News from structure production task force – T18_CERN

G. Riddone on behalf of the task force team

20.03.2009
Content

• Introduction and task force motivation

• T18_CERN: Fabrication history and results from CERN investigations

• Differences from other CERN/SLAC/KEK/Fermilab structures

• Actions for future structures

• Conclusions
Introduction to T18

- T18 structures: 5 manufactured
  - 4 KEK/SLAC (2 tested: 1 at SLAC and 1 at KEK)
  - 1 CERN (tested at SLAC)
- All T18 have the same RF design
- It is the first time that the test results of a CERN structure can be compared with those from the same structure made at KEK/SLAC
T18 high power test results

Breakdown distribution of
T18Disk_SLAC (red, last 500hrs),
210~230 ns, 110~120 MV/m
T18Disk_CERN (Blue, 40hrs).
180 ns, 45~49 MV/m

‘Hot’ cells 13 +15

C. Adolphsen, S. Doeber
Task force program

- Following the test results of the T18_CERN a “Task Force” has been set-up to understand the cause (isolated problem or general problem of CERN structures) and to define the actions for the future structures.

- Program
  - Review the fabrication and preparation of the T18_CERN
  - Cut and inspect the T18_CERN
  - Compare the T18 preparation other structures made at CERN, KEK, SLAC and Fermilab and identify the differences
  - Define actions for future structures


- Contributions from C. Achard, M. Aicheler, A. Cherif, J. Kovermann, M. Polini, A. Toerklep, ...

GR, BE/RF, 090321
CERN assembly cycle

QC

Cleaning (CERN procedure)

Vacuum brazing of disk stack including couplers (815 °C, Ag/Cu/Pd 68.4/26.5/5)

Vacuum brazing (790 °C, Ag/Cu 72/28) of cooling circuits

Machining of the couplers

Installation on cover plate/tank and conditioning

Packaging
<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.04.2000</td>
<td>Shipping of raw material (01.05.2000 order)</td>
<td>Different material although not Cu confirmed in written that used CERN material</td>
</tr>
<tr>
<td>19.05.2000</td>
<td>Fabrication - Kugler (New firm)</td>
<td>Fabrication NC (ID, OD) ➔ remachining needed</td>
</tr>
<tr>
<td>14.07.2000</td>
<td>Reception at CERN</td>
<td>3 brazing cycles (1 additional)</td>
</tr>
<tr>
<td>16.07.2000</td>
<td>Dimensional control</td>
<td>Mismatch output matching cell</td>
</tr>
<tr>
<td>18.08.2000</td>
<td>Reception at CERN</td>
<td>No special packaging</td>
</tr>
<tr>
<td>18.09.2000</td>
<td>Machining of couplers</td>
<td>T18_CERN followed the nominal CERN assembly cycle</td>
</tr>
<tr>
<td>29.09.2000</td>
<td>Brazing disks</td>
<td></td>
</tr>
<tr>
<td>02.10.2000</td>
<td>Brazing of the cooling plugs, T18_CERN</td>
<td></td>
</tr>
<tr>
<td>13.10.2000</td>
<td>Brazing cooling plugs</td>
<td></td>
</tr>
<tr>
<td>24.03.2000</td>
<td>Machining of couplers</td>
<td></td>
</tr>
<tr>
<td>25.09.2000</td>
<td>Fit check</td>
<td></td>
</tr>
<tr>
<td>08.10.2000</td>
<td>Brazing of cooling plugs, T18_CERN</td>
<td></td>
</tr>
<tr>
<td>28.10.2000</td>
<td>Fit check</td>
<td></td>
</tr>
<tr>
<td>19.11.2000</td>
<td>Brazing check</td>
<td></td>
</tr>
<tr>
<td>29.11.2000</td>
<td>Shipping to SLAC</td>
<td></td>
</tr>
<tr>
<td>30.11.2000</td>
<td>Replacement in tank</td>
<td></td>
</tr>
</tbody>
</table>

T18_disk_CERN Fabrication history
CERN investigations

- Cutting of the structure (S. Atieh)
- Material analysis (A. Toerklep)
- SEM inspections (A. Toerklep, G. Arnau): focus on brazing joints and presence of craters

No visible damage
## Analysis of raw material supplied to Kugler

- **Grain size**
  - Technical specification: 
    - In accordance with the standard ASTM E112-96/2004e1
  - Testing Results: 
    - Standard Test Methods for Determining Average Grain Size E112
  - Grain size ≤ 90
  - Average diameter = 89.8µm

- **Hardness**
  - Technical specification: 
    - With Brinell hardness test. Hardness HBS 2.5±0.5
  - Testing Results: 
    - Temper state estimated from 106 is between H04 and H08
    - H04: (tensile=345MPa, yield=310MPa, Elongation at break A5=6%)
    - H08: (tensile=380MPa, yield=345MPa, Elongation at break A5=4%)

- **Electro conductivity**
  - Technical specification: 
    - Conductivity (as per ASTM B193) in annealed condition states:
    - minimum of 101 % IACS
  - Testing Results: 
    - Testing with a conductivity meter (Foerster Instruments, SIGMATEST 2.069, Uncertainty +/- 1%)
    - 100.6 % IACS

- **Composition**
  - Technical specification: 
    - The reference publications are standards ASTM F68-93 and B170-93. Cu min: 99.99%
    - The impurities shall be in accordance with ASTM F170-93 except:
    - O2 traces: Maximum 5 ppm
  - Testing Results: 
    - From external lab. Metalor Technologies SA
    - O2 traces: All measurements: ≤ 2 ppm
    - The following metallic impurities were found (in ppm):
      - Ag: 5
      - Mg: 2
      - Ca: 1
      - Ni: 1
      - Fe: 2
      - Se: 1
    - All other metal components are analyzed below the detection Limit (1 ppm)
    - Total of metallic impurities: 12 ppm

A. Toerklep

---

### Material property and impurity content within the specification

**GR, BE/RF, 090321**
Inspection of brazing joints

1-1 1-2 1-3 1-4
2-1 2-2 2-3
3-1 3-2 3-3
2-4
3-4

Good bonding without gaps

Cavity
Inspection of brazing joints

Joint

No brazing alloy coming inside the cells
Craters at grain boundary

- Frequent small craters
- Question on grain size (interesting to cut other T18 and compare)
Craters at grain boundaries

Presence of small craters ➔ association with soft breakdown ➔ S-residue in some craters
Inspection on iris 12

Breakdown clusters
Inspection on iris 12 (special case)
Inspection on iris 12

Contamination between brazing and testing
Inspection on iris 12

Region of craters

Piece 3, Iris 12

GR, BE/RF, 090321
Inspection on iris 12
Sulfur features also in bulk material

In agreement with technical specification
Summary of observations

• Material composition according to CERN specification
• No sign of defects or activities in brazing region
• Frequent small craters in the grain boundaries
• S-rich particles in the grain boundaries
  – S-residue found in craters
• S-rich particle also in bulk
• Grain size raises questions, but issue to be followed in future
• Special case, iris 12
  – Region of iris 12 with intense activity, evidence of contamination ➔ coherent with test results
What we learned

• S-rich particles in the grain boundaries
  – association with soft breakdown
  – S can be present in Cu-OFE up to 18 ppm
    → completely soluble above 750 °C but
    in equilibrium – slow cooling – forms Cu$_2$S
    at room temperature

• Grain size could be an issue

• Cleaning/handling procedures shall be improved

• Additional steps on dimensional control and SEM are required during preparation

Dedicated program with heat treatments and material origin

Comparison with assembly cycles at KEK/SLAC and Fermilab
CERN and SLAC/KEK bonding

Diffusion bonding

Brazing

T18_SLAC/KEK [D: 45 mm]

T18_CERN [D: 80 mm]
Fermilab assembly cycle

1. QC
2. Cleaning (SLAC procedure)
3. Pre-fire of disks (Ar, 1000 °C)
4. Ar brazing of couplers (1030 °C, Au/Cu 35/65)
5. Ar brazing of couplers to RF flanges (990 °C, Au/Cu 50/50)
6. Ar brazing of disk stack (780 °C, Ag/Cu 72/28)
7. Ar brazing of coupler to disk stack (780 °C, Ag/Cu 72/28)
8. Ar brazing – structure to cooling pipes (750 °C, Ag/Cu 61.5/23.5)

9. Baking (3% H2, 97% Ar @ 1Torr) to remove oxide
10. Vacuum baking (72 h at 500 °C)
Investigation on S-presence and grain size

<table>
<thead>
<tr>
<th></th>
<th>CERN Cu OFE (fly cutting Ra 0.008) 50 mm</th>
<th>KEK Cu OFE (fly cutting Ra=0.008) 55 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>As machined and cleaned</td>
<td>As machined and cleaned</td>
</tr>
<tr>
<td>1 (4 samples)</td>
<td>Vacuum Brazing 820 C (Bodycote)</td>
<td>Vacuum Brazing 820 C (Bodycote)</td>
</tr>
<tr>
<td>2</td>
<td>Vacuum Brazing 820 C (CERN)</td>
<td>Vacuum Brazing 820 C (CERN)</td>
</tr>
<tr>
<td>3</td>
<td>Vacuum Diffusion bonding 1045 C (Bodycote)</td>
<td>Vacuum Diffusion bonding 1045 C (Bodycote)</td>
</tr>
<tr>
<td>4</td>
<td>H2 Brazing 820 C (Bodycote)</td>
<td>H2 Brazing 820 C (Bodycote)</td>
</tr>
<tr>
<td>5-6-7-8</td>
<td>As machined (annealing)</td>
<td>As machined (annealing)</td>
</tr>
<tr>
<td>6-7-8</td>
<td>H2 Diffusion bonding 1050 C (Bodycote)</td>
<td>H2 Diffusion bonding 1050 C (Bodycote)</td>
</tr>
<tr>
<td>7-8</td>
<td>H2 Brazing 1000 C (Bodycote)</td>
<td>H2 Brazing 1000 C (Bodycote)</td>
</tr>
<tr>
<td>8</td>
<td>Vacuum baking after H2 brazing (Bodycote)</td>
<td>Vacuum baking after H2 brazing (Bodycote)</td>
</tr>
</tbody>
</table>

SEM inspections after each step
Future short-term structures

- T24 undamped (disks for tank version at CERN) ➔ new assembly procedure
- T24 undamped x2 ➔ fabricated by KEK/SLAC
- T24 undamped D = 45 mm (under mechanical design) x2 ➔ new design and new assembly procedure
- T18 KEK/SLAC design x2 (under tendering) ➔ SLAC/KEK assembly procedure
- TD18 (already brazed) ➔ cleaning
CERN new assembly cycle

- Intermediate transport in dedicated boxes
- Intermediate assembly work under laminar flow atmosphere (portable device under evaluation)
Dimensional control

- Present situation
  - Machine with an accuracy of +/- 3 um insufficient with respect to needs subcontracting to outside institutes
  - General rule for machine accuracy: 3-4 times better than required accuracy on pieces
  - Serious problem of probe: too high forces marks on pieces
  - Machine Veeco: good for roughness and topography measurement
  - Room adapted for this machine and required tolerance

- To be improved
  - Low force probe: 15 kCHF
  - New machine +/- 0.3-0.4 um (3 suppliers) [High Priority]
    - Needed personnel
    - Needed adaptation of existing room

Meeting S. Atieh, A. Cherif, M. Polini, G. Riddone 06.03.2009
PLANEITE MESUREE SUR CELLULE 35 mm SUR MACHINE VEECO

A. Cherif

GR, BE/RF, 090321
Marques dues au palpeur

GR, BE/RF, 090321

A. Cherif
Fabrication

• Present situation
  – VDL, Kugler (only turning)
  – LT Ultra under qualification
  – Promising Kaleido, Engineering and TNO

• To be improved
  – New firms in Europe
  – New firms in Japan
  – New firms in USA
  – Development work in collaboration with firms (very difficult with VDL) and other institutes
  – Procurement of combined machine at CERN [prototyping phases, special pieces, pre-qualification for series, fall-back solution]
    – qualified people (1 Eng. + 1 Tech) to be trained [Priority 2]

Meeting S. Atieh, A. Cherif, M. Polini, G. Riddone 06.03.2009
Conclusions

- T18_CERN showed bad test results (same structures made at KEK/SLAC showed good results, demonstrating nominal CLIC performance)
- Investigations on T18_CERN, showed that iris 12 is a special case: contamination and evidence of high activity region
- Program to investigate S-presence and grain size launched
- New assembly procedure established: *pre-fire at 1000 °C, cleaning procedure, separate preparation of RF couplers*
- Additional QC steps identified
- Fabrication of T18 with SLAC/KEK design launched
Extra slides
<table>
<thead>
<tr>
<th>No.</th>
<th>2a</th>
<th>2b</th>
<th>f</th>
<th>r</th>
<th>a</th>
<th>ea</th>
<th>eb</th>
<th>c</th>
<th>(d)</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.11</td>
<td>22</td>
<td>996</td>
<td>2.887</td>
<td>6.870</td>
<td>1.300</td>
<td>1.300</td>
<td>0.297</td>
<td>8.246</td>
<td>0.297</td>
</tr>
<tr>
<td>1</td>
<td>6.11</td>
<td>22</td>
<td>996</td>
<td>2.887</td>
<td>6.870</td>
<td>1.300</td>
<td>1.300</td>
<td>0.297</td>
<td>8.246</td>
<td>0.297</td>
</tr>
<tr>
<td>2</td>
<td>8.036</td>
<td>22</td>
<td>142</td>
<td>2.750</td>
<td>5.975</td>
<td>1.298</td>
<td>1.497</td>
<td>0.274</td>
<td>8.725</td>
<td>10.40</td>
</tr>
<tr>
<td>3</td>
<td>7.872</td>
<td>22</td>
<td>042</td>
<td>2.663</td>
<td>6.041</td>
<td>1.198</td>
<td>1.422</td>
<td>0.267</td>
<td>8.704</td>
<td>10.45</td>
</tr>
<tr>
<td>4</td>
<td>7.707</td>
<td>21</td>
<td>944</td>
<td>2.596</td>
<td>6.128</td>
<td>1.159</td>
<td>1.396</td>
<td>0.256</td>
<td>8.704</td>
<td>10.50</td>
</tr>
<tr>
<td>5</td>
<td>7.542</td>
<td>21</td>
<td>850</td>
<td>2.489</td>
<td>6.215</td>
<td>1.120</td>
<td>1.342</td>
<td>0.249</td>
<td>8.704</td>
<td>10.54</td>
</tr>
<tr>
<td>6</td>
<td>7.378</td>
<td>21</td>
<td>758</td>
<td>2.402</td>
<td>6.302</td>
<td>1.081</td>
<td>1.292</td>
<td>0.240</td>
<td>8.704</td>
<td>10.59</td>
</tr>
<tr>
<td>7</td>
<td>7.213</td>
<td>21</td>
<td>671</td>
<td>2.315</td>
<td>6.389</td>
<td>1.042</td>
<td>1.242</td>
<td>0.231</td>
<td>8.704</td>
<td>10.62</td>
</tr>
<tr>
<td>8</td>
<td>7.048</td>
<td>21</td>
<td>586</td>
<td>2.228</td>
<td>6.476</td>
<td>1.003</td>
<td>1.193</td>
<td>0.222</td>
<td>8.704</td>
<td>10.67</td>
</tr>
<tr>
<td>9</td>
<td>6.884</td>
<td>21</td>
<td>500</td>
<td>2.141</td>
<td>6.563</td>
<td>0.965</td>
<td>1.143</td>
<td>0.215</td>
<td>8.704</td>
<td>10.72</td>
</tr>
<tr>
<td>10</td>
<td>6.719</td>
<td>21</td>
<td>426</td>
<td>2.054</td>
<td>6.650</td>
<td>0.922</td>
<td>1.094</td>
<td>0.206</td>
<td>8.704</td>
<td>10.77</td>
</tr>
<tr>
<td>11</td>
<td>6.554</td>
<td>21</td>
<td>351</td>
<td>1.967</td>
<td>6.737</td>
<td>0.885</td>
<td>1.045</td>
<td>0.197</td>
<td>8.704</td>
<td>10.80</td>
</tr>
<tr>
<td>12</td>
<td>6.390</td>
<td>21</td>
<td>280</td>
<td>1.880</td>
<td>6.824</td>
<td>0.846</td>
<td>0.999</td>
<td>0.188</td>
<td>8.704</td>
<td>10.83</td>
</tr>
<tr>
<td>13</td>
<td>6.225</td>
<td>21</td>
<td>211</td>
<td>1.793</td>
<td>6.911</td>
<td>0.807</td>
<td>0.946</td>
<td>0.179</td>
<td>8.704</td>
<td>10.86</td>
</tr>
<tr>
<td>14</td>
<td>6.060</td>
<td>21</td>
<td>142</td>
<td>1.705</td>
<td>7.008</td>
<td>0.768</td>
<td>0.897</td>
<td>0.170</td>
<td>8.704</td>
<td>10.90</td>
</tr>
<tr>
<td>15</td>
<td>5.895</td>
<td>21</td>
<td>082</td>
<td>1.618</td>
<td>7.105</td>
<td>0.729</td>
<td>0.849</td>
<td>0.161</td>
<td>8.704</td>
<td>10.93</td>
</tr>
<tr>
<td>16</td>
<td>5.731</td>
<td>21</td>
<td>025</td>
<td>1.531</td>
<td>7.202</td>
<td>0.698</td>
<td>0.802</td>
<td>0.154</td>
<td>8.704</td>
<td>10.96</td>
</tr>
<tr>
<td>17</td>
<td>5.566</td>
<td>20</td>
<td>970</td>
<td>1.444</td>
<td>7.309</td>
<td>0.660</td>
<td>0.752</td>
<td>0.145</td>
<td>8.704</td>
<td>10.98</td>
</tr>
<tr>
<td>18</td>
<td>5.401</td>
<td>20</td>
<td>979</td>
<td>1.357</td>
<td>7.416</td>
<td>0.611</td>
<td>0.703</td>
<td>0.136</td>
<td>8.704</td>
<td>10.99</td>
</tr>
<tr>
<td>19</td>
<td>5.319</td>
<td>20</td>
<td>863</td>
<td>1.341</td>
<td>7.417</td>
<td>0.561</td>
<td>0.677</td>
<td>0.127</td>
<td>8.704</td>
<td>11.01</td>
</tr>
<tr>
<td>20</td>
<td>10.490</td>
<td>21</td>
<td>596</td>
<td>2.157</td>
<td>7.433</td>
<td>0.950</td>
<td>0.950</td>
<td>0.257</td>
<td>8.589</td>
<td>10.67</td>
</tr>
</tbody>
</table>

**NOTES:**
1. **DIMENSIONS IN THIS DRAWING ARE AT 20X, WHILE OPERATING TEMPERATURE IS 30%.
2. LUBRICANT BASED ON CHLORINE OR SULFUR SHOULD BE AVOIDED.
3. NO POLISHING IS ALLOWED.
4. POSITIVE CORKERS ARE CHAMFERED CO2 UNLESS SPECIFIED.
5. NEGATIVE CORKERS ARE R=0.2 UNLESS SPECIFIED.
6. NO HAMFUL BURRS, NOSCRATCHES ARE ALLOWED.
7. NUMBERING IS REQUIRED.
8. **NOTICE** No.89-201-110-(11) As!-1 ex. (10-A)
9. **NOTICE** Section L-041-120.
10. REVISION HISTORY

**T18_SLAC/KEK**

---

**DIAGRAM:**

- **NOTES:**
  - **DIMENSION:**
  - **TOLERANCE:**
  - **FINISHING:**
  - **MATERIAL:**
  - **REMARKS:**

**DRAWING NAME:**

- **DRAWING NUMBER:**
- **DRAWN BY:**
- **DATE:**
- **SCALE:**

**REV.:**

- **DRAWING NUMBER:**
- **DATE:**
- **SCALE:**

**REMARKS:**

- **NOTICE:**
- **TOLERANCE:**
- **FINISHING:**
- **MATERIAL:**

**HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION**

**DRAWING NAME:**

- **DRAWING NUMBER:**
- **DATE:**
- **SCALE:**

**REMARKS:**

- **NOTICE:**
- **TOLERANCE:**
- **FINISHING:**
- **MATERIAL:**
Inspection on iris 11

Dirty region which came after the test
Inspection on iris 13

Dirty particles which came after the test
Rugosimètre – profilomètre optique VEECO NT3300

CLIC

Sous-système LHCb

Pièce de 2 CHF

CMS

8 cm

Ø25µm

5µm

A. Cherif

GR, BE/RF, 090321
Title: 
Note: 

GR, BE/RF, 090321
Title: Extremity cell B
Note: Piece 2 (11WNSDVG1.8)