Study on Fabrication of Superconducting RF 9-cell Cavity for ILC at KEK


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Abstract

We constructed a new facility for the fabrication of superconducting RF cavity at KEK from 2009 to 2011. In the facility, we have installed a deep-drawing machine, a half-cell trimming machine, an electron-beam welding machine, and a chemical etching room in one place. We started the study on the fabrication of 9-cell cavity for International Linear Collier (ILC) from 2009 using this facility. The study is focusing on the cost reduction with keeping high performance of cavity, and the goal is the establishment of mass-production procedure for ILC. This article reports the current status of the studies in CFF.

Contents

• Mass-production of cavities in ILC.
• Purpose of Cavity Fabrication Facility (CFF) at KEK.
• Fabrication of 9-cell cavity KEK-00 w/o HOM.
• Plan/Purpose of 9-cell cavities: KEK-01, KEK-02, KEK-03.
• Fabrication of 9-cell cavity KEK-01 w/ HOM at CFF.
• Mass-production study on cavity fabrication.
• High-Pressure Gas safety act in Japan.
• Simulation study on mass-production factory for ILC
• Summary
SCRF Industrialization required for ILC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>C.M. Energy</td>
<td>500 GeV</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$1.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Beam Rep. rate</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>0.73 ms</td>
</tr>
<tr>
<td>Average current</td>
<td>5.8 mA (in pulse)</td>
</tr>
<tr>
<td>Av. field gradient</td>
<td>31.5 MV/m +/-20%</td>
</tr>
<tr>
<td></td>
<td>$Q_0 = 1E10$</td>
</tr>
<tr>
<td># 9-cell cavity</td>
<td>16,024 (x 1.1)</td>
</tr>
<tr>
<td># cryomodule</td>
<td>1,855</td>
</tr>
<tr>
<td># Klystron</td>
<td>~400</td>
</tr>
</tbody>
</table>

High quality

16024 x 1.1 (Yield = 90%)
~ 17600 cavities of mass-production

ILC

Linac (11km) x 2
Progress in SCRF Cavity Gradient

Production yield: 94 % at > 28 MV/m,
Average gradient: 37.1 MV/m reached (2012)

Issues of mass-production:
High Quality Assurance (QA)
Cost Reduction
Construction of Cavity Fabrication Facility (CFF)

Map of KEK

All machines are in class-100,000 clean-rooms.

Construction finished in FY2011

Clean room 19m x 14m x 5m (Height)
Class-100,000 / ISO 8 (Specification)

Chemical treatment
Press machine
EBW

Surface inspection
Vertical lathe

Clean room floor layout of CFF
Main Equipments of Cavity Fabrication Facility

EBW room
Installation of EBW machine started from April 2011 and finished in July 2011.

Chemical Piloshing room
Located in on place: Very important for QA.

Measuring system for half-cell shape (Under developing)

Press machine (servo control)

Vertical lathe for half-cell trimming
Purpose of Cavity Fabrication Facility (CFF)

- High performance / high yield rate = Good QA
- Reduction of fabrication cost
- R&D of mass-production processes/fixtures

All necessary machines for cavity-fabrication are in one place: Efficient R&D

Cooperation with STF (Surface treatments / VT in Lab.)

Studies in CFF

Cooperation with vendors (industries)

Speed up the R&D to establish the standard recipe for mass-production

Open to other lab. / vendors

Target is realization of mass-production technology for 17,000 cavities (ILC).
## Plan/Purpose of cavities in CFF/KEK

<table>
<thead>
<tr>
<th>Cavity</th>
<th>FY2012</th>
<th>FY2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEK00</td>
<td>VT</td>
<td>Jacket weld training</td>
</tr>
<tr>
<td>KEK01</td>
<td>fabrication</td>
<td>VT</td>
</tr>
<tr>
<td>KEK02</td>
<td></td>
<td>fabrication</td>
</tr>
<tr>
<td>KEK03</td>
<td></td>
<td>VF</td>
</tr>
</tbody>
</table>

- **KEK00**: Fabrication and jacket weld training.
- **KEK01**: Fabrication.
- **KEK02**: Fabrication.
- **KEK03**: Preparation for complying with high pressure gas code.
- **STF/KEK**: Cryomodule-1 (8 cavities), CM2a (4 cavities), CM2b (4 cavities).
- **KEK-03 cavity**: Fabrication in CFF/KEK.
Fabrication of KEK-00 Cavity (w/o HOM)

- Beam-pipe (Nb)
- End-Plate (Ti) + Nb ring
- End-cells (Nb)
- End-Plate (Ti) + Nb ring
- Flanges (Nb-Ti alloy)
- Beam-pipe (Nb)
- Input-port pipe (Nb)
- Dumb-bell (Nb)
- Center cells (Nb) / EBW at job shop
Repair of 9-cell cavity KEK-00 in CFF/KEK

Failure in EBW of Cell#1 in job-shop

Contamination in welding joint?

EBW bead

Re-EBW

EBW with 120kV, 20mA, and 5 mm/s.

Small Nb piece was made and it was set into the hole.

Bulk EP (100 um), Degreasing (50 °C, 30 min.), HPR (1.5 h), Annealing(4 h, 750 °C), and final EP (20 um) were performed in STF/KEK.

EBW bead

EBW bead

EBW bead
Vertical Test of 9-cell cavity w/o HOM (KEK-00) at STF/KEK

KEK No.00 2nd. Vertical Test 04/05/2012
After Input Cable Exchange, Re-measurement

Eacc = 29 MV/m
Q0 = 9.5 E9

Quench at cell#2.

Final; Quench/Selfpulse
Eacc,max=29.0MV/m
Qo=9.51*10^9
Po=93W
Qt=3.88*10^11
He pres.=1.45kPa
He Temp.=1.75K

Initial; Quench/Selfpulse
Eacc,max=29.2MV/m
Qo=9.19*10^9
Po=98W
Qt=4.05*10^11
He pres.=1.76kPa
He Temp.=1.80K

Cell#1 (repaired cell) reached to 42.7 MV/m in the 6pi/9 mode.
Fabrication of KEK-01 Cavity with HOM

- End-Plate (Ti) + Nb ring
- Flanges (Nb-Ti alloy)
- Beam-pipe (Nb)
- HOM coupler (Nb)
- End-cells (Nb)
- End-Plate (Ti) + Nb ring
- Beam-pipe (Nb)
- Input-port pipe (Nb)
- Center cells (Nb) / EBW with horizontal beam in CFF
- Dumb-bells (Nb)
Configuration choice of cavity attitude and gun position

- Direction of electron beam is vertical.
- Setting cavity in horizontal way is rather complicated (KEK-00).
- Direction of gravity.
- Setting cavity in vertical way is simple (KEK-01).
- Stacking dumbbells is easy in the vertical configuration of cavity.
- Better for mass-production.
Set-up of Nb-plate test for side-gun configuration

1. Fixture for Nb plates
2. Direction of electron beam
3. Alignment target
4. Gun on the side-wall
Search for good EBW parameter was done by changing the welding beam-voltage, beam-current, focus-current, working-piece distance from gun, working-piece moving speed, Nb-plate thickness, and the gun and working-piece configuration. In particular, the gun and working-piece configuration affects the results of welding seam.

For more details of studies on EBW parameters, see following presentation.
ID: 3364 - WEPWO015 / 15th May (Wed.), poster session by T. Kubo (KEK): Title: Electron Beam Welding Parameters for High Gradient Superconducting Cavity
Voltage = 120 kV, Moving speed = 5 mm/sec., Work-piece distance (W.D.) = 500 mm, Nb-plate thickness = 2.0 mm

Region for good welding. (Upper focus)

Region for good welding. (Lower focus)

Solid lines for good welding condition with margin.

Focus lens current on Nb-plate (mA)

Welding beam current IB (mA)
EBW at equator for stacked dumbbells (KEK-01)

Rotation

EBW test by a dummy Nb-pipe

EBW of 2-dumbbell

EBW of 4-dumbbell

Direction of electron beam

Direction of electron beam

Parameter for equator

120 kV, 5 mm/s

Overlap

Rotation angle (degree)

Beam current (mA)

Smooth inner surface of welding seam was achieved.

Smooth inner surface of welding seam was achieved.
EBW of dumbbell at iris (KEK-01)

EBW test by a dummy Nb-pipe

Setup of dumbbell EBW for side-gun

Parameter for iris (Downward welding)

Rotation angle (degree)

Beam current (mA)

Overlap

120 kV, 5 mm/s

Picture during EBW (KEK-01)
Fabrication of HOM cup by deep-drawing for KEK-01

End-group shape is complicated and then there is a possibility of cost-reduction in fabrication.


Nb sheet thickness: 2.8 mm

Achieved 70 mm by single forming

Collaboration with industry: Shinohara Press Service Co. Ltd.

HOM cup (φ48 × 64)

Trial to fabricate the freq. tuning tab by press-forming. (Under study)
Fabrication of HOM antenna by water-jet cutting and press-forming for KEK-01

Conventional method: Machining
New method: Water-jet cutting + Press-forming

Water-jet cutting in a job shop

Press-forming

Result of low power test is OK. (Master thesis by F. Yasuda, Jan. 2013, the university of Tokyo, JAPAN)
Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW processes.

Multiple dumbbells are loaded inside the EBW chamber at once and the EBW of dumbbells will be done continuously after pumping down.
Design of 9-cell cavity fixture for EBW machine

Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW process. The time is reduced if multiple-seams are welded in one pumping cycle.
One must fabricate cavities complying with **Japanese High-Pressure Gas (J-HPG) safety act** if we use the cavities in accelerators.

For cavities by venders,
Manufacturer: KEK
Applicant: venders

For cavity KEK-03 in CFF,
Manufacturer: KEK
Applicant: KEK/CFF

In case of ILC in Japan, a significant fraction of cavities might be imported from foreign vendors. KEK/CFF can guide them for the procedures of J-HPG safety act.
Estimation of cavity production plant

Simulation study assuming CFF housing area (53m x 30m)

Assuming Nb plates for cell, fabricated end-group parts are input, 200 working days/year, 2 shifts/day with 30 people times 2 shifts

Max. production rate will be ~530 cavities/year, ~2650 cavities for 5 years.

Assuming that final treatment and vertical test will be done in other place.
Summary

• In order to realize the mass-production technology of ILC for ~17,600 cavities, we constructed Cavity Fabrication Facility (CFF) at KEK and the installation of all equipment finished in July 2011.

• The maximum acceleration gradient of cavity KEK-00 w/o HOM which was fabricated in job-shop + CFF reached 29 MV/m.

• Fabrication of KEK-01 with HOM is ongoing in CFF.

• We are planning to fabricate 2 more cavities (KEK-02, 03) in CFF. Cavity KEK-03 will be fabricated complying with Japanese High Pressure Gas (HPG) safety act and will be installed in CM in STF/KEK.

• Mass-production studies are ongoing in parallel. Fabrication methods of HOM-cup and HOM-antenna are improved for KEK-01. 6-cavity fixture and multi-dumbbell loader for EBW machine are designed and some proto-types are made.

• Plant simulation study on mass-production of cavities is done in collaboration with industry.