Fabrication Techniques for the X-band Accelerator Structures

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WORKSHOP ON X-BAND RF TECHNOLOGY FOR FELs
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1. Introduction
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   • Microwave tuning and characterization
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1. Introduction

• Brief history
• Achievements
Achievements of X-Band Structures R&D at SLAC

- Motivation:
  Main Linac for the Future Linear Colliders (NLC, GLC and CLIC)

- Brief History:
  1. 1998 – 2004 X-Band accelerator structures R&D for the NLC/GLC in collaboration with KEK, FNAL and LLNL.
     Designed, fabricated and tested 50 X-Band accelerator structure sections. (Among them, 8 were made with KEK collaboration and 12 were fabricated by FNAL).
  2. 2007 – Present X-Band accelerator structures R&D for the CLIC main linac in collaboration with CERN and KEK.
     Participated the design, fabrication and testing of more than 10 X-Band accelerator structure sections.
Contribution to the Accelerator Technology through NLC/GLC X-Band Structures R&D

• Theoretical analysis for full understanding of HOM suppression in RF accelerator structures.
• Damped and Detuned Structures can be applied to any low emittance, high beam loading accelerators.
• Simulation methods for beam-structure interaction: structure wakefield, emittance growth and analysis of structure alignment and dimension tolerances.
• Optimization of accelerator parameters for highest RF efficiency and dimension determination with sub-micron precision.
• Manifold damping gives structure position monitor with micron transverse sensitivity and frequency multiplexed longitudinal resolution of the order of several cells.
• Fabrication technologies for normal conducting accelerator structures such as precision machining, diffusion bonding and long structure alignment.
• Extensive studies for high gradient RF operation to meet the NLC requirement rate at 65 MV/m: new types of couplers, Procedure for structure treatments.
NLC Prototype Structures Can Stably Operate at 65 MV/m to Meet the Required RF Breakdown Rate.
Comparison of the measurement for a pair of dipole Interleaved 60 cm Damped Detuned X-Band Structures with error bars (red) and calculated wakefield (black) – Data from early 2005.
CLIC Prototype Structures Can Stably Operate at 100 MV/m to Meet the Required RF Breakdown Rate

RF BKD Rate Gradient Dependence for 230ns Pulse at Different Conditioning Time

After 250hrs RF Condition

After 500hrs RF Condition

After 900hrs RF Condition

RF BKD Rate Pulse Width Dependence at Different Conditioning Time

G=108MV/m

G=110MV/m

This performance maybe good enough for 100MV/m structure for a warm collider, however, it does not yet contain all necessary features such as wake field damping. Future traveling wave structure designs will also have better efficiencies.
2. Basics of X-Band Accelerator Structures

- What the X-Band structures look like?
- How to make the accelerator cavities?
Damped Detuned Structures for the NLC/GLC

DDS1 (Round Damped Detuned) \(2\pi/3\) Mode TW Structure

Single diamond turning discs without tuning; Micron level cell-to-cell alignment.
High Gradient Test Structures

One of four T-type Structures -- T53VG3, 60-Cell $2\pi/3$ Mode TW.

SW20PIL
15-Cell $\pi$ Mode SW

One of more than 10 High Phase Advance $5\pi/6$ Mode TW Structures, H60VG3S18 with HOM Slots and Manifolds.

For the LLNL Campton Scattering Light Source.
Prototype Accelerator Structure for the NLC/GLC Main Linac

Cutoff view of a structure end

A 60 cm structure with most of final design features
Some of KEK/SLAC Made Accelerator Structures for Testing CLIC Main Linac Design

T18_VG2.4_DSC with SLAC Flanges

TD18_VG2.4_DISC with SLAC Flanges

T28_VG2.9 (T26) with SLAC Flanges

TD18_VG2.4_DISC with KEK Flanges
Some CERN made Structures Tested at SLAC

- T24_VG2.4_DISC
- C11vg5Q16 (HDX11)
- TD18_VG2.6_QUAD
Precision Fabrication for Accelerator Discs

Profile tolerance 1 μm and Surface finishing better than 50 nm
Super Precision Machining with Single Diamond Cutter – Tuning Not Needed

Single-disk RF-QC

Accelerating mode frequency

Measured Frequency
Integrated Phase Slip

RMS = 0.4 MHz

Single-Crystal Diamond Turning

RMS = 1.0 MHz

Polycrystalline Diamond Turning
Lathe with Twin Spindles and Twin Turrets

Profile tolerance 5 μm and Surface finishing 300 - 400 nm
Regular Precision Machining with Polycrystalline Diamond Cutter – Tuning Needed

Microwave QC of Fundamental Modes for H60VG4SL17A/B Regular Cups
Temperature and humidity corrected
Microwave QC of Dipole Modes for H60VG4SL17A/B Regular Cups  
Temperature and humidity corrected
3. Structure Fabrication Technology

- Mechanical QC and Microwave QC
- Chemical cleaning
- Accelerator parts joining (diffusion bonding, brazing and welding)
- Microwave tuning and characterization
- Vacuum baking
- Alignment
ZYGO Surface Flatness Measurement for Typical Cups of T18_VG2.4_DISC Structures

Both sides show less than 1 micron concaved
Stacking for Body Diffusion
Bonding of a CLIC Structure
Diffusion Bonding of T18_vg2.4_DISC

Pressure: 60 PSI (60 LB for this structure disks)
Holding for 1 hour at 1020º C
Brazing of QUAD with Water Flange

Au/Cu Alloy: 25/75
Brazing temperature: 1041-1045° C
First Assembly Brazing of T18_vg2.4_DISC

Body / Two Coupler Assemblies / Cooling/One Beam Pipe / Tuning Studs

Au/Cu Alloy: 35/65
Brazing temperature: 1021-1025° C
Final Brazing of T18_vg2.4_DISC

Au/Cu Alloy: 50/50
Brazing temperature: 979-983º C
Adding One Beam Pipe
Microwave Tuning and Characterization
Vacuum Baking of Two Structures

650° C
10 days
Alignment Measurement Using CMM Machine
4. Fabrication Technology and Locations
1. National Laboratories for the X-Band Structures R&D:
   - SLAC
   - KEK
   - LLNL

2. Private Vendors for the X-Band Structures R&D:
   - US
     Robertson Precision, Inc. (California)
     LeVezzi Precision, Inc. (Illinois)
   - Japan
     IHI
     Morikawa co.
   - Europe
     VDL Enabling Technologies Group (Netherland)
Manufacturability

- Case of Small Amount Production (less than few hundreds)
- Case of Mass Production (10k for future X-Band compact FEL or even 1.8 millions precisely machined parts for Linear Collider, which was studied extensively in late 1990s)

Design of Manufacturability (DFM) Studies with Huge Cost Reduction