High-Gradient Results and Plans

SLAC


FNAL


KEK

Y. Higashi, T. Higo, N. Toge
Structure Development Overview

- In 2000, after improvements to the rf processing capabilities at NLCTA, realized 1.8 m prototype NLC/GLC structures were being damaged during operation and would not meet performance requirements.

- Launched aggressive R&D program:
  - Build/Test low group velocity traveling wave structures and standing wave structures.
  - Improve structure handling, cleaning and baking methods.
  - Study characteristics of rf breakdown in structures, cavities and waveguides.
  - Thus far have tested 28 structures (over 15 khr operation at 60 Hz).

- T-Series Structures (Second Generation - Experimental)
  - Essentially the low group velocity (downstream) portion of the 1.8 m structures, which had shown little damage.
  - Produced structure with acceptable trip rate at gradients up to 90 MV/m.

- H-Series Structures (Third Generation - Designed for NLC/GLC)
  - Developing low group structures with acceptable iris sizes to limit short-range wakefields and slots in cells to damp long-range wakefields.
H-Series Structures

- Although the structure with the improved couplers (T53VG3MC) performed very well, this design cannot be used for NLC/GLC.
  - The average iris radius \(a/\lambda\) is smaller (0.13) than desired (0.17-0.18), yielding a transverse wakefield three times larger than acceptable.
- As the next step toward an ‘NLC/GLC-ready’ structure, 150 degree phase advance designs with \(a/\lambda = 0.18\) & 0.17 (called H-Series structures) are being developed.
  - Pay twice in loss of shunt impedance (higher \(a/\lambda\) and thicker irises) \(\rightarrow\) input power/length 50% larger than T-Series.
  - Eight \(a/\lambda = 0.18\) and two \(a/\lambda = 0.17\) structures tested so far.
## H-Series Structures Tested in 2003

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Breakdowns Locations at 65 MV/m after Processing

H90VG3 (Inline Taper)

Each Cross-Hatch = Cell Iris

Location from RF Timing (ns)
Location from RF Phase (degrees)

H60VG3-FXB3 (No Taper)

Location from RF Timing (ns)
Location from RF Phase (degrees)
Stainless Steel 'Mushroom' Found on the Outer Wall of Cell 35 in H90VG3
Preliminary Results on Particles (< 10 µm) Found in H90VG3 Cells

Higher breakdown rate; Lower numbers of particles?
Prototype Cells to Damp Long-Range Wakefields

- Modified from earlier design to lower pulse heating.
- Expect \( \sim 40 \, ^\circ C \) temperature rise at 65 MV/m, 400 ns.

- First two tests with slotted cells.
  - H60VG3-6C, which includes six slotted cells near middle of structure.
  - H60VG3S18, which has all slotted cells except the first and last two.
Breakdown Statistics for H60VG3-6C at 65 MV/m, 400 ns

Breakdown Rate

Breakdown Location

Average Trips per Hour Each Day

Goal

Mean

Location from RF Timing (ns)

Location from RF Phase (degrees)

Slotted Cells
‘Spitfest’ Statistics for H60VG3-6C with 400 ns Pulses

65 MV/m

70 MV/m

Number of Trips (162 Total)
Time Between Trips (Minutes)
(Times > 30 Plotted at 30)

Number of Trips (114 Total)
Time Between Trips (Minutes)
(Times > 30 Plotted at 30)
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H60VG3S18 & H60VG3-FXB4 Processing History

Structure Gradient (MV/m) and Trip Rate/5 (#/hr)  
(S18 = Black, FXB4 = Red)

400 ns Pulse Width

FXB4 Disconnected
Breakdown Statistics for H60VG3-FXB4
at 50-65 MV/m, 400 ns Pulse Width
(Green = After Pulse Timing)
Breakdown Statistics for H60VG3S18 at 65 MV/m, 400 ns Pulse Width

All Events

Events in First 6 Cells
WR90 Input Waveguide Arms

Found 20 degree phase length difference between the two arms
Effect of H60VG3S18 WG Phase Mismatch

Depending on phase, produce up to a 15% enhancement of the electric field on the matching iris, and a greater than 20% enhancement of the magnetic field there.

Electric Field Pattern in Structure Excited Asymmetrically

C. Nantista
H60VG3S18 Field Profile with Mode
Converter Coupler (Symmetrically Excited)
See acoustic activity on top of coupler body, but it also occurs for events in the interior of the structure and in later structures where breakdowns are not concentrated near the coupler – may be due to upstream breakdown currents. Visual inspection of the coupler showed no obvious damage.
Breakdown Statistics for H60VG3S18 at 65 MV/m, 400 ns

Time with RF On (hr)

Gradient (MV/m)

Missing Transmitted Energy (Threshold ~ 0.10)
‘Spitfest’ Statistics for H60VG3S18 at 400 ns

- **60 MV/m**
- **65 MV/m**
- **70 MV/m**

Time Between Trips (Minutes)
(Times > 30 Plotted at 30)
Breakdown Rates at 400 ns Pulse Width

![Graph showing breakdown rates vs gradient]

- H90VG3
- H60VG3-FXB3
- H60VG3-6C
- H60VG3S18
- SW20a375

Breakdown Rate (#/hr/0.6 m) at 60 Hz

Gradient (MV/m)

SW Goal

TW Goal
Program Overview

- To improve structure efficiency (+10%) and likely provide more operating overhead, an \( a/\lambda = 0.17 \) version of the H60VG3 structure has been adopted as the NLC/GLC baseline design (H60VG3S17 / H60VG4S17).

- The main goal for the next year is to operate eight of these structures for >2000 hr at 65 MV/m in the NLCTA linac.
  - FNAL and KEK will fabricate these structures.

- Other Structures:
  - Two more H60VG3’s \((a/\lambda = 0.18)\) built by FNAL (start in December).
    - Fire cells to \( \sim 1000 \degree C \) to increase grain size.
  - Standing Wave (test of fourth pair finished in July).
  - CERN structure made with molybdenum irises (run recently completed).
  - Single cell structures made with molybdenum or copper cells (2004).
H60VG3 Structure Parameters -vs- Iris Radius (a/\lambda)

- Shunt Impedance (MΩ/m)
  - Input Power (MW) for 65 MV/m
  - a/\lambda = 0.180 → 63.1
  - a/\lambda = 0.170 → 55.8
  - a/\lambda = 0.165 → 52.4
  - a/\lambda = 0.160 → 49.6

- Peak Non-Slotted Cell Temperature Rise (°C)

Short-Range Transverse Wakefields

\[ W_\perp \sim (a/\lambda)^{-3.5} \]
Considering Two $a/\lambda = 0.17$ Designs

- One (H60VG3S17) has ‘natural’ surface field profile determined by detuning requirements.
- The other (H60VG4S17) has a tailored profile to lower upstream surface field. For this purpose:
  - Maintain same average iris diameter ($a/\lambda = 0.17$), efficiency and input power.
  - Use larger dipole frequency spread (9.4% to 11%).
  - Allow dipole spectrum to be asymmetric. The resulting wakefield with 4-fold interleaving appears acceptable but more study is needed.

\[ \text{Mode Density} \]

\[ \text{Dipole Frequency} \]

\[ \text{H60VG3S17} \]

\[ \text{H60VG4S17} \]

Z. Li
Peak Surface Field Profile vs. Structure Type

- **H60VG3** (a/λ = 0.18, Rounded Irises, Inline Taper, Already Tested)
- **H60VG3S18** (Elliptical Irises - Reduces Peak Fields by 5% but Requires +5% Power, Currently Under Test)

NLC/JLC Candidates:
- **H60VG3S17** (Elliptical Irises, Lower a/λ, Different vg and Thickness Profile, Requires 10% Less Input Power Than H60VG3)
- **H60VG4S17** (Same as Above but Wider, Asymmetric Dipole Spectrum)
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H60VG3R17 Items of Note

Vacuum Pump Pressures (Torr) During In-situ 220 °C Bake

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<th>Structure</th>
<th>Ratio of Trips during Ramp to Trips after Ramp during Initial 400 ns Processing</th>
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<td>H90VG5</td>
<td>0.8</td>
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<td>H60VG3</td>
<td>1.2</td>
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H60VG3R17 Full Processing History
(9200 Breakdowns)

400 ns = Pulse Width
30 ns 50 ns 100 ns

Trip Rates (#/hr)
0.8 0.3 3

0.03 0.05 1.1 17 2.5

Structure Gradient (MV/m) and Trip Rate/5 (#/hr)

Time with RF On (hr)
Trips = 20  Time (hr) = 69.4  Rate (#/hr) = 0.29

-Gradient (MV/m) vs-Time (hr)-

-Missing Trans Eng vs-Time (hr)-

-Trip Rate (#/hr)-

10 Hour Period

Period Between Trips (minutes)
Breakdown Locations in H60VG3R17 at 400 ns Pulse Width

During Processing from 60-74 MV/m

During Operation at 65 and 70 MV/m
Breakdown Rates with 400 ns Pulses

- H90VG3 (1600 Hours Operation)
- H60VG3-FXB3 (700)
- H60VG3-6C (1400)
- H60VG3S18 (460)
- H60VG3R17 (500)

Breakdown Rate (#/hr / 0.6 m) at 60 Hz

Gradient (MV/m)

Goal
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H60VG4S17-1 Cell Contact Problem

Cell Cross-Section Illustrating Gap Between Cells Before Bonding

‘Mesa’ Left After Machining (size exaggerated)

Resulting Field Attenuation After Bonding

Ez Field Comparison for H60VG3S17-1

Ez (MV/m)

Cell #
H60VG4S17-1 Processing History to Date
(2900 Breakdowns)

Fastest H-Structure to Reach 75 MV/m, 240 ns

Structure Gradient (MV/m) and Trip Rate/#/hr

Time with RF On (hr)

Trip Rate (#/hr)

Pulse Width (ns)
Breakdown Locations in H60VG4S17-1 at 400 ns Pulse Width

During Processing from 60-70 MV/m

Recent Operation at 60 and 65 MV/m
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  - Standing Wave (test of fourth pair finished in July).
  - CERN structure made with molybdenum irises (run recently completed).
  - Single cell structures made with molybdenum or copper cells (2004).
Power Eight Accelerator Structures in NLCTA (R2 Requirement)

Phase 2a Configuration

Eight, 0.6 m Long Structures: Run at 65 MV/m, 400 ns Pulses
## Structure Testing Schedule

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<tr>
<td>4 x FXC H60VG3 S17 (0.17, 150°, slots)</td>
<td>FNAL</td>
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<tr>
<td>2 x H60VG4R17 (0.17, 150°, no slots)</td>
<td>SLAC</td>
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<tr>
<td>H60VG4S17-3 (0.17, 150°, slots)</td>
<td>KEK/SLAC</td>
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<tr>
<td>2+2 FXD (H60VG4S17, 0.17, 150°, slots, HOM couplers)</td>
<td>FNAL</td>
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<tr>
<td>H60VG4SL17-A (0.17, 150°, slots, HOM couplers)</td>
<td>KEK/SLAC</td>
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<tr>
<td>H60VG4SL17-B (0.17, 150°, slots, HOM couplers)</td>
<td>KEK/SLAC</td>
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To improve structure efficiency (+10%) and likely provide more operating overhead, an $a/\lambda = 0.17$ version of the H60VG3 structure has been adopted as the NLC/GLC baseline design (H60VG3S17 / H60VG4S17).

The main goal for the next year is to operate eight of these structures for $>2000$ hr at $65$ MV/m in the NLCTA linac.

- FNAL and KEK will fabricate these structures.

Other Structures:
- Two more H60VG3’s ($a/\lambda = 0.18$) built by FNAL (start this week).
  - Cells fired to $\sim 1000$ °C to increase grain size.
- May retest H60VG3S18 with matched waveguide arms.
- CERN structure made with molybdenum irises (run recently completed).
- Single cell structures made with molybdenum or copper cells (2004).
CERN X-Band ‘Clamped’ Structure with Mo Irises

(CI, 30 cm, 5% c v_g, a/λ = .175, 90 MW Input for 65 MV/m Average)
Breakdown rates

1/Slopes:
100 ns: 6.1
50 ns: 10.6

S. Döebert
C30vg4-Mo Breakdown Locations
(no apparent change in phase advance)

Early 100 ns run

Last 100 ns run

Position of Breakdown (ns)

Phase of Reflected RF (degrees)
Pulse length dependence

S. Döebert
Making Steady Process Toward an ‘NLC/GLC – Ready’ Structure:

- Developing fully featured structures:
  - Achieved acceptable breakdown rates at 60 MV/m and are within a factor of three at 65 MV/m.
  - Adopted a lower $a/\lambda$ design to improve efficiency and performance at the cost of somewhat larger wakefields.
  - See no difference in performance with slotted cells.
  - Find that each structure has its own breakdown and processing ‘signature’, although there is some performance correlation with manufacturer.
  - Identified problems during construction and installation, but no clear connection to performance.
  - Nearly finished designing HOM ports, to be added to later structures for ASSET measurement of long-range wakefields.

- Will operate 8, 60 cm structures at NLCTA to improve performance statistics and demonstrate larger-scale accelerator operation (satisfy R1 and R2 requirements in the process).