20th IAEA FUSION ENERGY CONFERENCE
1-6 November 2004
Vilamoura, Portugal

The Results of the KSTAR Superconducting Coil Test

Nov. 5 2004

Presented by Yeong-KooK Oh

Y. K. Oh, Y. Chu, S. Lee, S. J. Lee, S. Baek, J. S. Kim, K. W. Cho, H. Yonekawa, Y. Chang, K. R. Park, W. Chung, S. H. Lee, S. H. Park, I. S. Woo, N. Song, K. P. Kim, Y. J. Song, H. Park, Y. M. Park, Y. S. Kim, S. W. Kwag, Y. J. Lee, H. S. Chang, M. K. Kim, K. Kim, J. S. Bak, G. S. Lee, and the KSTAR Team

National Fusion R&D Center
Korea Basic Science Institute

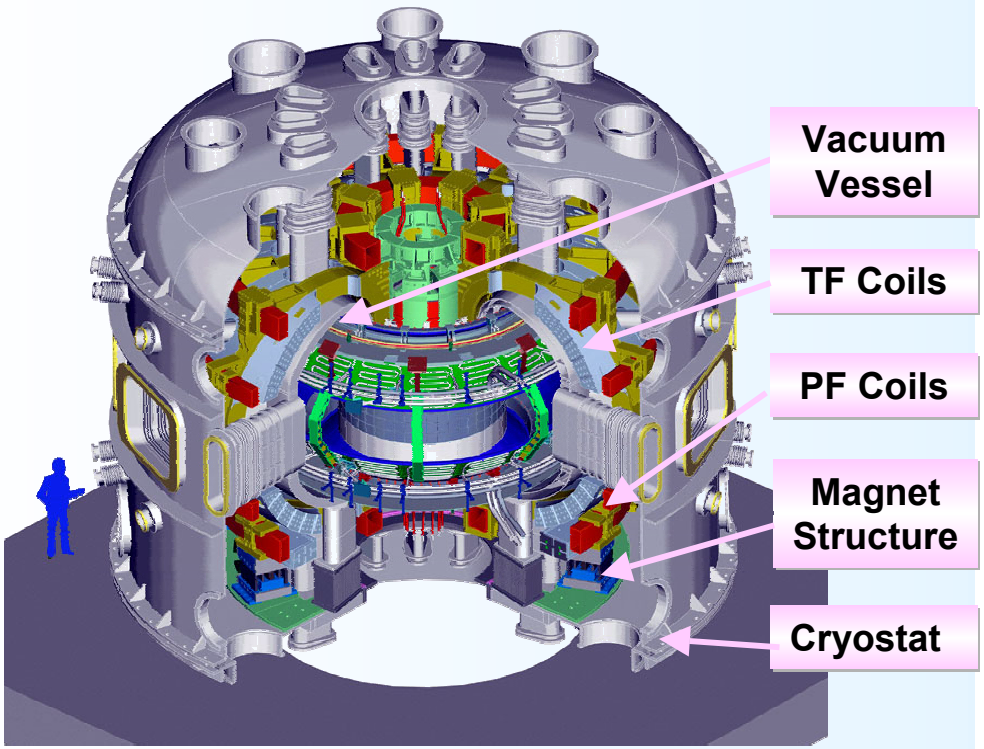
Ykoh@kbsi.re.kr

Contents

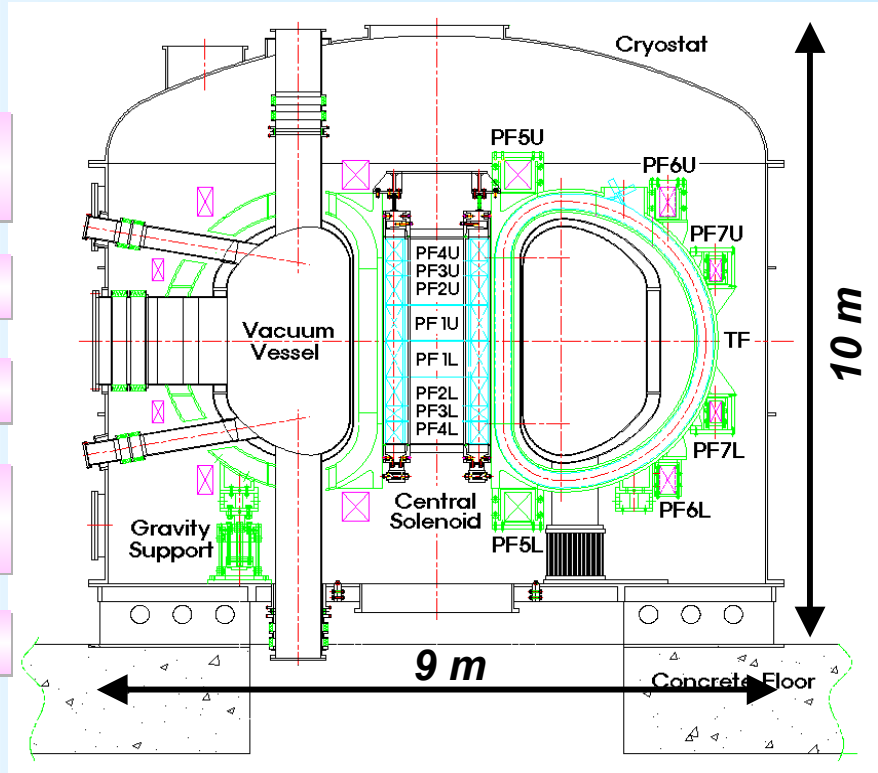
KSTAR Device

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

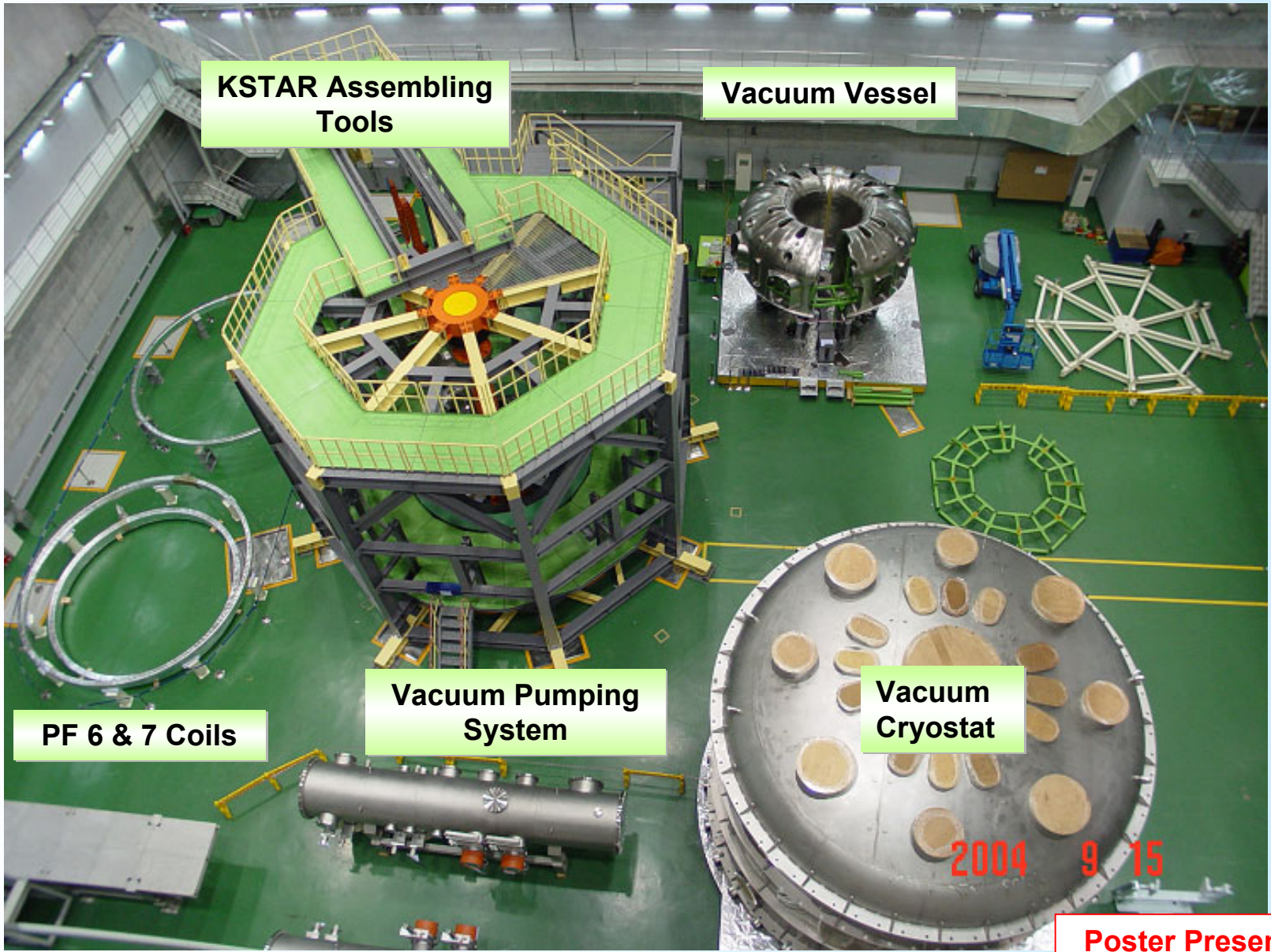
KSTAR Device & Major Components



Elevation View of KSTAR

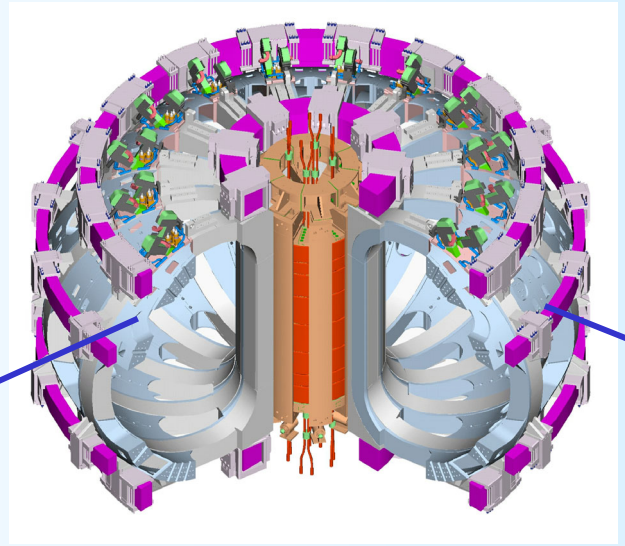


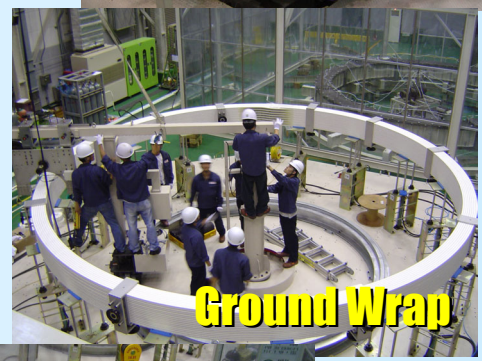
KSTAR Device Assembling Status



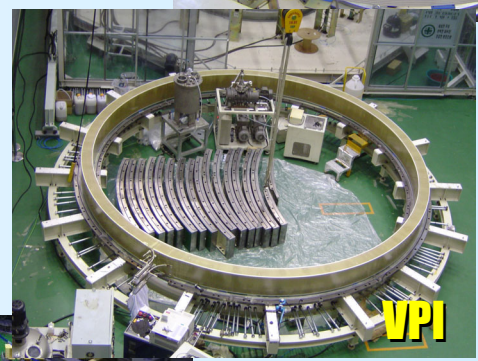
Poster Presentation:
FT/P7-17

SC Coil Fabrication Status





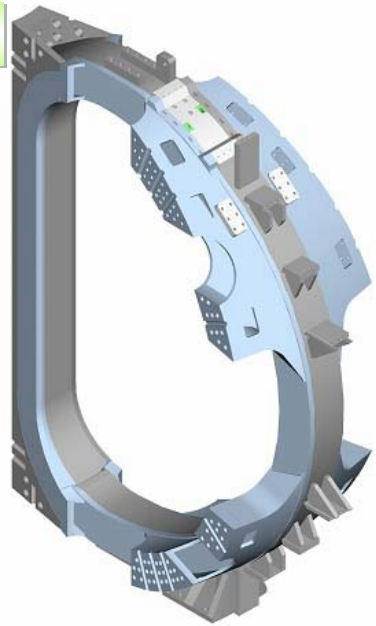
- TF Coils
  5 Completion
- PF Coils
  4 Completion



Poster Presentation: FT/P7-16

Magnet Structure Fabrication Status

TF Magnet Structure



Poster Presentation: FT/P7-14

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

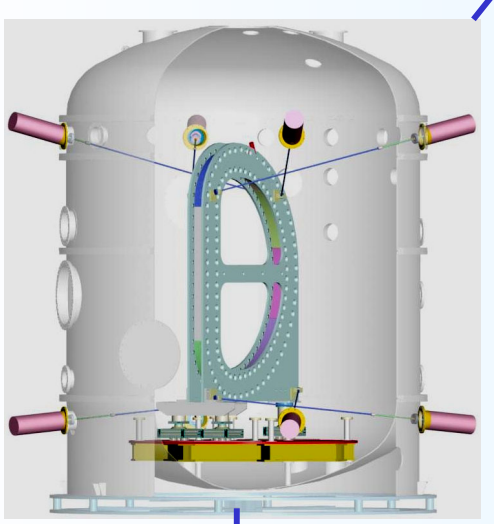
SC Coil Test Overall Schedule

Test Activities	Objectives	Schedule
Prototype TF Coil Test	**TF Coil Engineering & Operation Verification**	**2002 ~ 2003**
CS Model Coil Test	**CS Coil Operation & Engineering Verification**	**2004**
TF Coil Cool-down, CS Joint, TF Structure	**KSTAR Coil Integrity Test**	**2005 ~**
Coil Acceptance Test	Dimension Check Pressure & Flow Check DC Hipot Test AC Hipot Test Impulse Test SC Strand Jc Measure	**2003 ~ 2006**

SC Coil Test Facility Layout

Vacuum Pumping System

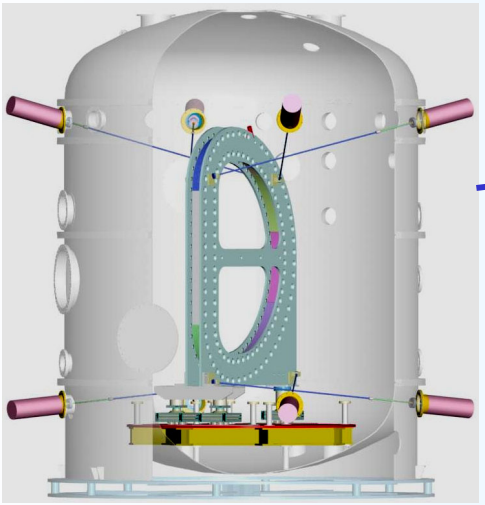
- Diffusion pump
- Piston pump & booster pump
- Safety valve



Vacuum Cryostat

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

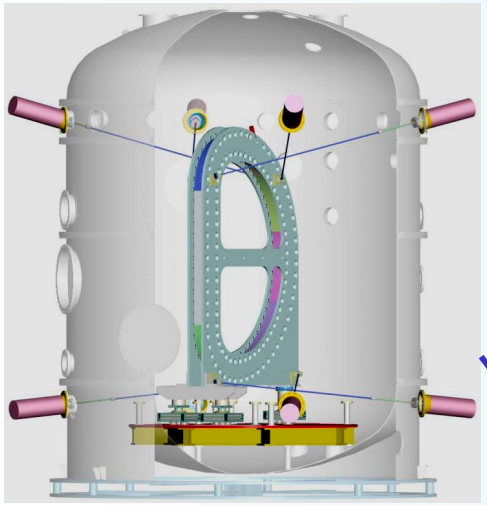
SC Coil Test Facility Layout



Cryogenic Helium Facility

- 1 kW Helium refrigerator
- 140 l/h Helium liquefier
- 3000 l LHe dewar
- Helium recovery station
- LN2 storage

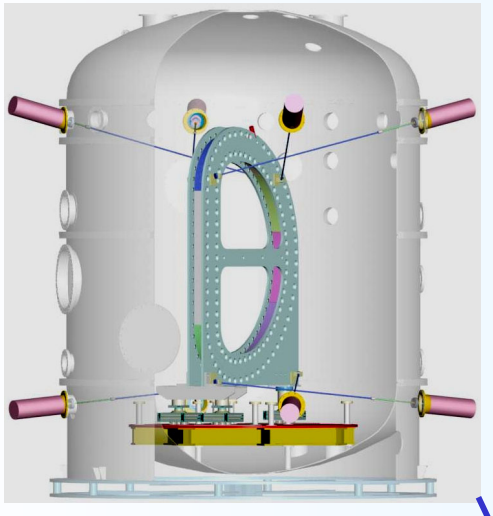
SC Coil Test Facility Layout



Power Supply

- 35 kA TF power supply (unipolar)
- 20 kA PF power supply (bipolar)
- 10 kA bipolar

SC Coil Test Facility Layout



Monitoring System

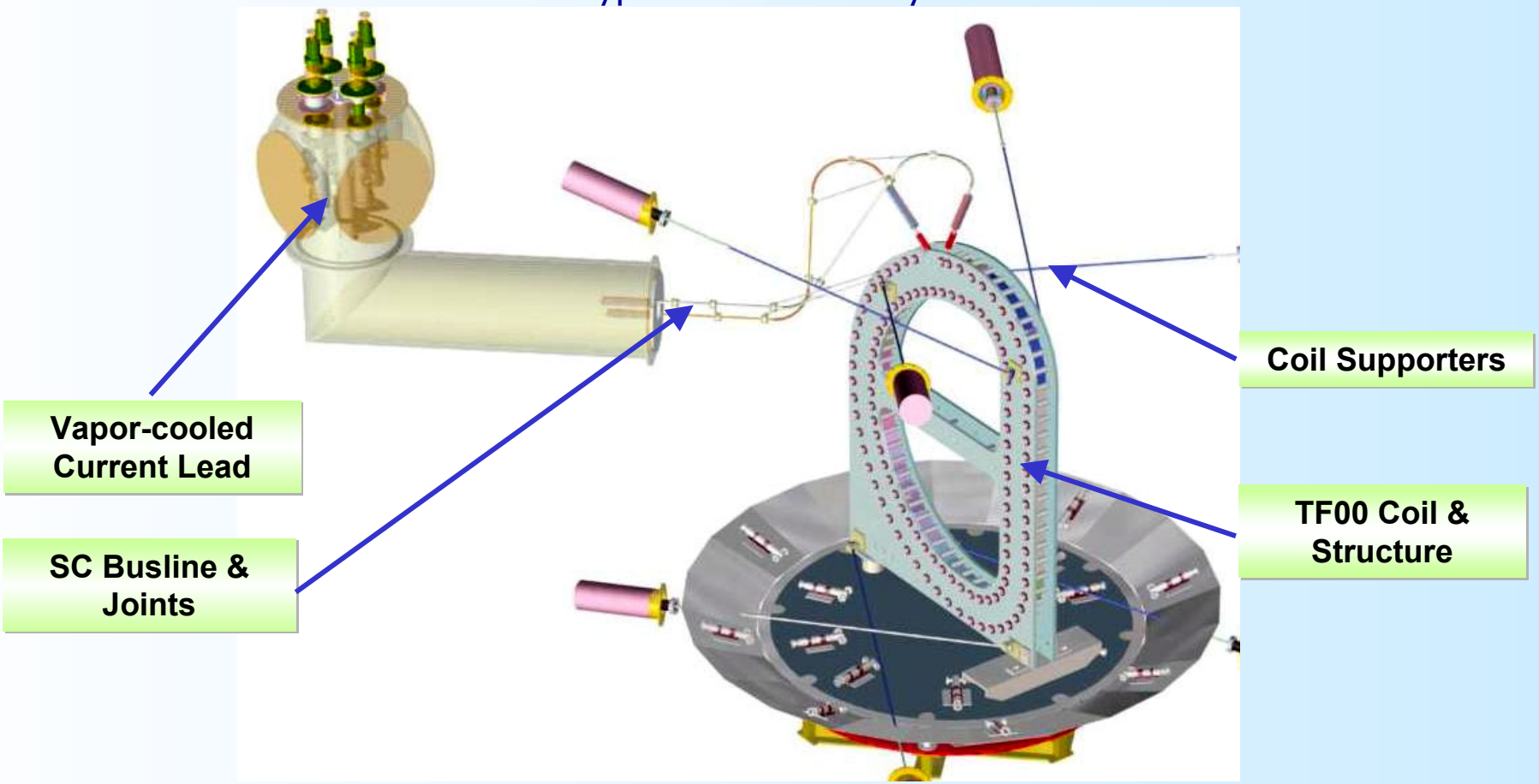
- VME
- PXI
- Quench detector
- Vacuum & RGA
- Cryogenic monitoring

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 Test Layout



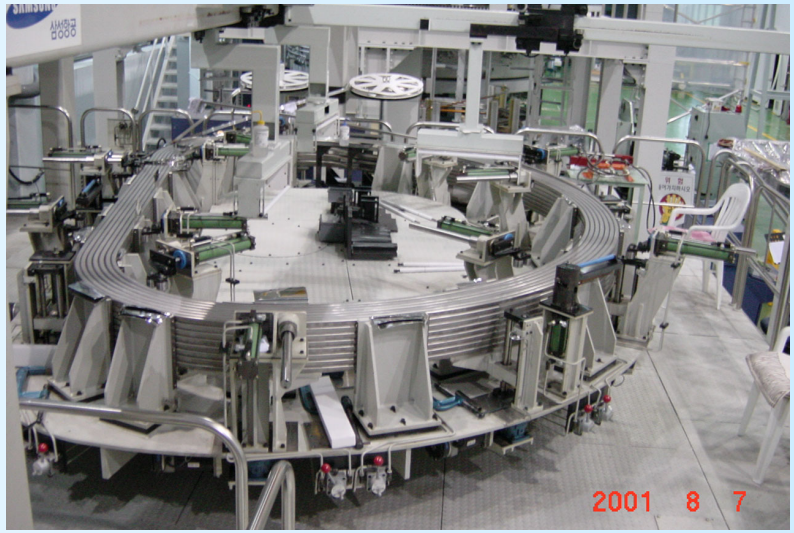
Prototype TF Coil Fabrication

KSTAR

KSTAR TF Coil Specifications

Parameters	Values
Number of coils	16
Major radius [m]	1.8
Toroidal field at major radius [T]	3.5
Peak field in conductor [T]	7.2
Operating current [kA]	35.2
Stored magnetic energy [MJ]	~ 500
Superconductor	NB_3Sn
Jacket material	Incoloy908
CICC length per coil [m]	640
Winding	56 turns
Overall height of a TF case [m]	4.2
Overall width of a TF case [m]	3.0
Weight of a TF coil [ton]	2.87
Weight of a TF structure [ton]	6.4
Total weight of TF magnet system [ton]	148

TF00 Winding Finished on August 2001

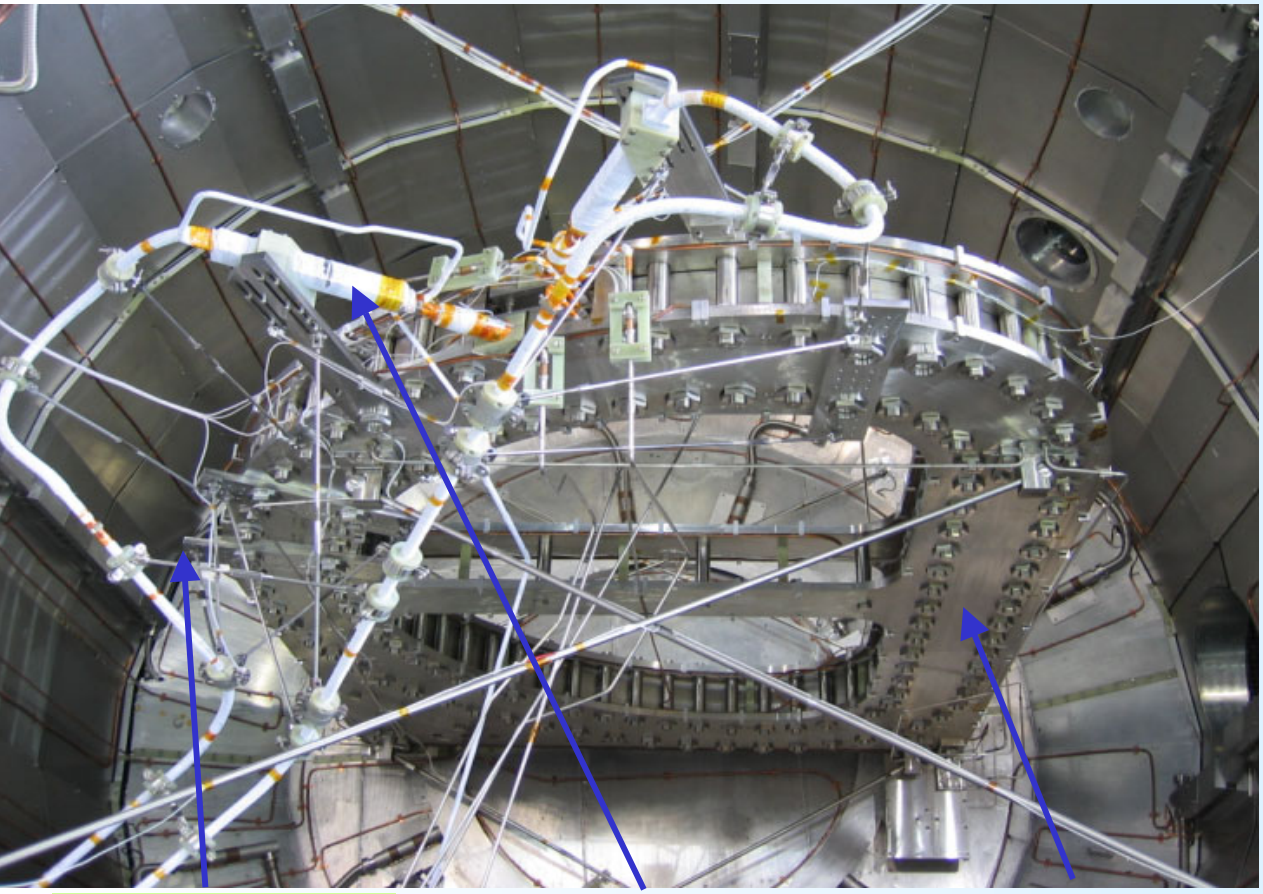


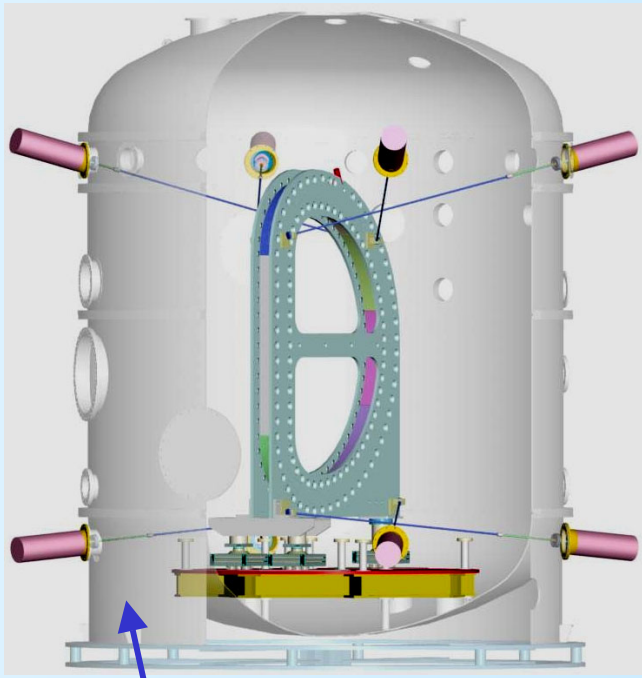
TF00 VPI Finished on April 2002

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

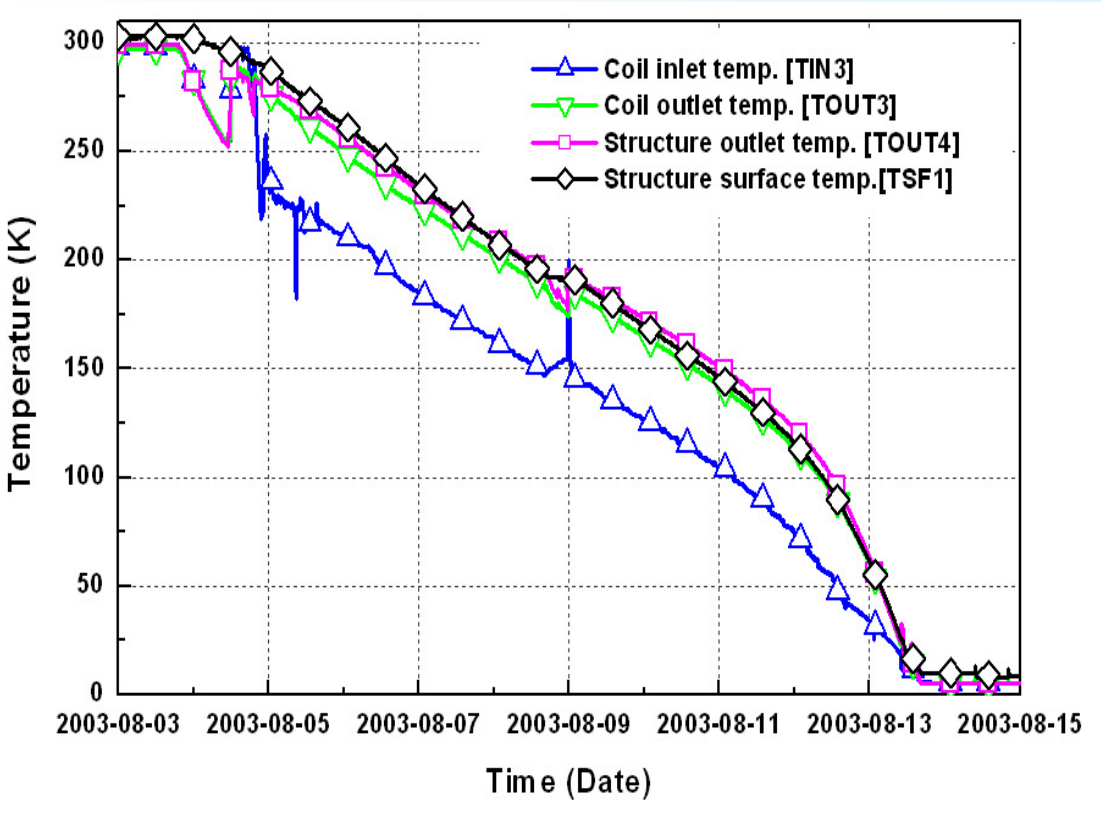




TF00 Coil Cool-down

- 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

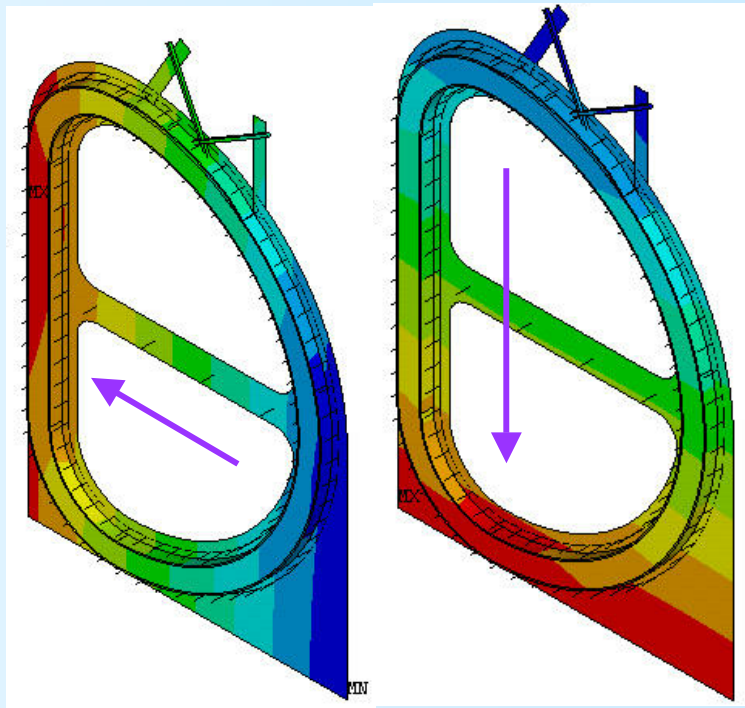
Temperature History during Cool-down



Thermal Contraction by Cool-down

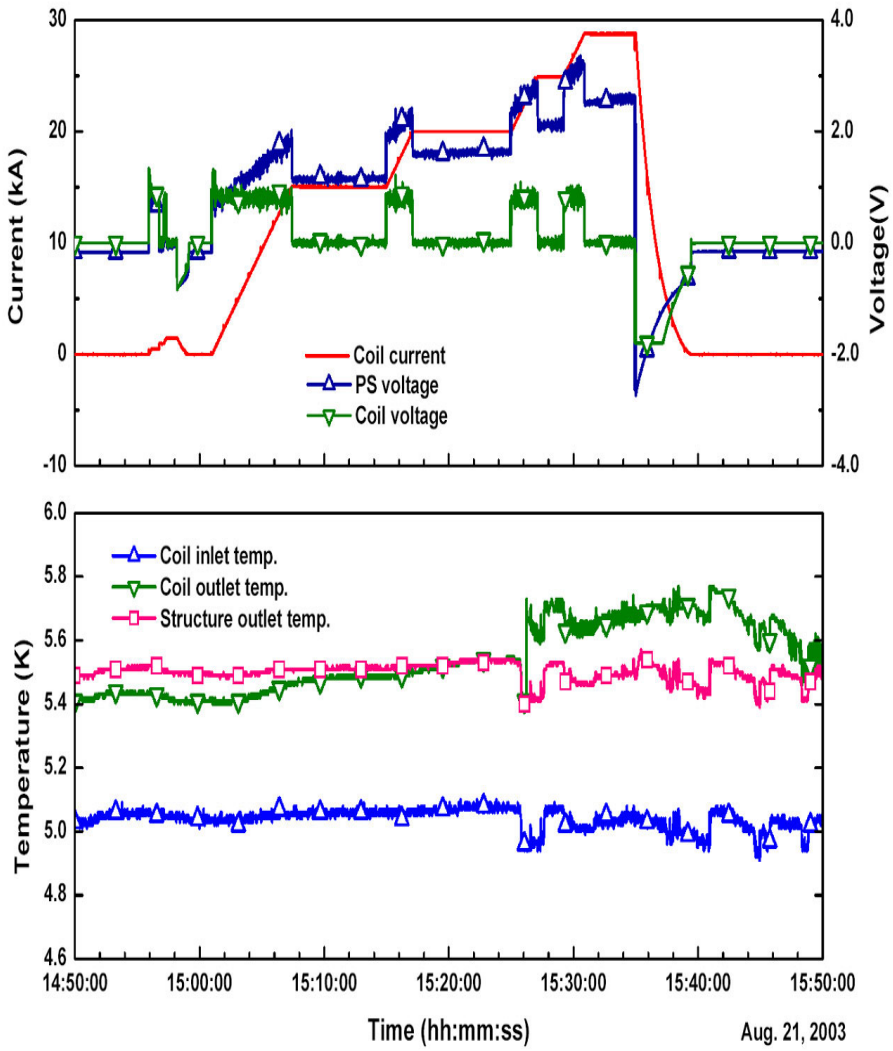
Horizontal
(- 9.3 mm)

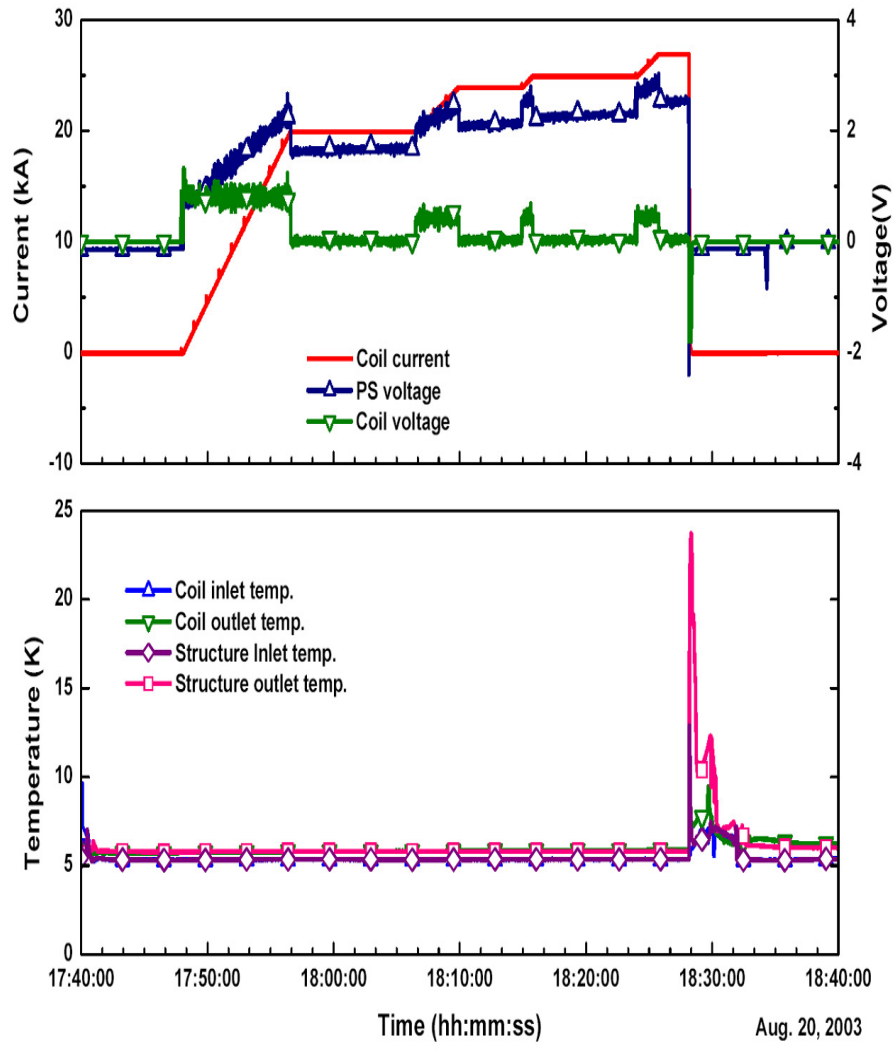
Vertical
(-13.3 mm)



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
  - τ_dump ~ 2 sec
  - Structure heating by eddy current

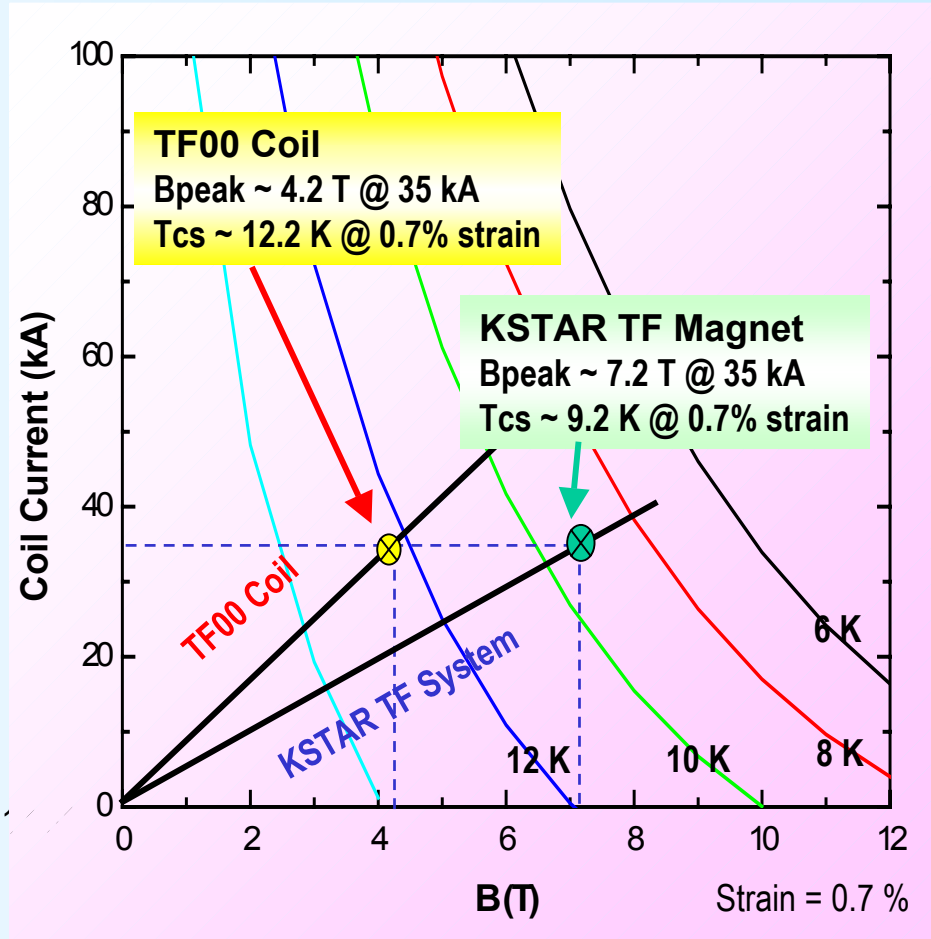




Results of the TF00 Coil Test

- 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.

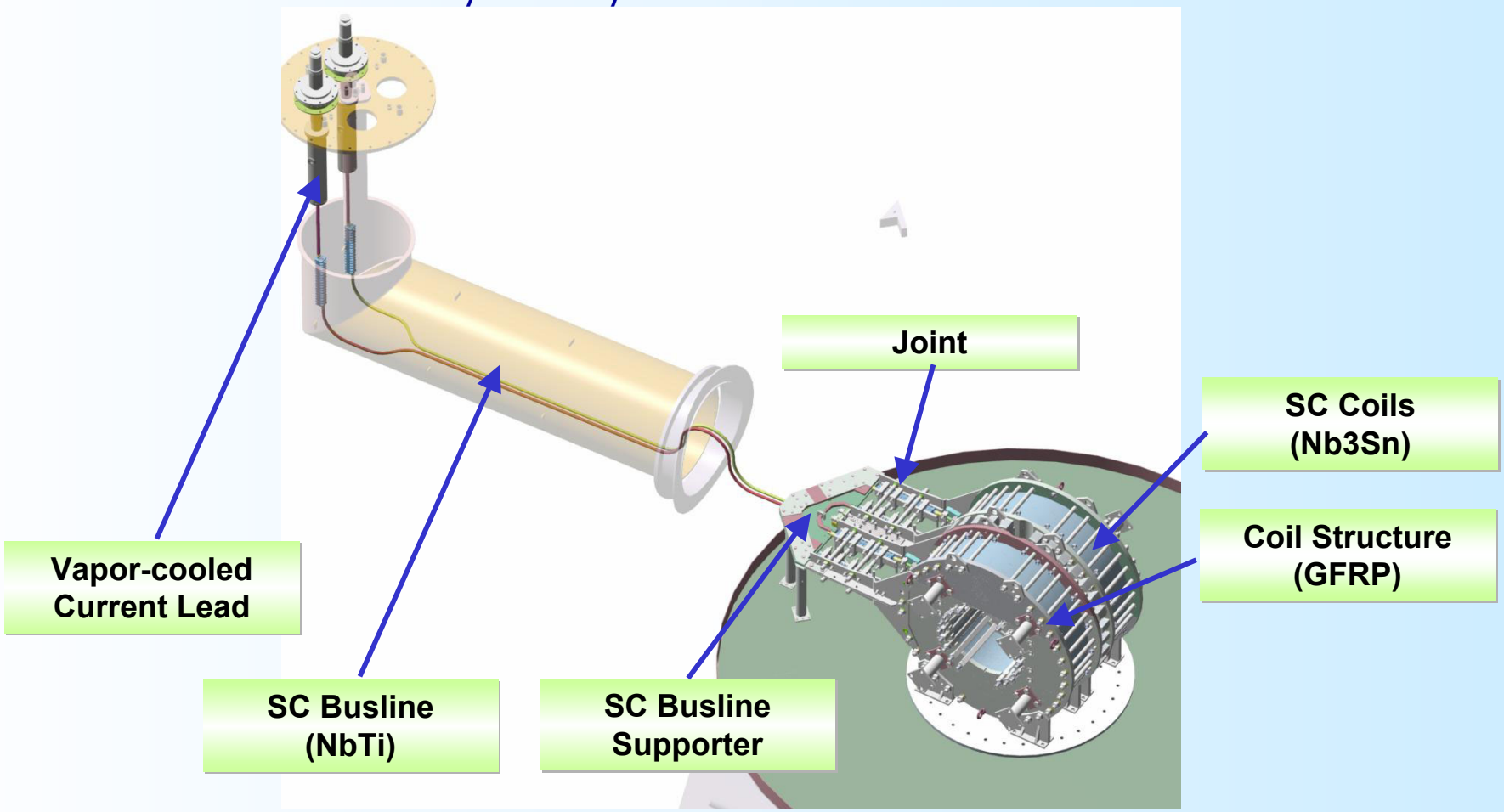


CS Model Coil Test

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 Jc & joint loss
  - To measure the ac performance of the coil, such as ac loss

System Layout of CS Model Coil Test



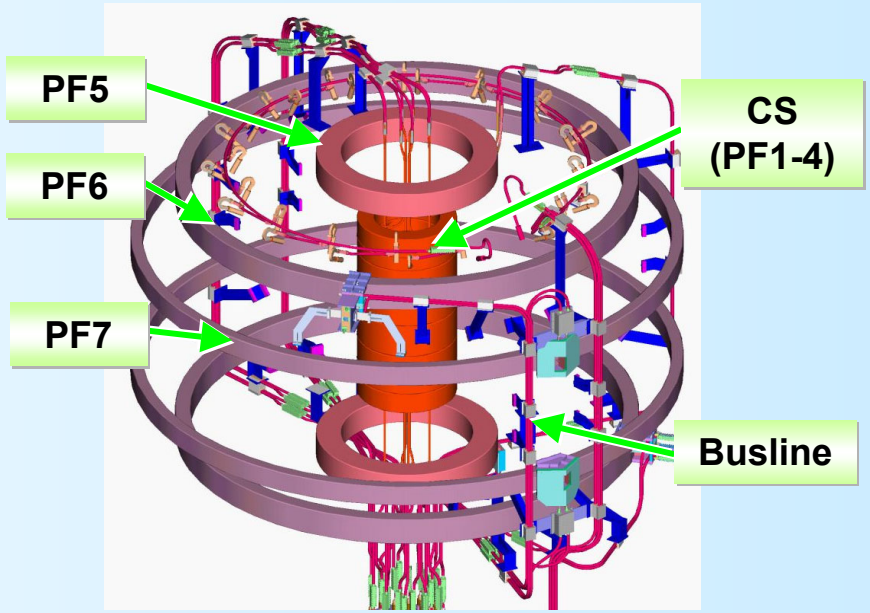
CSMC Fabrication

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

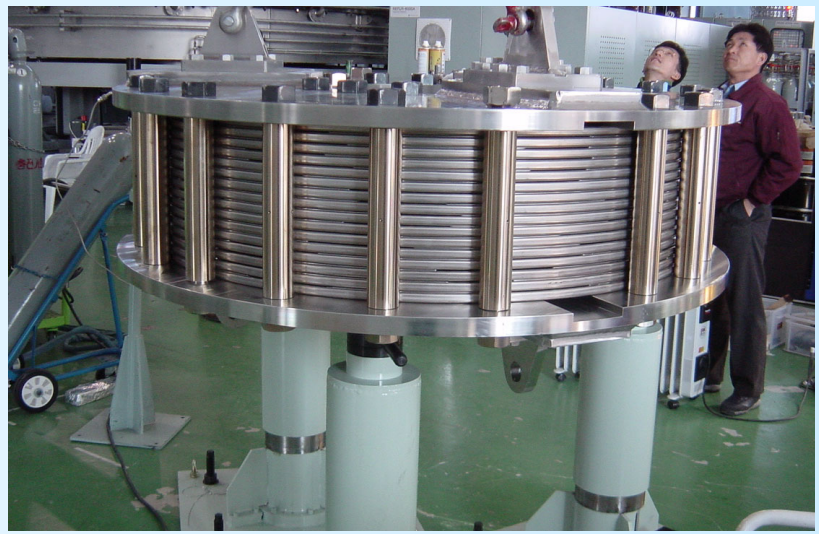
Comparison between CS Coil & CS Model Coil

Parameters	CS Coil (PF1 U&L)	CS Model Coil
Number of coils	2	
Windings per coil	180	240
Mean radius [m]	0.57	0.56
Inner radius [m]	0.46	0.37
Outer radius [m]	0.69	0.74
Height [m]	0.49	0.40
Inductance [mH]	93	135
Superconductor	Nb3Sn	
Jacket	Incoloy908	
B_peak [T]		9.8 T @ 22.6 kA

KSTAR CS & PF Coils



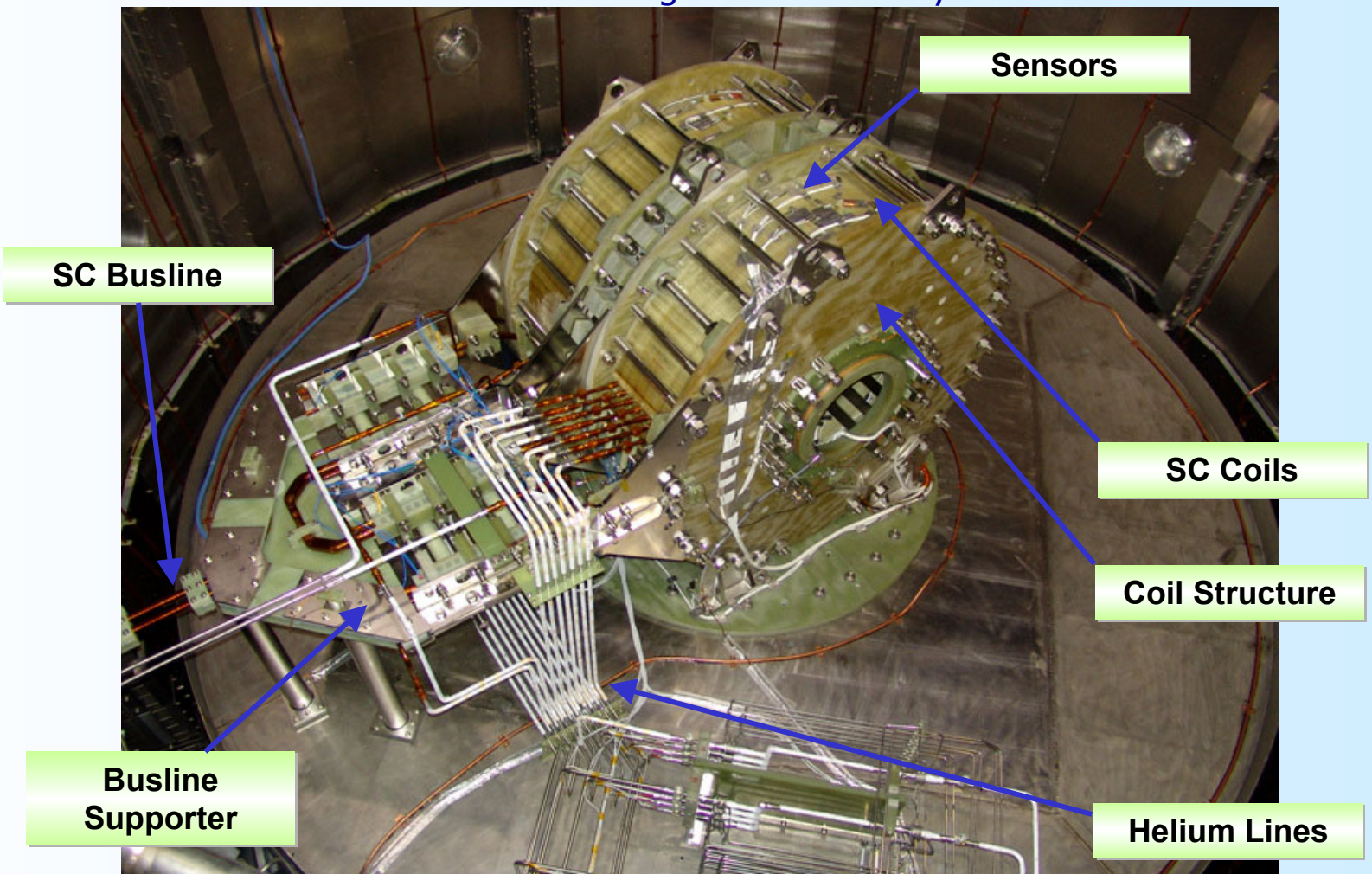
CSMC Winding Finished on Feb. 2002



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

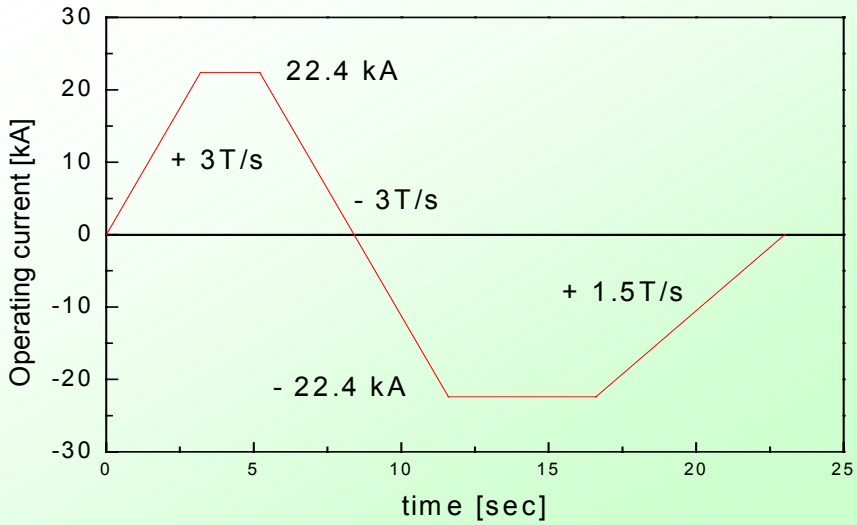
CS Model Coil Assembling Finished on July 2004



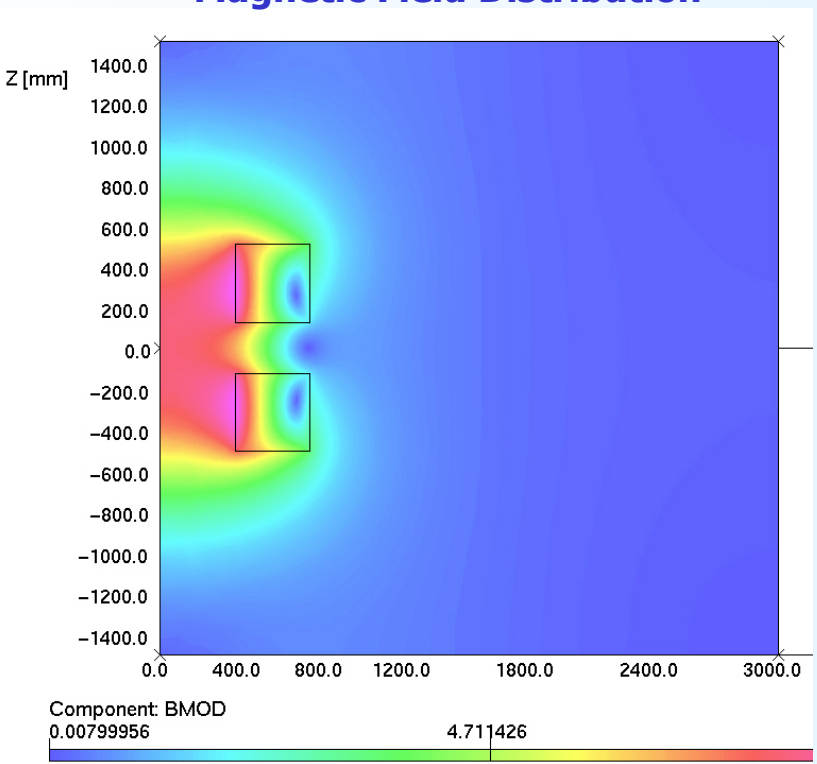
CSMC Operation Analysis

- 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

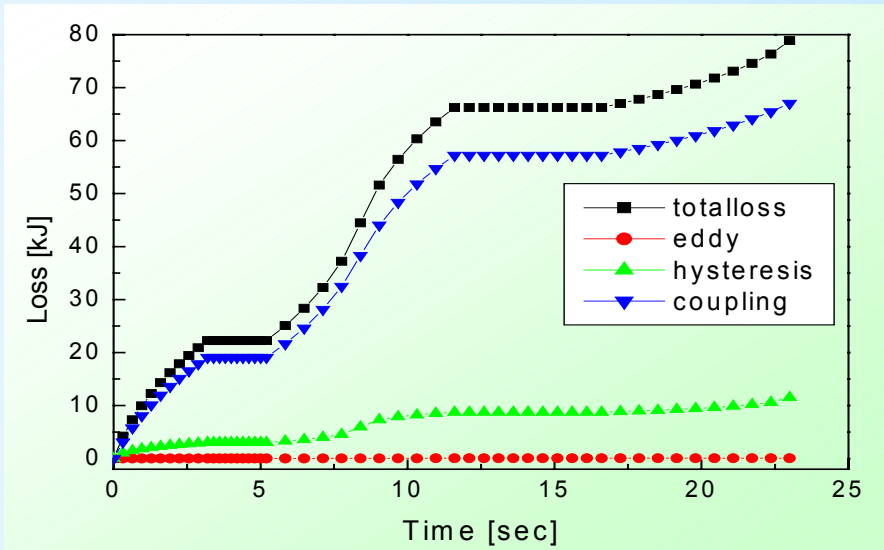
Current Waveform



Magnetic Field Distribution



AC Losses

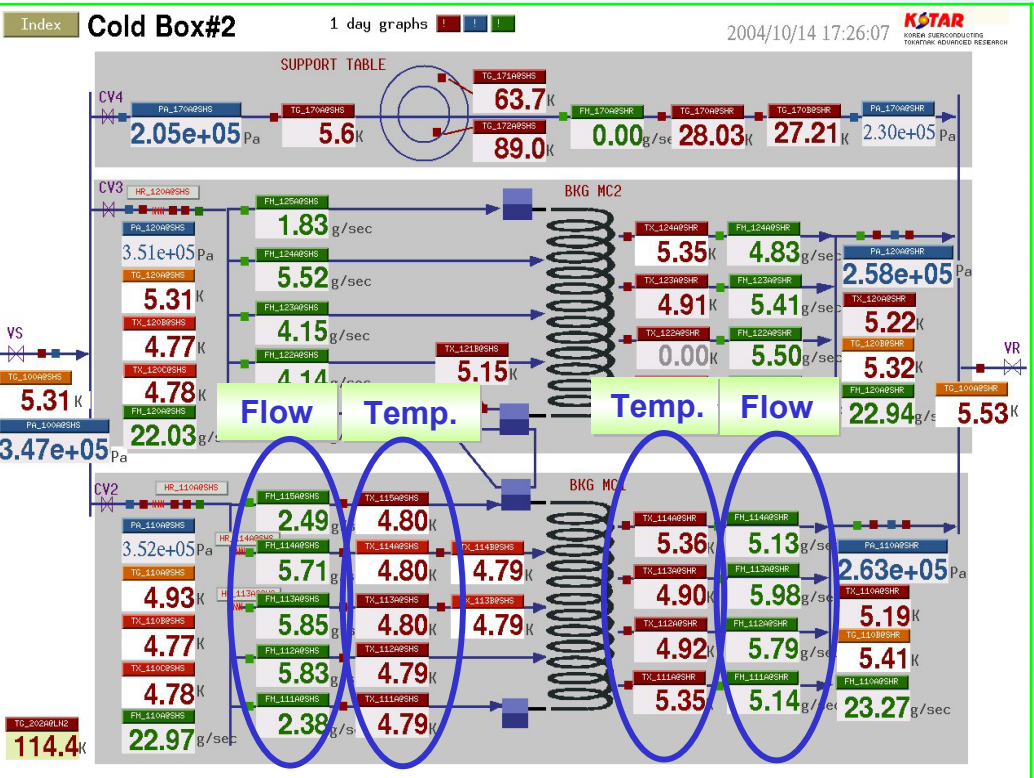


CSMC Cool-down

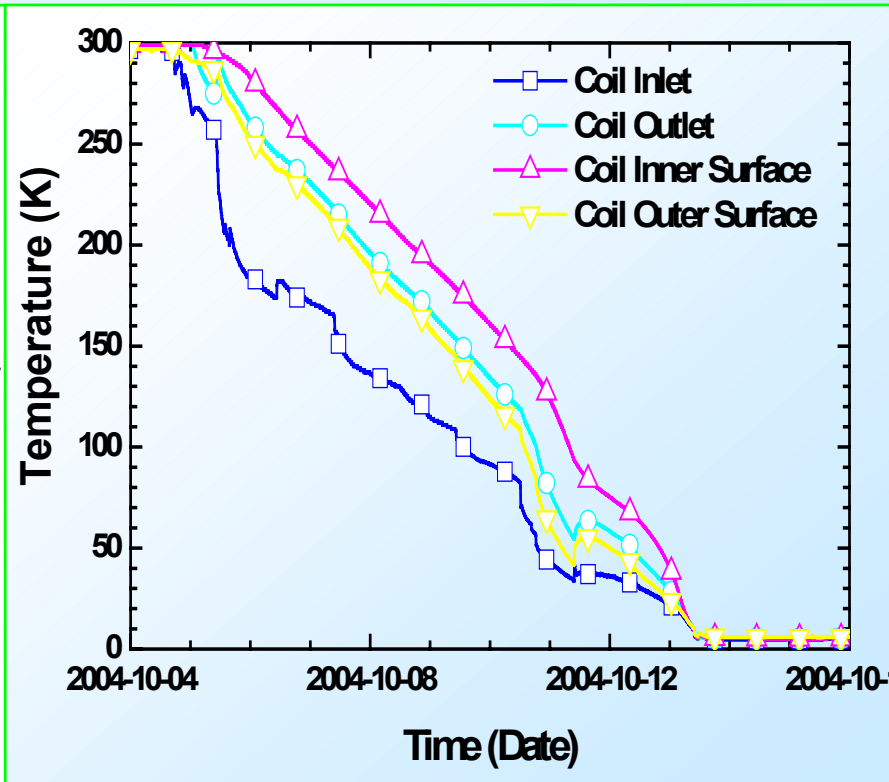
❑ Cool-down in 9 days

- 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



Temperature during Cool-down

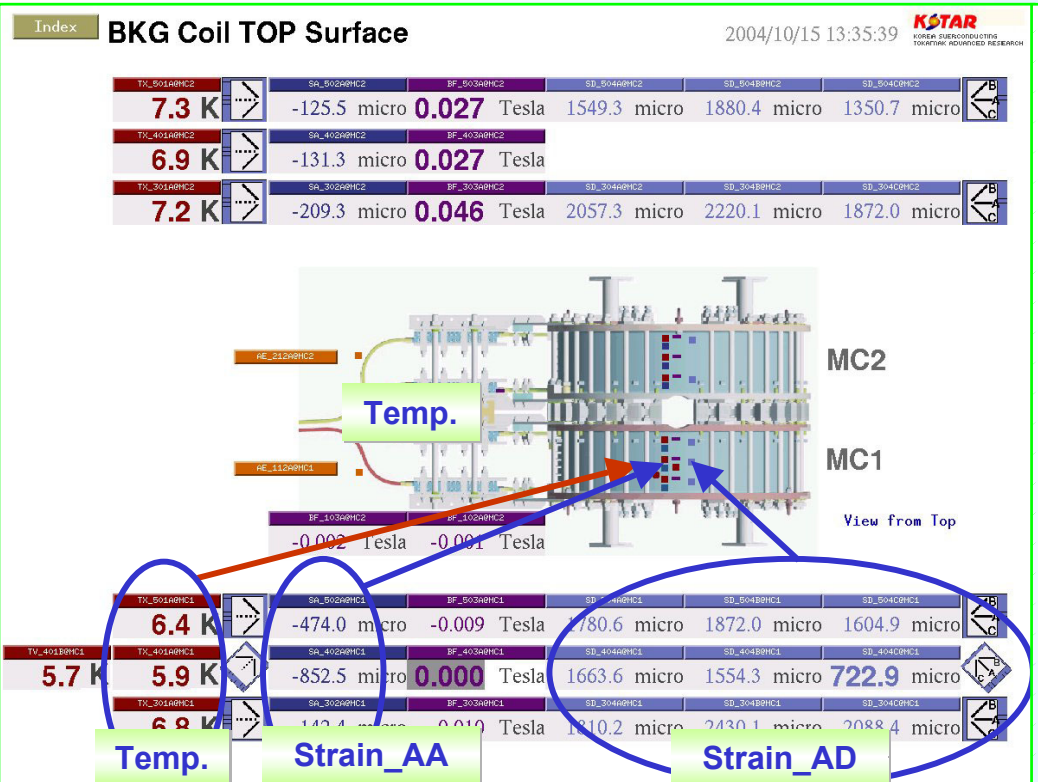


CSMC Cool-down

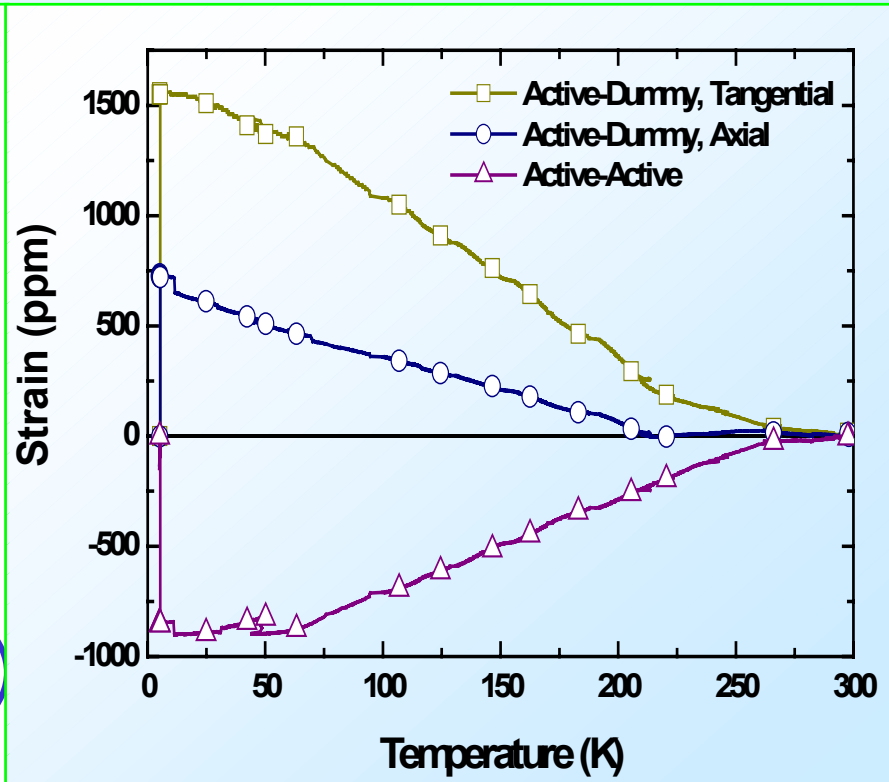
❑ Strain Sensors during Cool-down

- Temperature and field cancellation
- Active-active type & Active-dummy type with GFRP bracket
- Relative strain of coil insulation ~ 0.15 % tangential, ~ 0.07 % axial
- Low thermal contraction of Incoloy908

Sensors on Coil Surface



Strain on Coil Surface during Cool-down

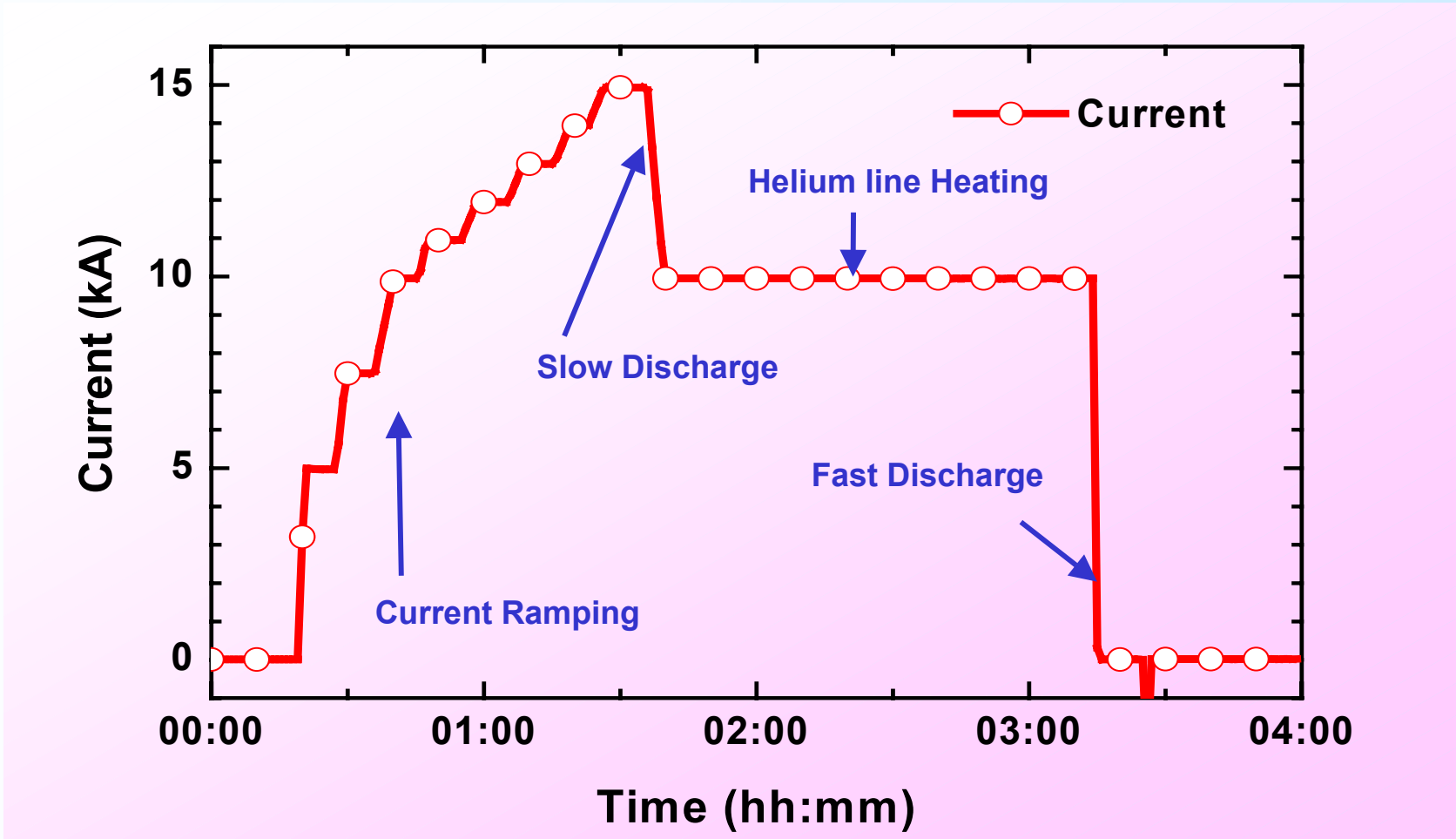


CSMC Current Excitation & Discharge

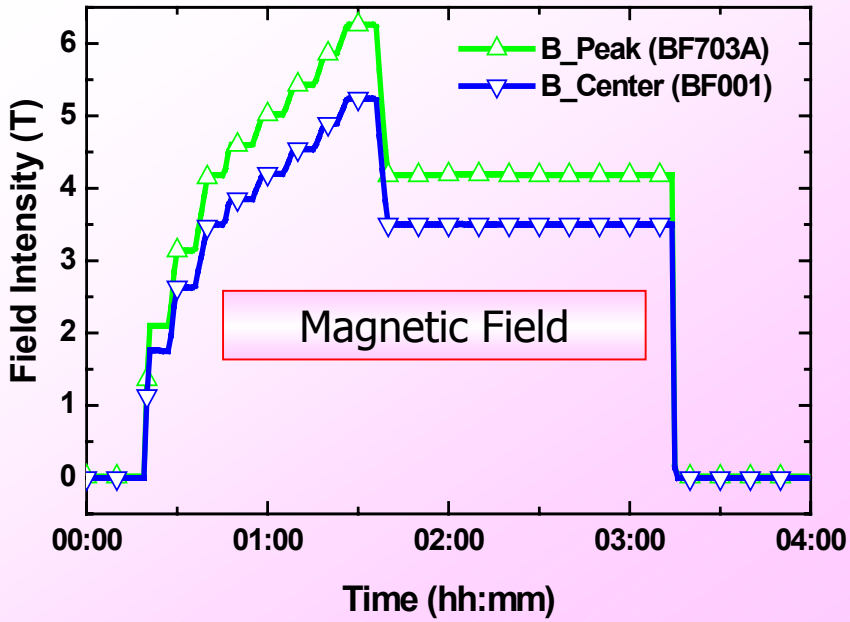
KSTAR

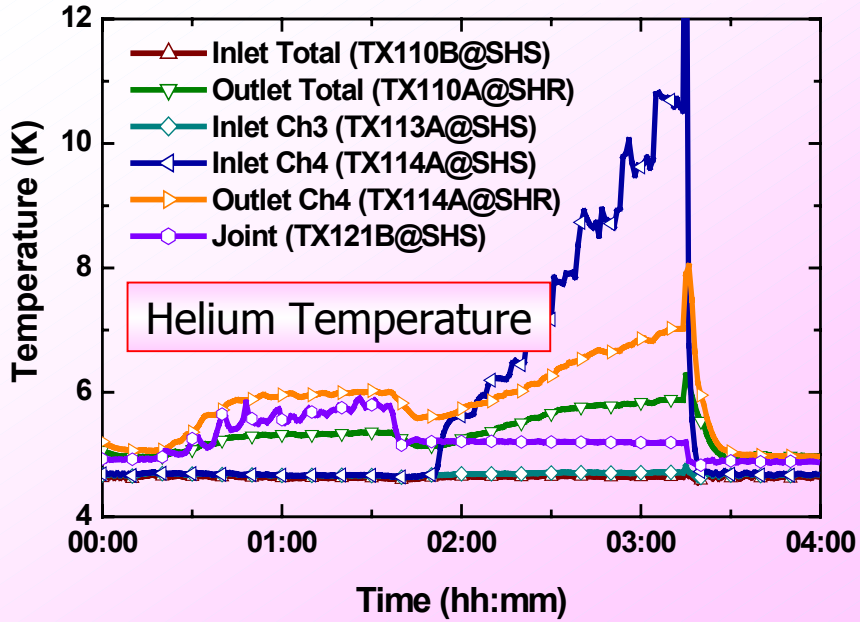
❑ Current Excitation and Discharge

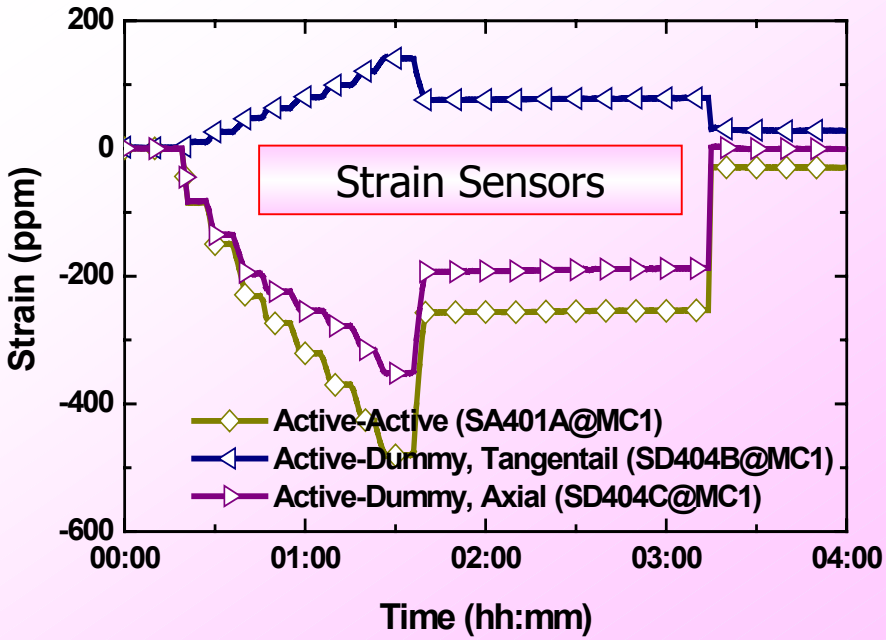
- Current Charge in step up to 15 kA
- Slow discharge to 10 kA
- Heating on helium inlet at 10 kA
- Fast discharge, τ_dump ~ 3 sec

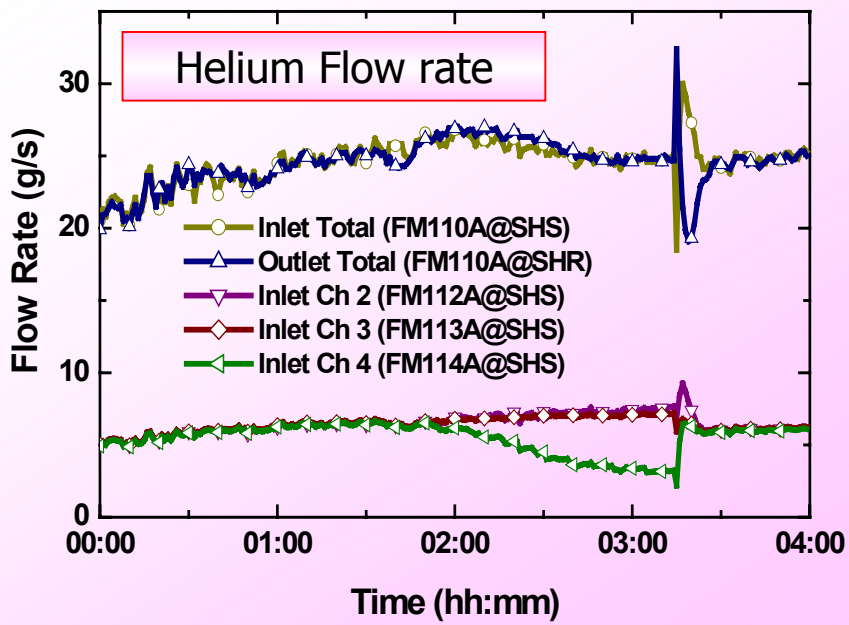


CSMC Current Excitation & Discharge





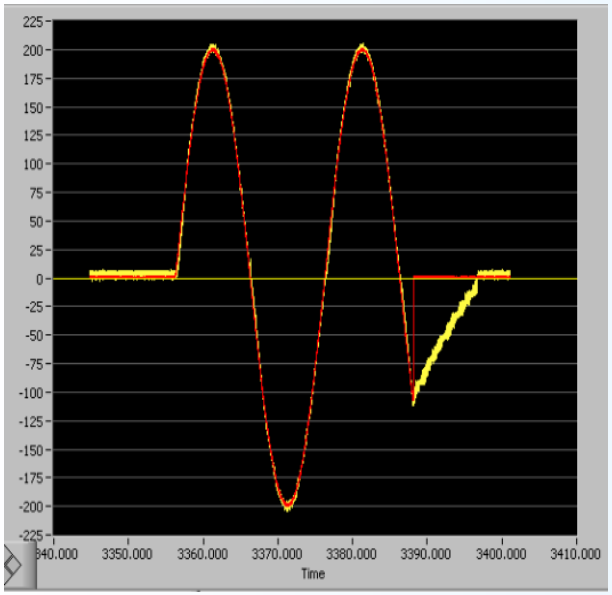


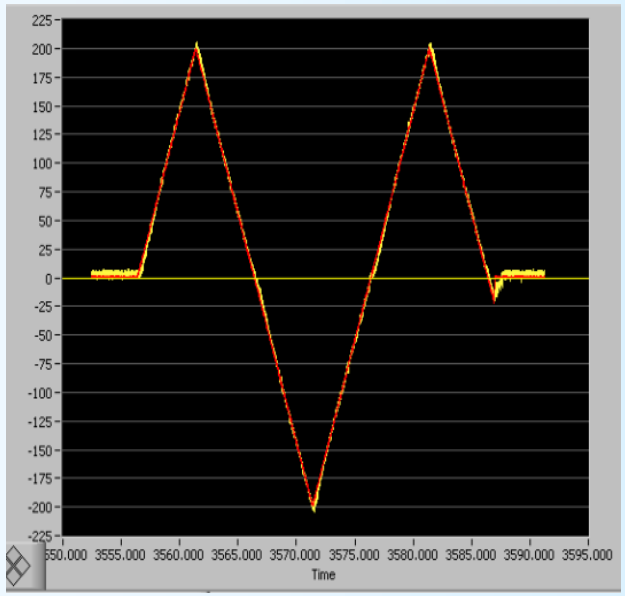


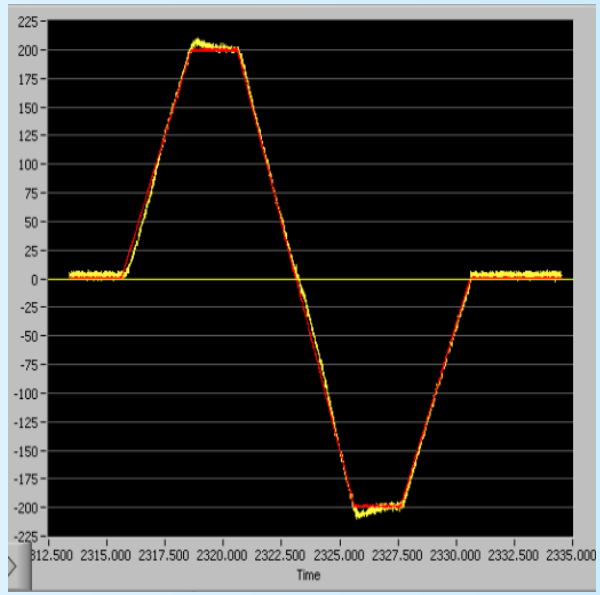
Results of the CSMC Test

- 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.

Reference Coil Current for AC Loss Measurement



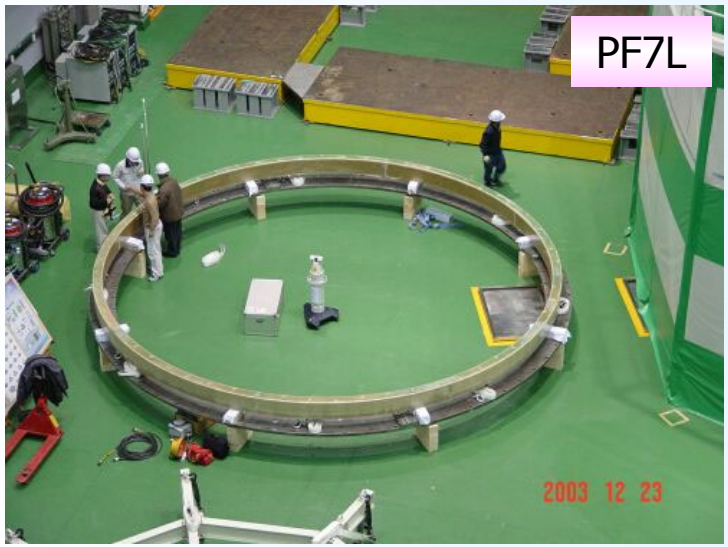


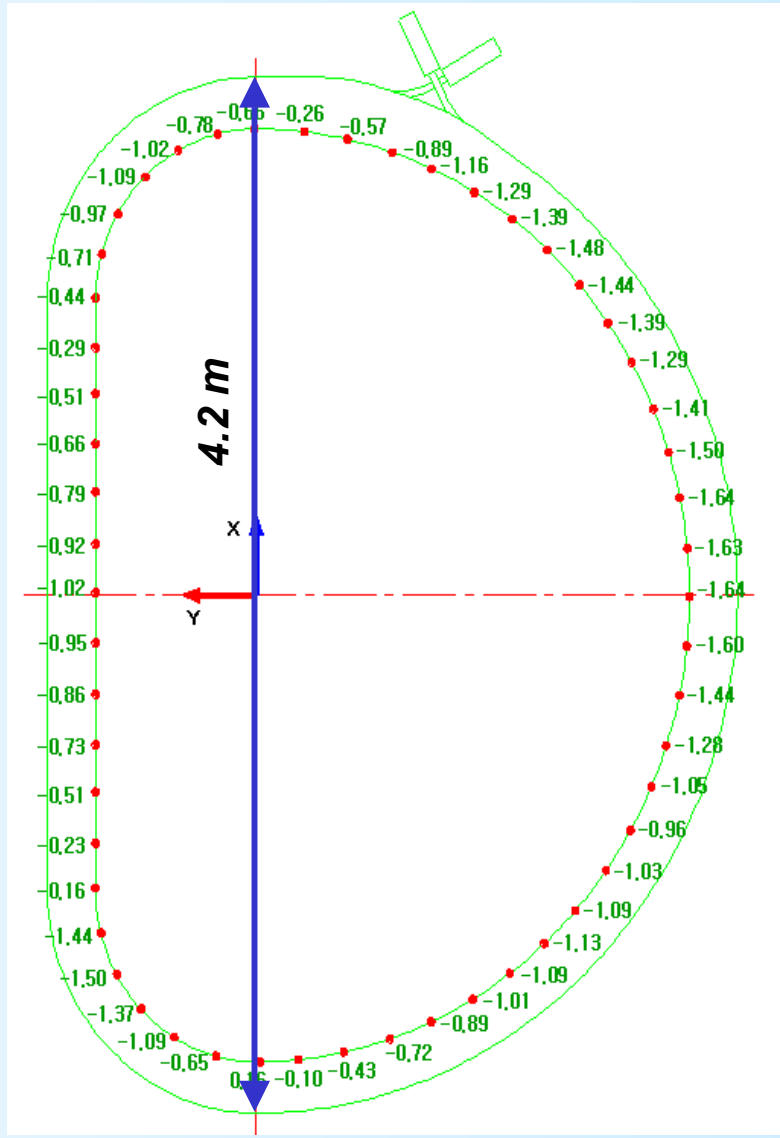


Other Test Activities

KSTAR Coil Acceptance Tests

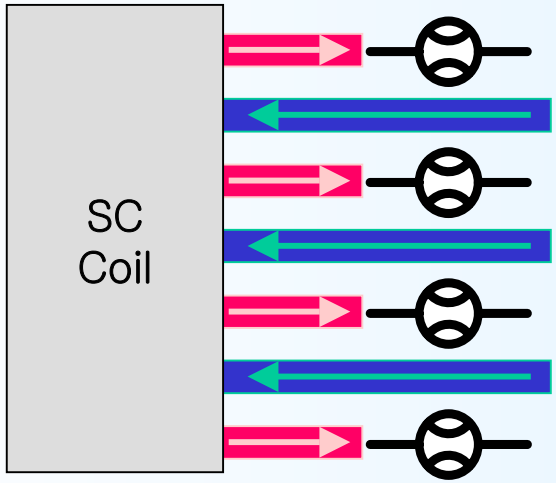
- Dimensional Measurement

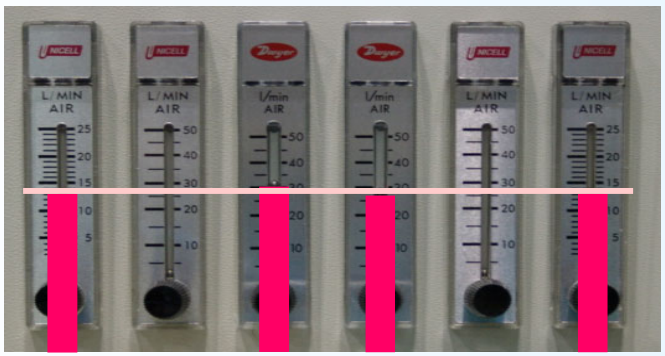




KSTAR Coil Acceptance Tests

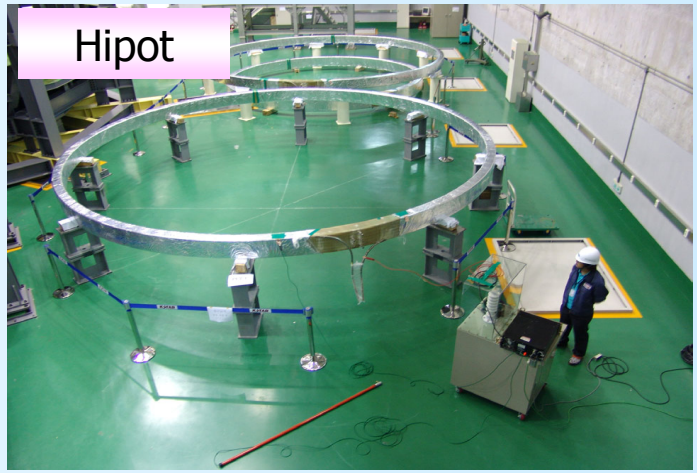
❑ Flowrate Measurement

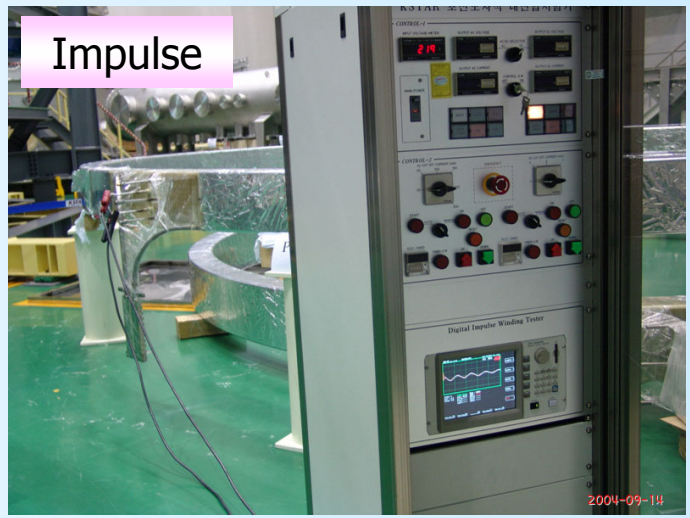




❑ High Voltage Test

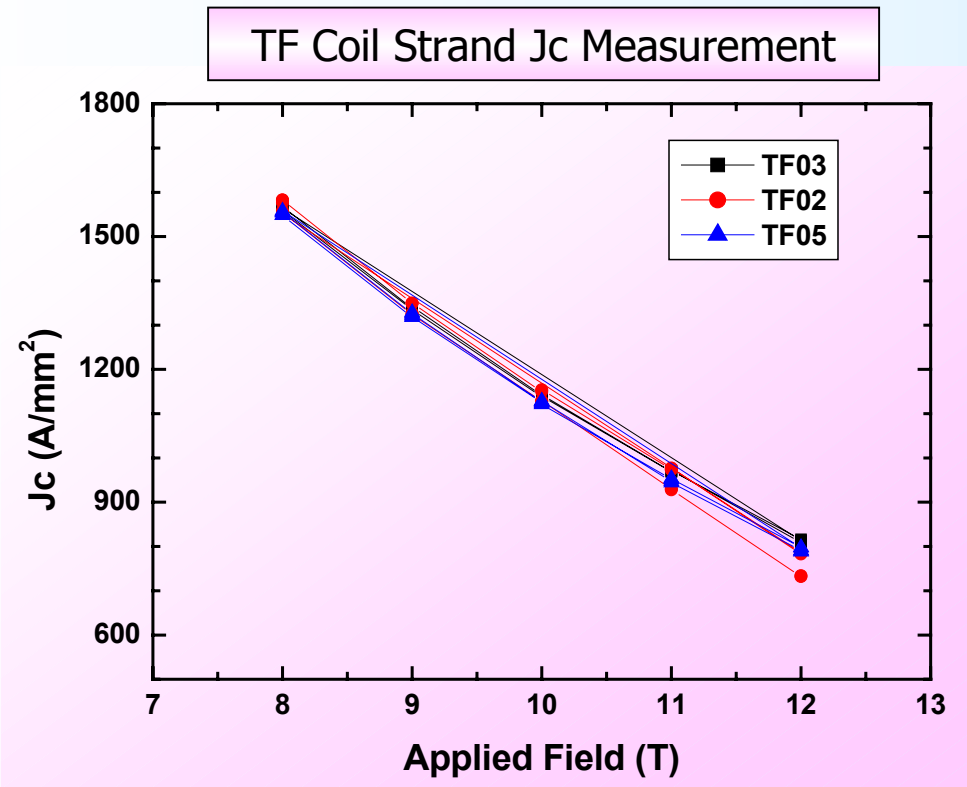
- DC Hipot : 15 kV
- AC Hipot : 10 kVrms
- Impulse



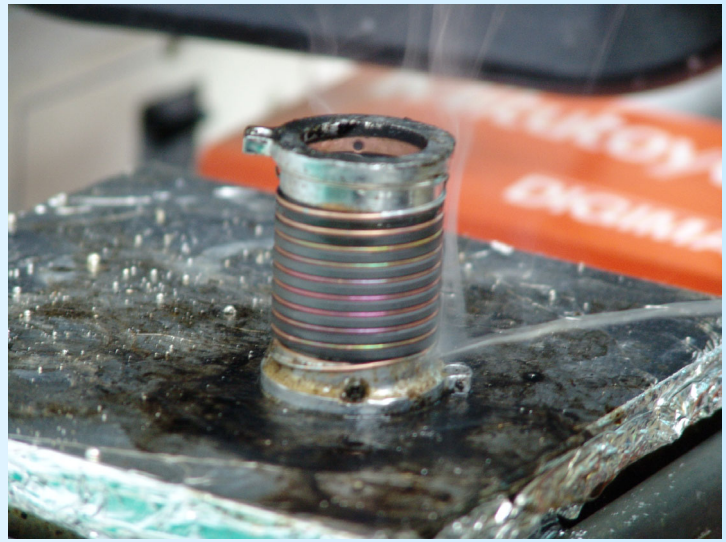


KSTAR Coil Acceptance Tests

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



Sample



Jc Measuring System

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.