ACCELERATOR STRUCTURE R&D FOR LINEAR COLLIDERS*

J.W. Wang#, C. Adolphsen, K.L.Bane, G.B. Bowden, D.L. Burke, H. Deruyter, J. Cornuelle, Z.D. Farkas, W.B. Fowkes, S. Hanna H.A. Hoag, J. Irwin, R.M. Jones, K.Ko, N.Kroll, Z.Li, G.A. Loew, R.J. Loewen, R.H. Miller, C.K. Ng, J.M. Paterson, C.Pearson, T.O. Raubenhemer, J. Rifkin, R.D. Ruth, S.G. Tantawi, K.A. Thompson, K.W. Vaillancourt, A.E. Vlieks, P.B. Wilson, SLAC, Stanford, CA
K. Asano, Y. Funahashi, Y. Higashi, T. Higo, N. Hitomi, T. Suzuki, K. Takata, T. Takatomi, N. Toge, Y. Watanabe, KEK, Tsukuba, JAPAN
J. Elmer, J. Klingmann, M. Mugge, K. Van Bibber, LLNL, Livermore, CA

Abstract

For more than ten years, we have been working on R&D for X-band accelerator structures for the JLC/NLC linear collider. Several types of Detuned (DS) and Damped Detuned Structures (DDS) have been successfully designed and fabricated. They have been experimentally tested at both low power and high power to characterize their mechanical and electrical properties. Recently we started developing a new type of damped detuned structure with optimized round-shaped cavities (RDDS). This paper discusses the special specifications, design methods, fabrication procedures, measurement technologies, and anticipated future improvements for all these structures.

1 REQUIREMENTS OF STRUCTURES FOR LINEAR COLLIDERS

The critical requirements for the next generation of linear colliders are high luminosity and high RF efficiency.[1] We need to design the accelerator structures to control short and long range transverse wakefields to ensure the preservation of low emittance for multi-bunch beams. The suppression of the deflecting modes is achieved through precision alignment of cells and by detuning and damping higher order modes. We have to design and fabricate the accelerator structures for reliable high-gradient operation in order to optimize the linac length and cost. The increase in RF breakdown threshold and suppression of field emission current is achieved through optimized cell design, advanced machining, processing and handling techniques.

2 STRUCTURE TYPES – A BRIEF HISTORY

Starting in 1988, we studied various damped structures, which can heavily damp (external Q_e<10) higher dipole modes. We made computer simulations, microwave tests and theoretical analyses on the disk-loaded waveguide structures with radial slots in the disks and/or radial rectangular waveguides in the cavity walls, azimuthal waveguide structures.[2] Due to the fabrication complexity of those heavily damped structures (HDS), in 1990 we began to explore the detuned structure (DS) in which the frequencies of HOMs differ sufficiently from cell to cell that the wakefields decohere rapidly. The experimental measurements of beam-excited wakefields in a 50-cavity detuned structure in 1991[3] encouraged us to design the first 1.8m full length detuned section (DS1). Its cell radii, iris radii and disk thicknesses were varied smoothly (in a Gaussian distribution). This section was constructed and an accurate wakefield measurement (ASSET) was done in 1994.[4] The wake recohered after a few meters because the mode distribution was discrete. The suppression of the wake reappearance can be obtained by providing a moderate damping via vacuum manifolds. As a joint effort, the first damped detuned section (DDS1) was completed in 1996.[5] Figure 1 shows the calculated wakefields for the above two types of structures. After DDS1, two more DDS sections were built by an improved fabrication method with better pumping and HOM matching. In order to increase the RF efficiency, we are developing a new type of damped detuned structure with optimized round-shaped cavities (RDDS), which will lead to the final design for the JLC/NLC main linac structure. In summary, the accelerator parameters and test data for all major sections are listed in Table 1.

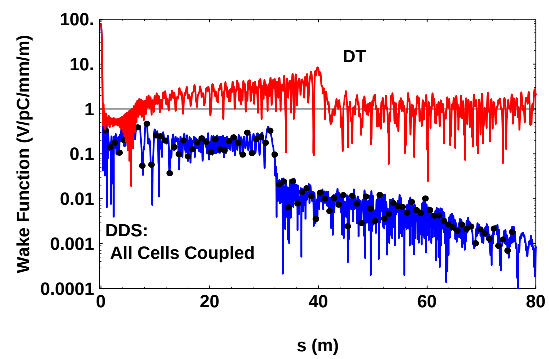

Figure 1: Wakefield Profiles for Detuned Structure and Damped Detuned Structure

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Email: jywap@slac.stanford.edu

Table 1. Characteristics of Structures

Structures Name	75 cm	DS1	DS2	INJE1&2	DDS1	DDS2	DDS3	RDDS1
Old Names		MARK-1 DT1	MARK-2 DT2		DDT1			DDS5
Structure Type	Constant Impedance	Detuned	Detuned	Detuned	Damped Detuned	Damped Detuned	Damped Detuned	Damped Detuned
Length (m)	0.75	1.8	1.8	0.93	1.8	1.8	1.8	1.8
Number of Cells	86	206	206	106	206	206	206	206
Cell Shape	DLWG	DLWG	DLWG	DLWG	DLWG	DLWG	DLWG	Optimize d
Phase Advance Per Cell	$2\pi/3$	$2\pi/3$	$2\pi/3$	$2\pi/3$	$2\pi/3$	$2\pi/3$	$2\pi/3$	$2\pi/3$
HOM Manifold Shape/ Size(mm)	N/A	N/A	N/A	N/A	Rect. / 5x11.0 - 5x9.8	Rect. / 5x11.0 - 5x10.0	Rect. / 5x11.0 - 5x10.0	Circular / Diameter 9.6 – 7.3
Iris Diameter, 2a (mm)	8.56	11.43 - 7.86	11.43 - 7.86	11.43 - 7.86	11.43 - 7.86	11.43 - 7.86	11.43 - 7.86	11.21 – 7.77
Cell Diameter, 2b (mm)	21.58	22.87 - 21.39	22.87 - 21.39	22.87 - 21.39	22.87 - 21.39	22.87 - 21.39	22.87 - 21.39	24.04 – 22.16
$\langle a \rangle / \lambda$	0.163	0.180	0.180	0.180	0.180	0.180	0.183	0.179
Disk Thickness, Web/Tip (mm)	1.46	1.0 – 2.0	1.0 – 2.0	1.0 – 2.0	1.0 – 2.0	1.0 – 2.0	1.0 – 2.0	0.8/1.2 – 1.4/2.2
Filling time, T_f (ns)	52	100	100	52	100	100	95	104
Shunt Impedance r (MΩ/m)	88.0	67.5 – 88.0	67.5 – 88.0	67.5 – 88.0	65.7 – 84.2	65.7 – 84.2	65.7 – 84.2	77.1 – 101.8
Group Velocity, v_g / c	0.048	0.118 – 0.03	0.118 – 0.03	0.118 – 0.03	0.118 – 0.03	0.118 – 0.03	0.118 – 0.03	0.111 – 0.029
<Q>, Fundamen-tal Mode	~7000	~7030	~7030	~7030	~6780	~6780	~6800	~7810
<Q>, Lowest Dipole Band	~6500	~6500	~6500	~6500	~1000	~1000	~1000	~1000
Lowest Dipole Band Detuning, $\Delta f_{1,tot} / \langle f_1 \rangle$	N/A	10.1%, dn/df_1 (4σ)	10.1%, dn/df_1 (4σ)	10.1%, dn/df_1 (4σ)	10.1%, dn/df_1 (4σ)	10.1%, dn/df_1 (4σ)	10.159% kdn/df (4.78σ)	11.25% kdn/df (4.75σ)
Detuning Stan-dard Deviation, $\sigma_{f1} / \langle f_1 \rangle$	N/A	2.5 %	2.5 %	2.5 %	2.5 %	2.5 %	2.125%	2.368%
Attenuation, τ	0.267	0.505	0.505	0.255	0.533	0.533	0.508	0.483
E_p / E_a	2.3	3.06 – 2.10	3.06 – 2.10	3.06 – 2.10	3.06 – 2.10	3.06 – 2.10	3.06 – 2.10	3.00 – 2.10
Machining Method	Single Diamond	Regular	Single Diamond	Regular	Single Diamond	Single Diamond	Single Diamond	Single Diamond
Cell Joint Method	Nested Brazing	Stacks, Nested Brazing	Stacks, Nested Brazing	Stacks, Nested Brazing	Stacks, Diffusion Bonding	Stacks, Diffusion Bonding	Section, Diffusion Bonding	Section, Diffusion Bonding
Completion Time	6/1993	1/1994	11/1996	4/1996	7/1996	4/1997	10/1998	Autumn, 1999
Wakefield Measurement		ASSET 3/1994			ASSET 8/1996		ASSET 11/1998	
Power Needed for $\langle E_a \rangle$=50 MV/m	52.2	88.8	88.8	69.7	89.8	89.8	94.5	82
Operated E-field $\langle E_a \rangle_{max}$ (MV/m)	79	68	50	70	68	50	N/A	N/A

3 DESIGN METHOD

Through a decade of working on various structures we have developed successful design procedures to:[6][7][8]

- Choose the basic accelerator parameters such as length, filling time and attenuation factor based on the rf source and system.
- Choose iris size and dipole detuning distribution based on beam emittance and wakefield suppression requirements.
- Optimize cavity shape for best shunt impedance, *r/Q* and low peak surface field.
- Calculate wakefield from a equivalent circuit and spectral function analysis using optimised HOM coupling slots and manifold size.
- Create cell dimension tables using high accuracy 3D modelling for typical cells.
- Design and simulate special portions of the structure like the input and output fundamental couplers and HOM couplers.
- Fabricate, mechanical QC and microwave QC typical cells and special coupler parts for final corrections of their essential geometries.
- Perform mechanical design to ensure electrical properties and manufacturability.

Figure 2: Disks for RDDS1 Structure

4 FABRICATION METHOD

A typical sequence follows. Disks and cells are rough-machined using regular lathes and milling machines with more than 50 μm of extra copper left on all surfaces except coupling slots and manifolds. Final machining is done using single crystal diamond turning with sub-micron accuracies and 50 nm surface finishs. After careful cleaning with ozonized pure water rinsing, the cells are stacked in a V-block of a special stacking fixture. The whole stack is pre-bonded at 180^{O} C and final diffusion bonded at 890^{O} C.[9] Final assembly including WR90 waveguides for fundamental mode and WR62 waveguides for HOM, flanges, and vacuum ports are brazed in a hydrogen furnace at 1020^{o}C. The brazed section is installed in a strongback for final mechanical measurement and straightening in CMM machine.

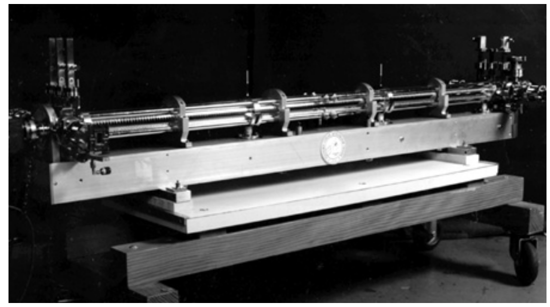

Figure 2: DDS3 Structure

5 CHARACTERIZATION TECHNIQUES

We have built several set-ups and facilities to evaluate the microwave properties and check the performance of various accelerator parts and sections.

- During fabrication we use two single cell microwave QC set-ups (one for the accelerating mode and one for the dipole modes) and a stack microwave QC set-up.
- At final assembly, a semi-automated bead pulling system gives a measurement of the field phase and amplitude along the accelerator sections.
- ASSET is used for wakefield and beam-based alignment experiments.
- NLC Test Accelerator and ASTA are used for high power tests and beam acceleration experiments. [10]

6 FUTURE R&D PLANS

We are making a schedule to design and fabricate more sections in order to finalize the JLC/NLC accelerator structure design and to study the manufacturability for low cost mass production of about ten thousand accelerator sections. The following are our main tasks:

- Design of more compact fundamental couplers with reduced and symmetric fields.
- Damping of all dipole modes in the output end.
- Wakefield simulation and analysis for high order deflecting modes.
- More detailed tolerance studies and application of the feedforward/feedback technique for large acceptance of mass production parts.
- Surface cleanliness techniques and high gradient considerations.
- More diffusion bonding studies to understand dimensional stability during high temperature processing.
- Automation for cell stacking and assembly lines.

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