long-pule operation, followed by the appearance of another peak in the upstream after 2100 hour point when the higher E_{acc} at 100 MV/m was realized. This we call “hot spots.”

Since these hot spots stayed in the following operation, the structure seems damaged. This phenomenon was firstly observed in the five structures. The mechanism and how to prevent it should be studied.

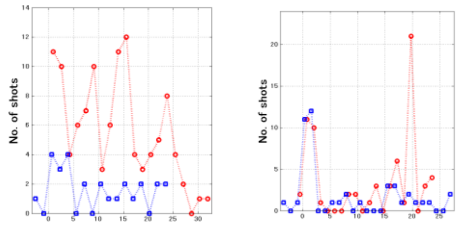


Figure 5: Breakdown cell distribution in TD24R05#2. (a) is before and (b) after emerging hot spots.

BDR vs. pulse width and breakdown timing

BDR is a function of pulse width T_p as shown in Fig. 6(a). That of TD24R05#2 case showed T_p^6 dependence. If $BDR \propto T_p^{\alpha}$, it is natural to speculate that the probability of breakdown onset time *f(t)* within the pulse distributes as $f(t) \propto t^{\alpha-1}$ if the breakdown trigger mechanism develops within the pulse. In some cases, the breakdown increases toward the end of the pulse, but it is much less steep than that expected, $\sim T_p^5$, from a simple estimation based on BDR behaviour. As shown in Fig. 6, the measured timing distribution of the breakdowns is almost flat in time. Note that the red points show the usual breakdowns, while the blue show the first-pulse breakdowns just after the nominal breakdown. In the latter case, most breakdown start almost at the beginning of pulse.

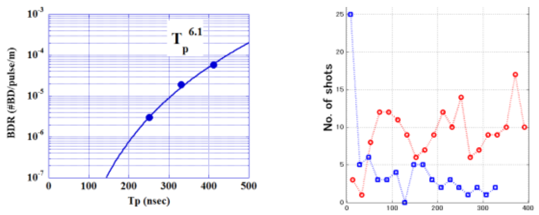


Figure 6: Breakdown characteristics of TD24R05#2. (a) BDR vs. pulse width and (b) breakdown timing distribution.

DISCUSSION AND FUTURE IMPROVEMENTS

The breakdown rate, BDR, of the un-damped structure T24 clearly met the CLIC requirement of a few 10^{-7}/pulse/m at 100 MV/m. However, the processing speed and the resultant breakdown rate in the damped structures showed poor performance than those of undamped ones with the similar RF acceleration parameters. Here such gradient level as 80 MV/m seems feasible if based on the present technology.

The biggest difference in electromagnetic field from undamped to damped is the increase of H_s at the magnetic coupling slots for the high-order-mode damping and it plays an important role[6]. The mechanism governing this relation should definitely be identified to realize the CLIC design specification in the damped structure. If the high BDR is inevitable due to the high H_s, we may need to introduce such structure as choke-mode type where no big enhancement of H_s is needed for damping. The study is on-going in collaboration with Tsinghua University.

In addition, we encountered, for the first time at Nextef, the hot spot. This might have been introduced by accidental introduction of dust particles. The mechanism and the technology to suppress such cases should be studies. We have been preparing such studies in a small-sized experiment with the simpler geometries. If the actual origin of the hot spot comes from any intrinsic characteristics and appeared sometimes but not always, the R&D strategy should be different.

ACKNOWLEDGMENT

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