SC Cavities

W. Singer

• Material,
• Fabrication
• Preparation
9-cell Niobium Cavity of TESLA Shape

Operating temperature 2K

Niobium  RRR 300  Deep drawn from sheets  Welding with electron beam

9 cells: compromise between filling factor and trapped modes

1.3 GHz

1038mm

1258mm
Material: High purity Nb, ca. 30 t. required

Niobium company qualifying Nb sheet vendors:

- Two qualified Nb sheet suppliers: Wah Chang (USA), Tokyo Denkai (Japan).
- Several companies anticipate to be qualified. Most of companies installed or overhauled the EB melting facilities
  - Plansee (Austria): Sheet fabrication from Nb300 of Fa. HERAEUS; ca. 20 sheets anticipating to be delivered middle of 2005
  - CBMM (Brazil): new melting facility (up to now RRR<300)
  - Cabot (USA): upgrade of melted facility, delivered 30 Nb sheets from a new ingot RRR>300
  - NINGXIA (China): Nb ingots with low Ta content, RRR>300, first sheets will be delivered end of June

W. Singer, MAC Meeting, Mai 31th, 2005
Seamless end tubes, main coupler tubes, RRR300:

- At the moment only one vendor (Heraeus, seamless tubes)
- Option: tubes welded from Nb sheets. Test series of tubes produced. Tubes will be tested in frame of single cell R&D program

Welded Nb end tubes (Fa. ZANON)

- NINGXIA (China), anticipate delivering seamless tubes for tests (end of June)

W. Singer, MAC Meeting, Mai 31\textsuperscript{th}, 2005
Cavity annealing parameters.
Are the TTF cavity annealing parameters 800°C, 2h correct? (In conflict with SNS parameters 600°C, 10 h)
Main question: Yield Strength after annealing (cavity stiffness), hydrogen degassing.

<table>
<thead>
<tr>
<th>Annealing</th>
<th>Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 10hr 2nd</td>
<td>69.68</td>
</tr>
<tr>
<td>600 10hr 1st</td>
<td>76.68</td>
</tr>
<tr>
<td>700 5hr</td>
<td>68.97</td>
</tr>
<tr>
<td>800 1hr</td>
<td>68.98</td>
</tr>
<tr>
<td>800 2hr</td>
<td>68.80</td>
</tr>
<tr>
<td>800 5hr</td>
<td>68.07</td>
</tr>
<tr>
<td>Control</td>
<td>71.19</td>
</tr>
</tbody>
</table>

Practically no change of Yield Strength and Grain Size after annealing at 800°C

FNAL and JLAB Grain Size Study Comparisons

W. Singer, MAC Meeting, Mai 31th, 2005
Small change of Yield Strength even after annealing at 850°C (DESY)

Hydrogen partial pressure versus annealing temperature (FNAL)

Preliminary conclusion: no heavy reasons to change the TTF cavity annealing parameters (800°C, 2h)

W. Singer, MAC Meeting, Mai 31th, 2005
Search for cluster in Nb sheets. Eddy current or SQUID scanner.

DESY eddy current scanning apparatus. More than 1000 Nb sheets for TTF scanned and sorted out.

Example of the Nb sheet eddy current scanning test. The spot was identified as an inclusion of foreign material. Cu and Fe signal has been observed in the SURFA spectrum in the spot area.

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Development of SQUID based scanning system for testing of niobium sheets

An excitation coil produces eddy currents in the sample, whose magnetic field is detected by the SQUID.

Prototype of SQUID based scanning system for niobium sheets (in work)

After finishing of SQUID development a decision should be taken what scanning system is more reasonable for XFEL. SQUID system seems to be more sensitive but more complicate

W. Singer, MAC Meeting, Mai 31th, 2005
Rework of the specifications for high purity niobium

Technical Specification for Niobium Applied for the Fabrication of 1.3 GHz Superconducting Cavities RRR 300. W. Singer, D. Proch

<table>
<thead>
<tr>
<th>Concentration of impurities in ppm (weight)</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>≤ 500</td>
</tr>
<tr>
<td>W</td>
<td>≤ 70</td>
</tr>
<tr>
<td>Ti</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Fe</td>
<td>≤ 30</td>
</tr>
<tr>
<td>Mo</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Ni</td>
<td>≤ 30</td>
</tr>
</tbody>
</table>

Could be the Ta content increased? Possibly material cost reduction, new vendors

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Influence of tantalum content on cavity performance
In collaboration with JLab

P. Kneisel: Single cell cavities produced from three CBMM ingots with different Ta content (150-1300 ppm).

<table>
<thead>
<tr>
<th>Material #</th>
<th>Sheet #</th>
<th>Ta [wt. ppm]</th>
<th>Average Eacc, MV/m</th>
<th>Post Pur.+100 µm BCP Eacc, MV/m</th>
<th>Baking Eacc, MV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1164_12_12</td>
<td></td>
<td>1300</td>
<td>18.1</td>
<td>29</td>
<td>29.6</td>
</tr>
<tr>
<td>1164_11_14</td>
<td></td>
<td>1300</td>
<td>22.2</td>
<td>24.8</td>
<td>27.2</td>
</tr>
<tr>
<td>1161_31_34</td>
<td>~150</td>
<td>1161_32_33</td>
<td>~150</td>
<td>21.9</td>
<td>27.8</td>
</tr>
<tr>
<td></td>
<td>~150</td>
<td>1162_33_34</td>
<td>~600</td>
<td>23.2</td>
<td>27.3</td>
</tr>
<tr>
<td></td>
<td>~600</td>
<td>1162_33_35</td>
<td>~600</td>
<td>23.1</td>
<td>31.5</td>
</tr>
<tr>
<td></td>
<td>~600</td>
<td></td>
<td></td>
<td>Not tested yet</td>
<td>Not tested yet</td>
</tr>
</tbody>
</table>

Treatment: EP + baking is desirable

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Thermal conductivity

Preliminary results:

Ta influence on cavity performance within 100-1300 ppm is not significant in order to reach moderate Eacc.

For high gradient 30-35 MV/m it plays a role
Fabrication: ca. 1000 cavities required

Current fabrication of 30 TTF cavities at ZANON - good test bed for XFEL

Fabrication procedure

- fabrication of dumb bells and end groups (half cells: without recess)
- assembling of all parts on special tool
- tacking
- disassembling from tool
- completing

Standard procedure has more steps (welding of dumb-bell after dumb-bell)

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Recently verified that Eacc of 30 MV/m can be reached in the welding areas.

No limitation in the welding areas.

Fabrication procedure of ZANON could be a prototyping procedure for XFEL cavity fabrication.

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Application of EDMS for cavity fabrication. Aim: - paperless documentation, up to date information, tracking the trends.

EDMS - Engineering Data Management System

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Application of EDMS for cavity fabrication

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Involvement of ZANON

DESY

• produce the cavity part
• log in to EDMS. Open the Inbox.
• fill out the template of inspection sheet (protocol)
• submit the protocol to EDMS

Zanon

• check and release the protocol.
• message to Zanon (in EDMS).

DESY

• create the inspection sheet template (in EDMS).
• message to Zanon.

The procedure is tested on the level “cavity inspection sheet”

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New specification for fabrication of 1000 XFEL cavities (in work)

Specification for prototype cavity fabrication are available: What should be change for series production?

• New set of cavity drawings (possibly small change of design for cost reduction)

• Analysis of the sequences of part fabrication and completing and create a new specification from industry point of view (experts of former DORNIER involved)

• Create a new strategy for QC and QA and create a new specification for parts inspection (experts of Babcock Noel Nuclear involved)

• Check some requirements of the present spec.: e.g. < 8 hours between etching and welding (on single cell cavities)

• Reduce the number of steps “frequency measurements + trimming”

• Improve the half cells shape control (3 dimensional shape measurement)

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Aim:
Instead shape correction by trimming improve the shape accuracy

Optical 3D measurement of the deep drawn TTF half cell
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Single cell R&D program: fabrication and testing

1. Qualifying of new Nb suppliers
   • Cabot (USA)
   • GIREDMET (Russia)
   • Plansee (Austria)
   • Ningxia Orient Tantalum Industry Co. (China)

2. Rework the specification for fabrication of 9-cell cavity
   • Check the eight hours rule etc.

3. Rework the Nb specification:
   • Nb with high thermal conductivity (RRR 700-900)
   • Check the Ta content

4. Cavity from ingot with very large grain

First step: qualifying of DESY EB welding facility

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Qualifying of DESY EB welding facility. First cavity 1DE1.

Deep drawing (ZANON), machining, EB welding at DESY. EP (Henkel), 800°C annealing, HPR (hall NE). X-ray starts at 30.6 MV/m

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Cavity from ingot with very large grain

P. Kneisel; JLab (1,5 GHz single cells)

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Strain-stress curves of Nb sheet after annealing

Grain size versus annealing temperature

Specific behavior of the discs from large grain Nb ingot have to be understood:

- High elongation at break
- Grain boundaries
- Grain orientation

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**Steps of conventional sheet fabrication**

1. Roughing
2. Rectangular bar - 60 x 200 x length
3. Milling and sawing
4. Cleaning
5. Rolling to rough plate
6. Heating treatment
7. Rough plate
8. Rolling to intermediate size
9. Cleaning
10. Rolling to final thickness
11. Cleaning
12. Final heat treatment
13. Cutting to final size
14. Cleaning
15. Finishing
16. Testing procedure
17. Sheet
18. Disc

**Discs from large grain ingot**

- **Large grain ingot. Diameter 280-300mm**

**Possible advantages:**

- Seems to be cost effective
- Higher purity. RRR=600 in the ingot is achievable
- Simplified quality control (reduced number of measurements: grain size etc, possibly no scanning)

**Main question:** How cut discs cost effective keeping the thickness tolerances +/- 0,1 mm, producing smooth surface and keeping the high purity
Option for XFEL???

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Nb disc from ingot of Fa.

HERAEUS:

Half cell of TESLA shape deep drawn at Fa. ACCEL.

The half cell is leak tight. The steps on grain boundaries are pronounced.
Further activities on large grain cavities

- Fabrication and testing of single cell and (if successful) of 9 cell cavities
- More deep drawing experiments (use male and female tools)
- Continue joint efforts with EB melting companies in order to produce ingots with single crystal discs of sufficient dimensions for XFEL cavities
- Improve the discs cut procedure in order to prevent Nb pollution
- BCP and EP experiments, behavior of grain boundaries
- 3D measurement of the half cell shape
- EB welding experiments. Prove that no new grains grows in the EB welding area

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Treatment: $E_{acc}=30$ MV/m required for XFEL

Eacc versus RRR for TTF cavities

No RRR dependence for EP + baking treated cavities

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Post purification (annealing at ca. 1400°C with presence of titanium)

<table>
<thead>
<tr>
<th>Contra</th>
<th>Pro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softening of Nb (reducing of yield strength)</td>
<td>Increasing of RRR and thermal conductivity</td>
</tr>
<tr>
<td>Diffusion of Ti inside of Nb. The layer of ca. 100 µm should be removed after post purification</td>
<td>Elimination of purity degradation in welding area</td>
</tr>
<tr>
<td>Grain growth (2-3 mm grain size) leads possibly to additional heat losses in grain boundary areas</td>
<td></td>
</tr>
</tbody>
</table>

The post purification with Ti will not be applied for XFEL.
EP + baking: treatment for XFEL

<table>
<thead>
<tr>
<th>Main treatment of TTF</th>
<th>EP + baking: treatment for XFEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Degreasing + rinsing</td>
<td>1. Degreasing + rinsing</td>
</tr>
<tr>
<td>2. BCP inside 80 µm, BCP outside 20 µm</td>
<td>2. EP inside 50-150 µm, BCP outside 20 µm</td>
</tr>
<tr>
<td>3. 800°C annealing</td>
<td>3. 800°C annealing</td>
</tr>
<tr>
<td>4. Degreasing + rinsing</td>
<td>4. Tuning of field profile</td>
</tr>
<tr>
<td>5. Post purification at 1400°C with Ti</td>
<td>5. Degreasing + rinsing</td>
</tr>
<tr>
<td>6. BCP inside 80 µm, BCP outside 40 µm</td>
<td>6. EP inside 20-40 µm</td>
</tr>
<tr>
<td>7. Tuning of field profile</td>
<td>7. Baking 120°C, ca. 50 h</td>
</tr>
<tr>
<td>8. Degreasing + rinsing</td>
<td>8. 1st high pressure water rinsing</td>
</tr>
<tr>
<td>10. 1st high pressure rinsing</td>
<td>10. 2nd and 3rd high pressure water rinsing</td>
</tr>
<tr>
<td>11. Assembling of flanges + leak test</td>
<td>11. RF acceptance test</td>
</tr>
<tr>
<td>12. 2nd and 3rd high pressure rinsing</td>
<td></td>
</tr>
<tr>
<td>13. RF acceptance test</td>
<td></td>
</tr>
</tbody>
</table>

An industrial study for detailed costs estimation for EP + baking is in preparation
Summary:

1. Two qualified Nb vendors are available. More vendors could be qualified. No shortage in Nb supply for XFEL has to be expected.
2. Cavity fabrication procedure is mainly established. Two qualified cavity manufacturer are available. Fabrication of ca. 1000 cavities in 2-3 years seems to be realistic.
3. Electropolishing, 800°C annealing, baking, HPR will be the main treatment procedure for XFEL cavities.