Review of SRF Cavities for ILC, XFEL, and ERL Applications

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Outline

In a view point of cavity performance related to beam dynamics.

1. Superconducting multi-cell cavities
   Fabrication, Tuning, Surface treatment, Testing
   Gradient performance

2. Technology for High Quality Beam
   HOM damper, Piezo tuner, Digital feedback control
   Coupler kick issue
   Alignment tolerance for long ILC linac
   HOM-BPM for alignment confirmation
Superconducting Multi-cell Cavity
Superconducting Multicell Cavities

1.3GHz TESLA cavity for XFEL, project-X and ILC

KEK ERL 9-cell cavity (1.3GHz) with beam pipe HOM absorber.

JLAB 12GeV upgrade
7-cell cavity of 1.5GHz
with HOM coupler

JLAB 100mA cryomodule
5-cell cavity of 1.5GHz
with waveguide HOM coupler

BNL ERL 5-cell 703MHz cavity

Cornell 2 cell cavity
for ERL Injector

KEK 2 cell cavity
for ERL Injector

variations
Frequency
Cell shape
HOM damping scheme
Input coupler
TESLA Cavity Fabrication

Short End group

End cell : short side
HOM1
input port
beam pipe

Dumbell x8

Long End group

beam pipe
pickup port
HOM2
End cell : long side

56 parts: Nb (RRR>300)= 46, Nb-Ti = 10, by press, burring, machining
75 Electron Beam Welding (EBW) place
Cavity Frequency & Straightness Tuning

π-mode frequency, field flatness and eccentricity tuning done by 6 jaws.

Push and Pull freq. tuning by 6 jaws, keeping cavity straightness.

DESY-FNAL-KEK Pre-tuning machine

Each cell eccentricity measurement
Electro-Chemical Polish
Use Sulfuric acid + HF mixture
Apply voltage between center Al electrode and Nb cavity
Optimize parameter for smooth surface without sulfur residual particle
Voltage and temperature are key parameter
Successive rinsing is another key technology

KEK STF EP as an example
Cavity Testing

JLAB: AES cavity results March 09 – March 10

Vertical Dewar test for gradient performance check. (KEK-STF as an example)

6 cavities (9-cell) of AES second production run 4 out of 6 exceed ILC spec up to 2nd-pass proc.

Successive 4 cavities are beyond 35MV/m
Gradient Performance of TESLA cavities

Electropolished 9-cell cavities

1st pass Yield

2nd pass Yield

Qualified vendor recent 32 cavities (27 cavities for 2nd pass.) in the statics

>35MV/m : 48% Yield

ILC-GDE
Cavity Database Team
Mar.28, 2010 Beijing meeting
Diagnostics Instruments for quench location identification

T-map & Xray-map, 2nd sound sensor together with pass-band mode measurement, location of quench is identified. Inspection camera visualize what’s happen inside.
What’s inside at quench location
for example

Pit; appeared after bulk EP,
limit to 16MV/m
- local grinding & EP
- 27MV/m
- additional EP
- 38MV/m

Bump at heat affecting zone,
limit to 20MV/m
- local grinding & EP
- 30MV/m
- additional HPR and bake
- 34MV/m

MHI08 2-cell equator, t=172 degree

AES003 4-cell equator, t=306 degree

200um x 600um, depth 115um

600um x 600um, height ~50? um
Technology for High Quality Beam
**HOM Damper**

**TESLA Cavity HOM Coupler**

- Large area pickup for more gap distance

**ERL applications**

- Flange to Cavity
- RF Absorbing Tiles
- Shielded Bellow
- Flange to Cavity
- Cooling Channel (GHe)

**Cornell beam pipe HOM absorber of ERL 2 cell injector cavity**

**mirror symmetry orientation, asymmetric shape of half end-cell**

**XFEL, project-X, ILC**

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HOM Damper Performance

TESLA cavity HOM Q_{ext}

Comparison with the Q_{ext} on the STF and TESLA cavity

- Q_{ext} TESLA-Z84
- Q_{ext} STF#3

High impedance mode

1 \times 10^5

TE_{111} mode: 1 to 18
TM_{110} mode: 21 to 38
TM_{011} mode: 41 to 49

KEK 9cell ERL cavity HOM Impedance

\( R/Q \cdot f [\Omega/cm^2/\text{GHz}] \)

Frequency [GHz]

HOM impedance by Beam pipe HOM absorber damping is two-order smaller than TESLA HOM coupler damping.
Frequency Tuners for Pulsed RF operation

<table>
<thead>
<tr>
<th>Kept</th>
<th>Saclay Lever-arm Tuner</th>
<th>INFN Blade Tuner</th>
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</thead>
<tbody>
<tr>
<td>KeK</td>
<td>Slide-jack Tuner</td>
<td></td>
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</tbody>
</table>

Piezo actuator installed mechanical tuner for frequency control

GDE S1-Global project is a test stand of these three kind tuner comparison. (actually 4 kind of tuners)
At pulse flat-top, detuning still continues, the phase is still shifted. To fit into digital feedback allowable range, piezo is activated by half-sine wave pulse.
Precise digital feedback control with feed forward

cavity pickup -> Down converter -> AD -> FPGA -> DA -> IQ modulator

By vector sum control

STF feedback boards and its performance as an example

STF FPGA Board

STF DSP Board for online diagnostics

RF amplitude of each cavity

RF phase of each cavity

vector sum amplitude

vector sum phase

0.02% 1 hour stability

0.02 degree 1 hour stability

S. Michizono
When QL of each cavity are variated, voltage at flat-top will variate, and weak cavity tend to reach its quench level.
Even if QL are adjusted for nominal beam loading by tuning of input coupler coupling etc, the voltage will variate in case of beam off.
Asymmetric arrangement of couplers introduced discussion on emittance growth in ILC main Linac, in 2006-2008.

RF field asymmetry by main coupler and HOM antenna is another issue for beam kick.
Coupler kick effect in ILC Linac

reduced wake-field in new design, but it increase RF kicks.

(Dirk Krucker, Chicago GDE-meeting, Nov. 2008)

For 20.0 nm
(input emittance)

New design
- 25.1 nm (no correction)
- 21.8 nm (dispersion corrected)

Old design
- 20.3 nm (no correction)
- 20.3 nm (dispersion corrected)
## Alignment Tolerance of ILC Linac

Assume following local misalignment only:

<table>
<thead>
<tr>
<th></th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad Offset (µm)</td>
<td>360</td>
<td>1080</td>
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<tr>
<td>Quad Roll (µrad)</td>
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<td>300</td>
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<tr>
<td>Cavity Offset (µm)</td>
<td>640</td>
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<tr>
<td>Cavity Pitch and Yaw (µrad)</td>
<td>300 (pitch)</td>
<td>900 (yaw)</td>
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<tr>
<td>BPM Offset (µm)</td>
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<td>BPM Roll (µrad)</td>
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<td>BPM resolution (µm)</td>
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<td>1</td>
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<tr>
<td>BPM scale error</td>
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</tr>
</tbody>
</table>

Cavity offset contribution to vertical emittance growth is 7%
Cavity tilt contribution is 1%

Simulation by code SLEPT, using DMS (Dispersion Matching Steering), 15GeV -> 250GeV

(K. Kubo, Beijing GDE-meeting, Mar.2010)
HOM-BPM for Alignment Confirmation

HOM pickup RF signal and BPMs are recorded for many beam passage with orbit scan.

K. Watanabe
Cavity offset in cryomodule by HOM-BPM

FLASH module 4, 5, 6: cavity offset measurement

Recorded HOM signal are analyzed to estimate HOM center and polarization axis. Cavity offsets are estimated by HOM center, relative to BPMs axis.

3 modules average offset:  
X = -0.21 +/- 1.23 mm  
Y = -0.51 +/- 0.78 mm
Summary

1. TESLA cavity is a major one among high performance cavities. Fabrication, treatment, tuning, and testing are reviewed. Its gradient performance is close to 35MV/m average.

2. Difference of XFEL, ILC application and ERL application are; HOM damper (antena or absorber), LFD compensation (Piezo compensation or not)

3. Following beam dynamics related issues are also reviewed; HOM damping, Piezo LFD compensation, Vector-sum digital feedback control for flat energy beam, Coupler kick issue, Alignment tolerance for long ILC linac, HOM-BPM method for alignment confirmation, Cavity alignment in the cryomodule need to be considered.
Thanks for attention.

The figures and pictures are borrowed from many collaborators and the following web-site: ILC-GDE, DESY, workshop presentations and conference papers.

I would like to appreciate to all of collaborators, paper authors and presenters.