Refurbishment and status of FZK test facilities

Walter H. Fietz

• Introduction to FZK facilities
• Preparation for W7-X coil testing - TOSKA refurbishment
• Current Leads for W7-X
• Current Leads for JT-60SA
• Special Current Lead Test facility - CuLTKa
TOSKA  TOroidal Spulentestanlage Karlsruhe
Toroidal Test facility Karlsruhe

Cryostat
Ø 4.3 m, usable height 6.6 m

Power supplies
• three power supplies (20 kA, 30 kA & 50 kA)
  (connected 30 kA & 50 kA power supplies → 80 kA)
• switching circuits 30 kA & 80 kA

Cryogenics
• Refrigerator 2000 W (T = 3.5 – 4.5 K)
• Refrigerator 300 W (T = 1.8 – 4.5 K)
• Cooling circuits with supercritical He
  – 300 g/s (T = 3.5 - 4.5 K)
  – 50 g/s (T = 1.5 - 4.5 K)
Large fusion experiments in TOSKA
ITER TFMC Test

Test of ITER model coil to validate the design concept
70 kA HTS Current Lead Demonstrator for ITER

The High Temperature Superconductor (HTS) Current Lead consists of three parts:

- **Connection to busbar**: 4.5 K
- **HTS module (Bi - 2223/AgAu)**: 4.5 K - 65 K
- **Copper heat exchanger (HEX)**: 65 K - 300 K

Cooled by sc busbar He-flow@4.5 K

HTS module only conduction cooled

Cooling of HEX with 50 K He (design value)
Assembly and installation of 70 kA HTS current lead

Assembled and ready for installation

HTS CL installed in B300 of TOSKA facility

Install Detail

Conventional current lead

BBIII connection

HTS CL
High Voltage Area of Expertise

Expertise in cryogenic high voltage testing
• of superconductors in power applications e.g. low temperature high voltage testing up to 200 kV
• for fusion

To support ITER
• high voltage tests on TFMC
• transient voltage calculations for TF coil
• transient voltage calculations for PF coil
• definition of coil test procedures

Details ⇒ presentation of Stefan Fink
Mechanical characterization of fusion relevant materials in cryogenic environment

Numerous samples were measured in FZK in the CRYOgenic MAterial test facility Karlsruhe CRYOMAK with respect to tensile, fracture toughness, fatigue crack growth rate, fatigue life including ready component tests with Mock-ups.

In addition FBI facility to characterize superconductor strands od cables.

Details ⇒ presentation of Klaus Weiss
In 2006 politicians in German were concerned that the construction of the stellerator W7-X may be delayed in case of a problem in the W7-X coil testing environment in Saclay. As a consequence it was strongly suggested that TOSKA should be refurbished for W7-X coil testing as a back up of Saclay. In August 2007 a contract was signed for refurbishing TOSKA for W7-X coil testing.
From Stellerator to a "modular concept" → W 7-X

Toroidal field coils and helical coils are integrated to non planar modular coils

H.S. Bosch, 9.5.2006, HGF – Siemens Fusions-Workshop, Karlsruhe
W7-X coil testing in Saclay

W7-X coils are tested in a dedicated test facility in CEA - Saclay.

In several cases problems were found. Main problems are:
- high voltage faults (Paschen tightness)
- vacuum leaks

Therefore several coils have to be retested

Details ⇒ presentations of Markus Borlein
Coil frames and installation in TOSKA

CEA version

Version planned for TOSKA: 3 coils installed in parallel to optimize cool down + warm up time
An enormous amount of work ended in Nov 2008 with an "TOSKA ready for testing". However, Saclay had an optimal testing period and politics decided to stop this activity in TOSKA.
Current Leads for W7-X

W7-X needs 14 current leads with a maximum current of 18.2 kA installed in upside down position.

FZK will design, construct and build these current leads in an HTS version.

The use of HTS material mitigates the "upside down problem"
• Density difference He 4.4K/300K: factor 126
• Density difference He 50 K/300K: factor 8

HTS CL solve upside down problem
HTS CL lower the load on the cryo system

A contract between IPP and FZK was signed. The current lead design is progressing.

Details of HTS current leads ⇒ Rainer Wesche
HTS Current Leads for W7-X - General Parameters

Design features
- Upside-down orientation
- Clamp contact with Nb$_3$Sn inserts to sc bus bar
- HTS module (Bi-2223 stacks), conduction cooled
- Meander fin type heat exchanger (50 K He)
- Paschen tight HV insulation

Main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of current circuits of non planar/planar coils</td>
<td>5/2 (10 coils in series each)</td>
</tr>
<tr>
<td>Number of current leads</td>
<td>14</td>
</tr>
<tr>
<td>Maximum design current</td>
<td>18.2 kA</td>
</tr>
<tr>
<td>Nominal current</td>
<td>14 kA</td>
</tr>
<tr>
<td>Max. voltage to ground (test voltage)</td>
<td>$\pm$13 kV</td>
</tr>
<tr>
<td>Orientation</td>
<td>cold end at top</td>
</tr>
<tr>
<td>Overall length</td>
<td>2500 mm</td>
</tr>
<tr>
<td>Max. diameter</td>
<td>200 mm</td>
</tr>
<tr>
<td>Basic operation schedule</td>
<td>steady state for 4-5 days</td>
</tr>
</tbody>
</table>
HTS Current Leads for W7-X - HTS module

Design features

- Bi-2223
- AgAu matrix (low thermal conductivity)
- AgAuMg outer sheath (high mechanical strength)
- Bi-2223 HTS tapes soldered to stacks
- Stacks soldered to a stainless steel structure with Cu ends
- SS structure reduces thermal runaway in case of loss of coolant or quench

Main parameters of HTS tape

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix / sheath material</td>
<td>AgAu/AgAuMg</td>
</tr>
<tr>
<td>Ic (77 K, s.f.)</td>
<td>&gt;110 A</td>
</tr>
<tr>
<td>Width</td>
<td>3.9 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.23 mm</td>
</tr>
<tr>
<td>Filament number</td>
<td>121</td>
</tr>
<tr>
<td>Sc filling factor</td>
<td>39.8% (av.)</td>
</tr>
<tr>
<td>Tensile strength at RT (&lt;5% Ic-degradation)</td>
<td>&gt;95 MPa</td>
</tr>
<tr>
<td>Tensile strength at 77 K (&lt;5% Ic-degradation)</td>
<td>&gt;120 MPa</td>
</tr>
</tbody>
</table>
Current Leads for JT-60SA

Broader Approach

JT-60 -> JT-60SA

TF coils built by EU (major contributions from France and Italy)

Superconducting current leads for JT-60 SA
Broader Approach

During ITER location negotiation Japan & EU agreed to have a broader approach
JT-60 ⇒ JT-60SA

Japanese Tokamak JT-60 shall be equipped with superconducting coils
TF coils will be built by EU

More details ⇒ Christophe Portafaix
JT-60SA: ITP/FZK contribution: Current Leads

ITP shall design, construct and built the current leads for JT-60SA.

The design of the W7-X current leads will be adapted to the needs of JT-60SA.

First parameter for current leads:

<table>
<thead>
<tr>
<th>Coil</th>
<th>Number</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF</td>
<td>6</td>
<td>25.7 kA</td>
</tr>
<tr>
<td>CS</td>
<td>6</td>
<td>20 kA</td>
</tr>
<tr>
<td>EF</td>
<td>14</td>
<td>20 kA</td>
</tr>
</tbody>
</table>
Current Lead Test facility CuLTKA

To test the current leads for W7-X & JT-60SA the Current Lead Test facility Karlsruhe will be installed in the hall next to TOSKA.

CuLTKA integration has to preserve cryo linking for other experiments (e.g. TIMO). CuLTKa is under construction (valve boxes, control cryostat & transfer lines, ...)

H. Neumann | CuLTKa Cryo-Kick-Off Meeting | 03.04.2007
Current Lead test facility  **CuLTKa**

A location for current lead testing was identified next to the TOSKA hall, but has to be cleared first.

Here the **Current Lead Test facility Karlsruhe (CuLTKa)** will be located
Current Lead test facility  CuLTKa

CAD view of facility with two test cryostats
Pairs of current leads will be installed for testing
Current Lead Prototype Test using TOSKA

To allow a prototype testing before CuLTKa is completed, the prototype tests will be performed using TOSKA.

The test cryostat of CuLTKa will be flanged on the side of the TOSKA cryostat.
Summary

After upgrading the TOSKA facility the team currently concentrates on

- Construction of 2 prototype HTS current leads
- Construction of 14 HTS current leads for W7-X (18.2 kA)
- Construction of 26 HTS current leads for JT-60SA (20 kA / 25.7 kA)
- Construction of a dedicated current lead test facility CuLTKa
- Testing of these HTS current leads

In addition

- support of ITER by cryogenic material testing in CRYOMAK
- support of ITER in high voltage field
- basic development for high current HTS fusion conductor is started