The Results of the KSTAR Superconducting Coil Test

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Prototype TF Coil Test

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KSTAR Device

- Korea Superconducting Tokamak Advanced Research
- Assembly finish milestone on 2007
- Major components: Vacuum vessel, Cryostat, TF SC coils, PF SC coils, and Magnet structures
SC Coil Fabrication Status

- TF Coils
  - 5 Completion
- PF Coils
  - 4 Completion

Poster Presentation: FT/P7-16
SC Coil Test Program Overview
Objectives of the KSTAR SC Coil Test

- To verify the design and manufacturing engineering of the KSTAR SC coils
- To get the operating characteristics of the SC coils after cool-down and under current excitation
- To acquire the knowledge of the KSTAR magnet system commissioning and operation, and
- To test the KSTAR SC magnet interfaces before installation such as cryogenic sensors, monitoring system, power supply, and quench detector
## SC Coil Test Overall Schedule

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**SC Coil Test Facility Layout**

- **Vacuum Cryostat**
  - 6 m (D) x 8 m (H)
  - Thermal shield (LN2 cooled)
  - Helium flow distribution
  - Current lead

- **Vacuum Pumping System**
  - Diffusion pump
  - Piston pump & booster pump
  - Safety valve
SC Coil Test Facility Layout

Cryogenic Helium Facility

- 1 kW Helium refrigerator
- 140 l/h Helium liquefier
- 3000 l LHe dewar
- Helium recovery station
- LN2 storage
SC Coil Test Facility Layout

- 35 kA TF power supply (unipolar)
- 20 kA PF power supply (bipolar)
- 10 kA bipolar
SC Coil Test Facility Layout

Monitoring System

- VME
- PXI
- Quench detector
- Vacuum & RGA
- Cryogenic monitoring

Monitoring System

Quench Detector
Prototype TF Coil Test
Prototype TF Coil (TF00 Coil) Test

Test Objectives

- To verify the design and fabrication procedure of the KSTAR TF coil
- To solve the engineering issue in TF coil, void fraction, SAGBO, and joints
- Commissioning the SC magnet test facility
## Prototype TF Coil Fabrication

### KSTAR TF Coil Specifications

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of coils</td>
<td>16</td>
</tr>
<tr>
<td>Major radius [m]</td>
<td>1.8</td>
</tr>
<tr>
<td>Toroidal field at major radius [T]</td>
<td>3.5</td>
</tr>
<tr>
<td>Peak field in conductor [T]</td>
<td>7.2</td>
</tr>
<tr>
<td>Operating current [kA]</td>
<td>35.2</td>
</tr>
<tr>
<td>Stored magnetic energy [MJ]</td>
<td>~ 500</td>
</tr>
<tr>
<td>Superconductor</td>
<td>Nb$_3$Sn</td>
</tr>
<tr>
<td>Jacket material</td>
<td>Incoloy908</td>
</tr>
<tr>
<td>CICC length per coil [m]</td>
<td>640</td>
</tr>
<tr>
<td>Winding</td>
<td>56 turns</td>
</tr>
<tr>
<td>Overall height of a TF case [m]</td>
<td>4.2</td>
</tr>
<tr>
<td>Overall width of a TF case [m]</td>
<td>3.0</td>
</tr>
<tr>
<td>Weight of a TF coil [ton]</td>
<td>2.87</td>
</tr>
<tr>
<td>Weight of a TF structure [ton]</td>
<td>6.4</td>
</tr>
<tr>
<td>Total weight of TF magnet system [ton]</td>
<td>148</td>
</tr>
</tbody>
</table>

TF00 Winding Finished on August 2001

TF00 VPI Finished on April 2002
TF00 Coil Setup for Test

- TF00 coil set up in vacuum cryostat: August 2002
- Sandwich configuration with D shaped structures
- Overall weight of the coil and structure: about 10 ton
- Current feeder: 50 kA current lead, NbTi CICC busline, Joints

TF00 Assembling Finished on August 2002
TF00 Coil Cool-down

- Cool-down in 9 days
- RRR > 200 (requirement > 100)
- SC Phase transition @ 18 K
- No helium leak @ 5 K, 6 bar

Thermal Contraction by Cool-down

Temperature History during Cool-down

![Graph showing temperature history with time](image)

- Vertical: (-13.3 mm)
- Horizontal: (-9.3 mm)
TF00 Coil Current Excitation & Discharges

- **Slow Discharge**
  - Slow discharge at 29 kA
  - No remarkable heating on coil & structure

- **Fast Discharge**
  - Fast discharge at 27 kA
  - $\tau_{\text{dump}} \sim 2$ sec
  - Structure heating by eddy current
Results of the TF00 Coil Test

- Well cool-down although void fraction of 32%
- Uniform helium flow between channels although continuous winding scheme
- No helium leaks
- No SAGBO in spite of Incoloy908 jacket
- Stable operation of the TF power supply and quench detection system

TF00 coil was assembled with TF magnet structure.
CS Model Coil Test
CS Model Coil (CSMC) Test

- Test Objectives
  - To verify the design and fabrication procedure of the KSTAR CS coils
  - To measure the dc performance of the coil, such as $J_c$ & joint loss
  - To measure the ac performance of the coil, such as ac loss

System Layout of CS Model Coil Test
CSMC Fabrication

- CS model coil = background coil system
- Background coil design: 8 T, ±20 T/s

Comparison between CS Coil & CS Model Coil

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CS Coil (PF1 U&amp;L)</th>
<th>CS Model Coil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of coils</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Windings per coil</td>
<td>180</td>
<td>240</td>
</tr>
<tr>
<td>Mean radius [m]</td>
<td>0.57</td>
<td>0.56</td>
</tr>
<tr>
<td>Inner radius [m]</td>
<td>0.46</td>
<td>0.37</td>
</tr>
<tr>
<td>Outer radius [m]</td>
<td>0.69</td>
<td>0.74</td>
</tr>
<tr>
<td>Height [m]</td>
<td>0.49</td>
<td>0.40</td>
</tr>
<tr>
<td>Inductance [mH]</td>
<td>93</td>
<td>135</td>
</tr>
<tr>
<td>Superconductor</td>
<td>Nb3Sn</td>
<td></td>
</tr>
<tr>
<td>Jacket</td>
<td>Incoloy908</td>
<td></td>
</tr>
<tr>
<td>B_peak [T]</td>
<td>9.8 T @ 22.6 kA</td>
<td></td>
</tr>
</tbody>
</table>
CSMC Setup for Test

- CS model coil set up in vacuum cryostat: July 2004
- Two coil in series
- Structure: GFRP plates to reduce eddy current
- Sensors: about 240 in total

CS Model Coil Assembling Finished on July 2004
CSMC Operation Analysis

- Operating Condition at 22.6 kA
  - Peak field on conductor: 9.75 T
  - Central field: 8.0 T
  - Tcs: ~ 8.3 K @ 0.3% strain

Current Waveform

AC Losses

Magnetic Field Distribution
CSMC Cool-down

- **Cool-down in 9 days**
  - Vacuum pressure: 2 E-9 mbar
  - No helium leak
  - RRR ~ 200
  - Flow rate per coil ~ 23 g/s
  - Temperature: inlet 4.8 K, outlet 4.9 K
  - Side channel heating from structure

Sensors on Helium Line

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**Temperature during Cool-down**

- **Coil Inlet**
- **Coil Outlet**
- **Coil Inner Surface**
- **Coil Outer Surface**

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**Graphical Data**

- Time (Date) vs. Temperature (K)
- Flow vs. Temp.
Strain Sensors during Cool-down

- Temperature and field cancellation
- Active-active type & Active-dummy type with GFRP bracket
- Relative strain of coil insulation \( \sim 0.15\% \) tangential, \( \sim 0.07\% \) axial
- Low thermal contraction of Incoloy908
Current Excitation and Discharge

- Current Charge in step up to 15 kA
- Slow discharge to 10 kA
- Heating on helium inlet at 10 kA
- Fast discharge, $\tau_{\text{dump}} \sim 3$ sec
CSMC Current Excitation & Discharge

**Magnetic Field**
- Field Intensity (T)
- Time (hh:mm)
- B_Peak (BF703A)
- B_Center (BF001)

**Helium Temperature**
- Temperature (K)
- Time (hh:mm)
- Inlet Total (TX110B@SHS)
- Outlet Total (TX110A@SHR)
- Inlet Ch3 (TX113A@SHS)
- Inlet Ch4 (TX114A@SHS)
- Outlet Ch4 (TX114A@SHR)
- Joint (TX121B@SHS)

**Strain Sensors**
- Strain (ppm)
- Time (hh:mm)
- Active-Active (SA401A@MC1)
- Active-Dummy, Tangential (SD404B@MC1)
- Active-Dummy, Axial (SD404C@MC1)

**Helium Flow rate**
- Flow Rate (g/s)
- Time (hh:mm)
- Inlet Total (FM110A@SHS)
- Outlet Total (FM110A@SHR)
- Inlet Ch2 (FM112A@SHS)
- Inlet Ch3 (FM113A@SHS)
- Inlet Ch4 (FM114A@SHS)
Results of the CSMC Test

- CS model coil was cooled down in 9 days.
- Current charging and discharge up to 15 kA with TF power supply
- Measured heat load per coil was about 30 W at zero current and about 100 W at 15 kA.
- The test will be continued until the end of 2004.
Other Test Activities
KSTAR Coil Acceptance Tests

Dimensional Measurement

4.2 m

PF7L

TF05
KSTAR Coil Acceptance Tests

- Flowrate Measurement

- High Voltage Test
  - DC Hipot : 15 kV
  - AC Hipot : 10 kVrms
  - Impulse
KSTAR Coil Acceptance Tests

- Strand Sample Jc Measurement
  - heat treatment with KSTAR coil
  - Jc measurement
  - Jc ≥ 750 A/mm² @ 12T, 4.2 K

TF Coil Strand Jc Measurement

![TF Coil Strand Jc Measurement](image)

Jc Measuring System

![Jc Measuring System](image)
Summary and Future Works

- The SC coil test facility has been constructed and operated well.

- Two kinds of SC coils has been tested in the test facility, a prototype TF coil and a pair of CS model coil.

- The results of coil tests showed that the coils has been fabricated without any remarkable defect such as coil leak, and SAGBO in Incoloy908 jacket.

- The flow in the cooling channels was uniform in spite of continuous winding scheme.

- The test of the CS model coil are going on including cool-down, current excitation and discharges and the test will be continued until the end of 2004 for AC loss measurement.

- Acceptance test of the KSTAR coils are being conducted including the dimensional measurement, flow uniformity check, high voltage insulation test, and Jc measurement of the heat treated strand.