

PROVING HIGH-FIELD OPERATION OF X-BAND STRUCTURE FOR LINEAR COLLIDER

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Abstract

In 2003, several X-band structures with appropriate iris radius and detuning were operated in excess of the NLC/GLC design unloaded gradient of 65 MV/m. Three structures, including the one with damped cells with manifolds, had acceptable breakdown rates at 60 MV/m, and 2-3 times the rate limit at 65 MV/m. More structures with the latest parameters are being prepared and are expected to clarify the implications of improved fabrication and installation procedures in the high-field performance. This paper reviews the most up-to-date status of the design, manufacturing and testing of 60cm-long accelerator structures under development by the GLC/NLC group.

1 INTRODUCTION

Designs of the linear colliders, GLC and NLC, are both based on normal conducting accelerator structures operated at X-band, 11.424GHz [1,2]. This paper presents the design features, fabrication and the latest high-field performance of the recently tested structures.

2 STRUCTURE DESIGN

2.1 Basic cell parameters

The accelerator structures for a linear collider must satisfy two critical requirements: high-field acceleration of the multi-bunch beam and preservation of the low emittance through the long linac.

Having proven the sufficient wake-field suppression by detuning and medium damping [2], we have been focusing on establishing high-field performance[3]. At GLC/NLC, the nominal unloaded gradient is 65MV/m.

Early 1.8m-long structures with $vg/c \sim 10\%$ showed [2] frequent breakdowns (BDs) at $\sim 50\text{MV/m}$. Progressive damages were observed on their inner surfaces particularly in upstream parts. Subsequent studies with a series of test accelerator structures indicated that a use of low group velocity ($vg/c = 3 \sim 5\%$) is effective in reducing the BD rate and the damages to the extent acceptable for stable operation of GLC/NLC.

However, since reduction of vg/c usually requires reduction of a/λ , it results in tighter alignment tolerances in achieving the required short-range wakefield suppression. Thus an extensive re-optimization was devised for the electrical design. The present structure design includes the following improvements:

1. $vg/c \sim 4\%$: to reduce the BD rate to an acceptable level and to reduce the damages due to breakdowns.
2. $\phi/\text{cell} = 5\pi/6$: to maintain the relatively small vg/c mentioned above without excessively reducing a/λ .
3. $a/\lambda = 0.17$: optimisation aiming at high shunt impedance and low short-range wakefield.
4. Improved designs of input/output couplers and rounded corners of HOM slots in regular cells: to contain the RF heating of the corner edges.
5. Additional optimization of the profile of a/λ (consequently vg/c) along the structure: to reduce the field at the upstream end while maintaining the surface field below 140MV/m in nominal operation.

Subsequent sections outlines specifics of some of these points.

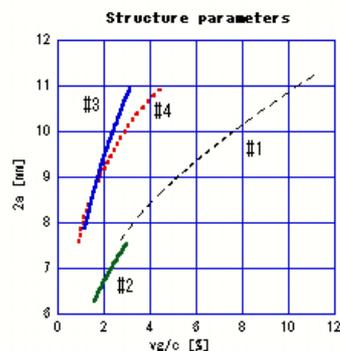


Figure 1: Cell parameter evolution

To make the parameter change clear on the items 1 and 2 above, Fig. 1 shows the evolution of typical structure parameters, ($2a$ vs. vg/c). The 1.8m design #1 is the earliest type before noticing the high-field problem. By adopting the extension of the downstream part we designed #2 with small $vg/c \sim 3-1\%$ by reducing a/λ . The structure behaved extremely well. Then, by increasing the phase advance per cell, the parameter #3 recovers a/λ . Finally the group velocity of the upstream end is increased a little to reduce the surface field there and also the average a/λ is reduced to 0.17 from 0.18 to increase shunt impedance in our latest design #4.

2.2 Surface field profile

Starting with #3 in Fig. 1, our recent design evolution is shown in Fig. 2 where the surface electric field is plot along the structure. The top curve adopts the in-line-taper (ILT) idea, where first few cells have fairly large aperture so that the field is very low. It resulted in a good performance at least at the upstream end. Further optimisations were applied in the lower three curves to reduce field; 1: beam hole shape from round to elliptical, 2: increasing shunt impedance by reducing a/λ $0.18 \rightarrow 0.17$ and 3: reducing upstream field by taking large v_g/c $0.03 \rightarrow 0.04$ to simulate ILT. All these curve correspond to the average gradient of 65MV/m. These structures have been tested recently and their breakdown rates are summarized in Chap. 5. The last curve, the bottom one, is the most recently tested structure and its performance is described in detail in Chap.4.

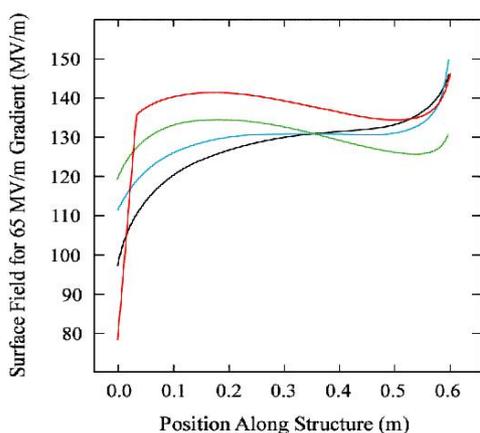


Figure 2: Surface field of recent 60cm structures.

3 FABRICATION

3.1 Cell fabrication

HDDS cells are made with a high precision milling followed by a diamond turning. A picture taken from the cup side is shown in Fig. 3.

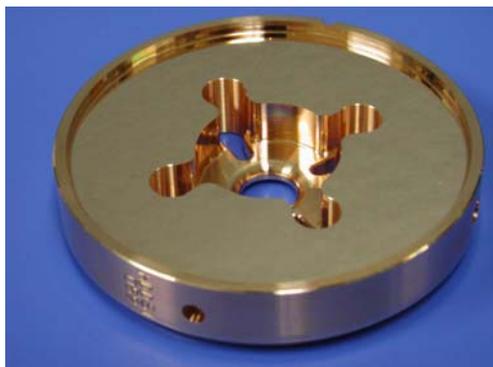


Figure 3: HDDS cell.

Magnetic field distribution over the surface of this type cell is shown in Fig. 4. There is an area with a very high magnetic field along the slot. The additional increase of the field was suppressed by carefully choosing the milling tool shape and adjusting its position with respect to the turning surface. The crossing angle at the boundary is typically 8 degrees given by the milling tool shape.

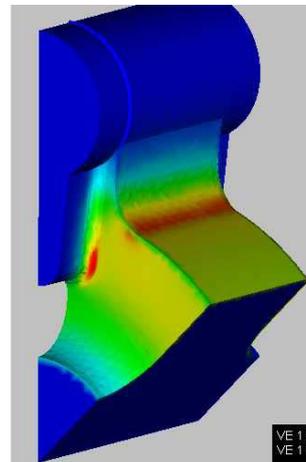


Figure 4: Magnetic field distribution of HDDS cell surface.

3.2 Assembly and treatments

The chemical etching is applied to remove about 3 microns. Then the assembly is performed to be diffusion bonded in hydrogen furnace at 1020C for one hour. Then, the structure is fired in the wet hydrogen furnace followed by the dry hydrogen furnace at 950C to remove hydrocarbon etc. The structure is then tuned it is vacuum-baked at 650C for more than a week.

4 HIGH POWER TEST OF H60VG4S17 STRUCTURE

In this chapter are presented the high field performance of the most recent fully-slotted structure, H60VG4S17, which corresponds to #4 in Fig. 1 and the lowest curve in Fig. 2.

Breakdown points acquired for certain hours during the operation of the nominal field of 65MV/m are plotted in Fig. 5. There are two type of breakdown seen here. Green points are localized at the upstream cell with low missing energy and triggered at 100ns or later. These breakdowns are probably related to pulse heating. We observed breakdown marks near the gap between cells (, which were formed by mistake). We believe that the structure normally fabricated will be operated without this type of breakdowns resulting in a much lower BD rate. The blue points are widely distributed all over the structure but with much less frequently.

In Fig. 6 are plotted the same breakdown in a 2 dimensional plot, vertical: breakdown position measured by RF pulse amplitude and horizontal: reflected RF phase. It shows fairly localized breakdown hot spots at a cell near upstream end, which correspond to the green points

in Fig. 5. From this we also speculate this frequent BDs are due to some special cells, which can be improved in later structures.

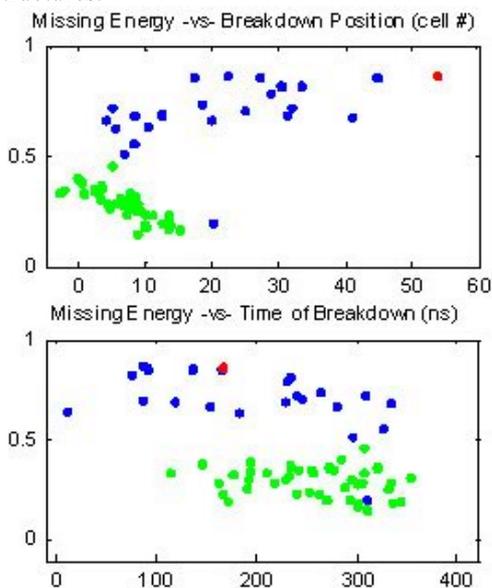


Figure 5: Missing energy and position (upper) and timing (lower) for each breakdowns.

at 65 MV/m, 400 ns Pulse Width

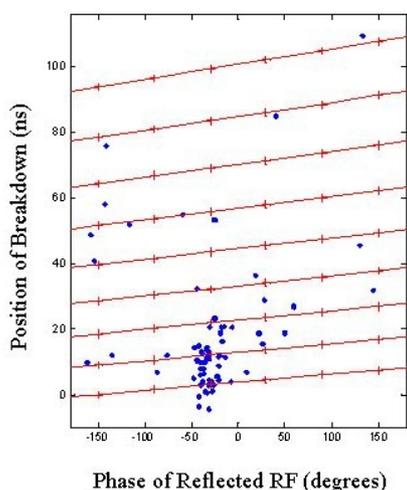


Figure 6: Breakdown position and phase

5 RECENT TEST SUMMARY

One of the most critical criteria on the high field performance for GLC/NLC is the breakdown (BD) rate at the nominal field. The allowed BD rate is 1BD/2MegaPulses assuming two percent spare RF unit and some assumptions on the recovery speed.

Fig. 7 shows a summary of BD rates of recently tested structures as a function of field. The reduction of BD rate became evident when operated with the design pulse shape, where the pulse is ramped during the initial structure fill time of 100ns instead of flat one. In this case

the pulse is effectively shortened from 400ns to 300ns as we exclude the ramping period.

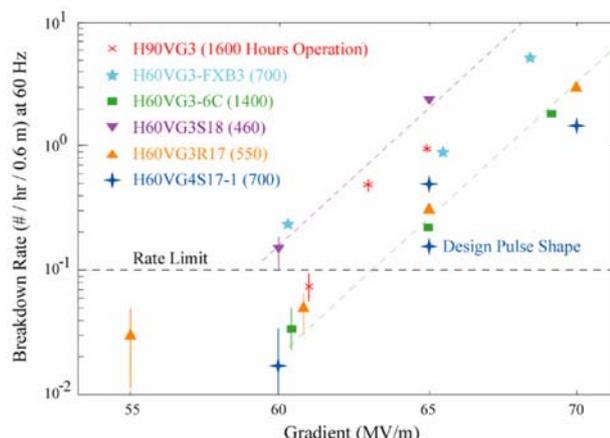


Figure 7: Breakdown rates of recently tested structures. Crosses show the last structure described in Chapt. 4.

6 CONCLUSIONS

- RF processing of HDDS structures is a relatively fast process. E_{NL} of 65MV/m can be reached in several tens of hours of operation at 60Hz.
- In the operation with 400ns flat pulses, the BD rate at $E_{NL} = 60\text{MV/m}$ satisfies the performance requirements at GLC/NLC. It is a factor ~ 5 larger at 65MV/m, the present specified E_{NL} . It is noted that when GLC/NLC is operated with $E_{NL} = 60\text{MV/m}$, instead, the loaded gradient will be 45MV/m and the resultant increase of construction cost of a linear collider is estimated to be $\sim 3\%$.
- However, operation with the design pulse, which includes a ramping of power for the initial 100ns period, reduces the BD rate by $\sim 1/3$, almost meeting the BD criteria.
- As of early 2004, the BD rates observed with several test structures exhibit large variations. They are speculated to be due to the existence of hot cells or some known problems during fabrication or vacuum bake-out. Repeated testing with better quality controls during structure preparation is currently under way.
- Issues with very long-term stability of accelerator structures in many thousand hours of operation are to be examined starting 2004. Possible studies include “accelerated damage testing” with E_{NL} higher than the nominal specifications.

7 REFERENCES

[1] KEK Report 2003-7, also available from <http://lcdev.kek.jp/ProjReport/>, May 2003.
 [2] SLAC R-559, KEK Report 2000-7, also available from <http://lcdev.kek.jp/ISG>
 [3] C. Adolphsen et al., Proc. PAC 2003, p668, Oregon, USA, 2003.