Cryogenic thermometry for refrigerant distribution system of JT-60SA

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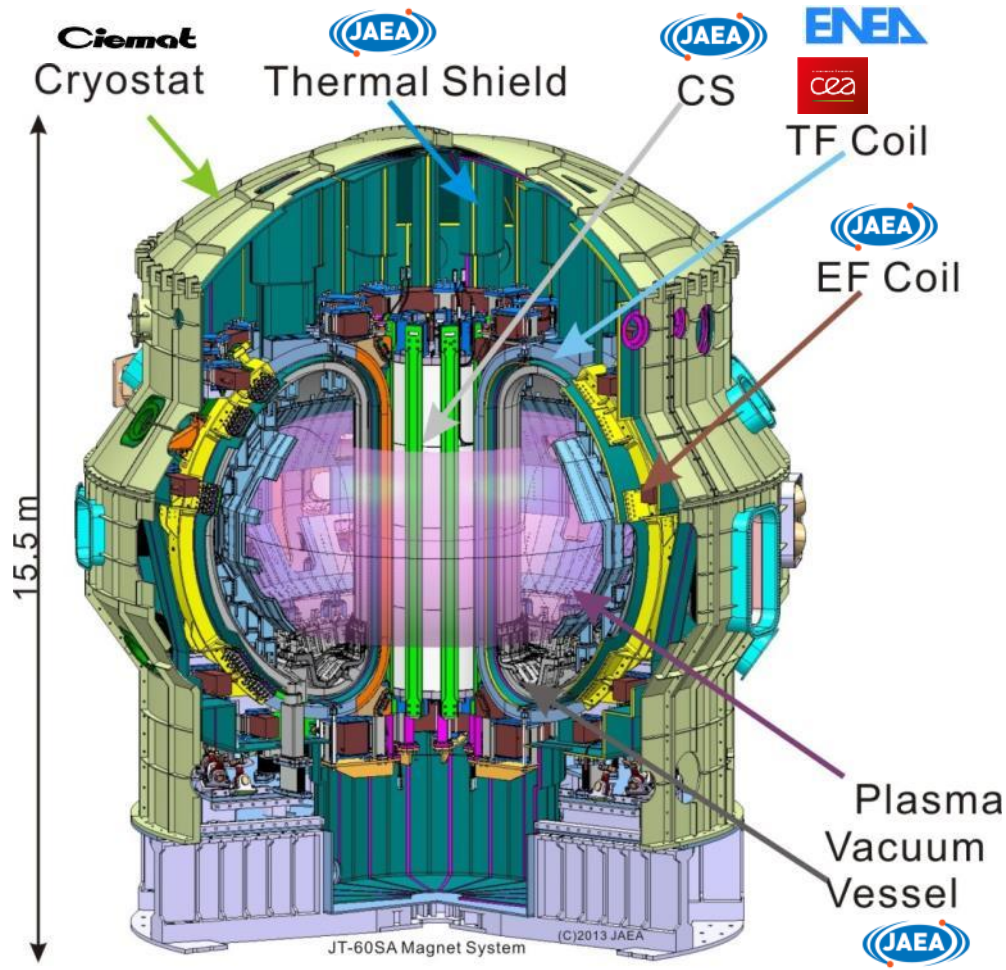
A Tokamak under construction in Japan

JT-60SA is a fusion experiment designed to support the operation of ITER and to investigate how best to optimize the operation of fusion power plants that are built after ITER. It is a joint international research and development project involving Japan and Europe, and is to be built in Naka, Japan using infrastructure of the existing JT-60 Upgrade experiment. SA stands for "super, advanced", since the experiment will have superconducting coils and study advanced modes of plasma operation.

(http://www.jt60sa.org/)



Superconducting Coils

Magnetic field for confinement plasma is generated by 18 Toroidal Field Coil (TFC), 6 Equilibrium Field Coil (EFC) and Central Solenoid (CS).

Specification	JT-60SA
Magnetic Energy of TFC (GJ)	1.1
Maximum Magnetic Field of TFC (T)	5.65
Centripetal Force of TFC (MN)	22.6
Magnetic Field of CS (T)	8.9
Cold Mass (ton)	~ 700

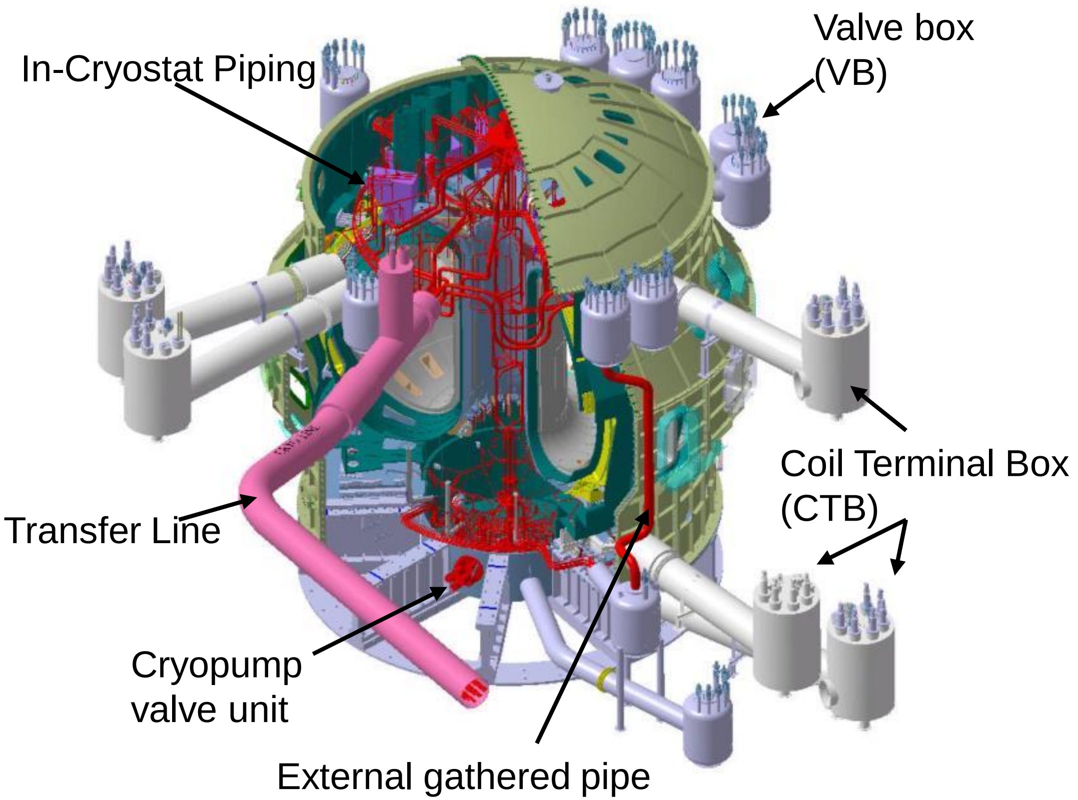
Refrigerant distribution system

Helium from a Refrigerator System is distributed to Toroidal Field Coil (TFC), Poloidal Field Coil (PFC)*, Thermal Shield (TS), High Temperature Superconducting Current Lead (HTSCL) and CryoPump. (*PFC are composed of Equilibrium Field Coil and Central Solenoid)

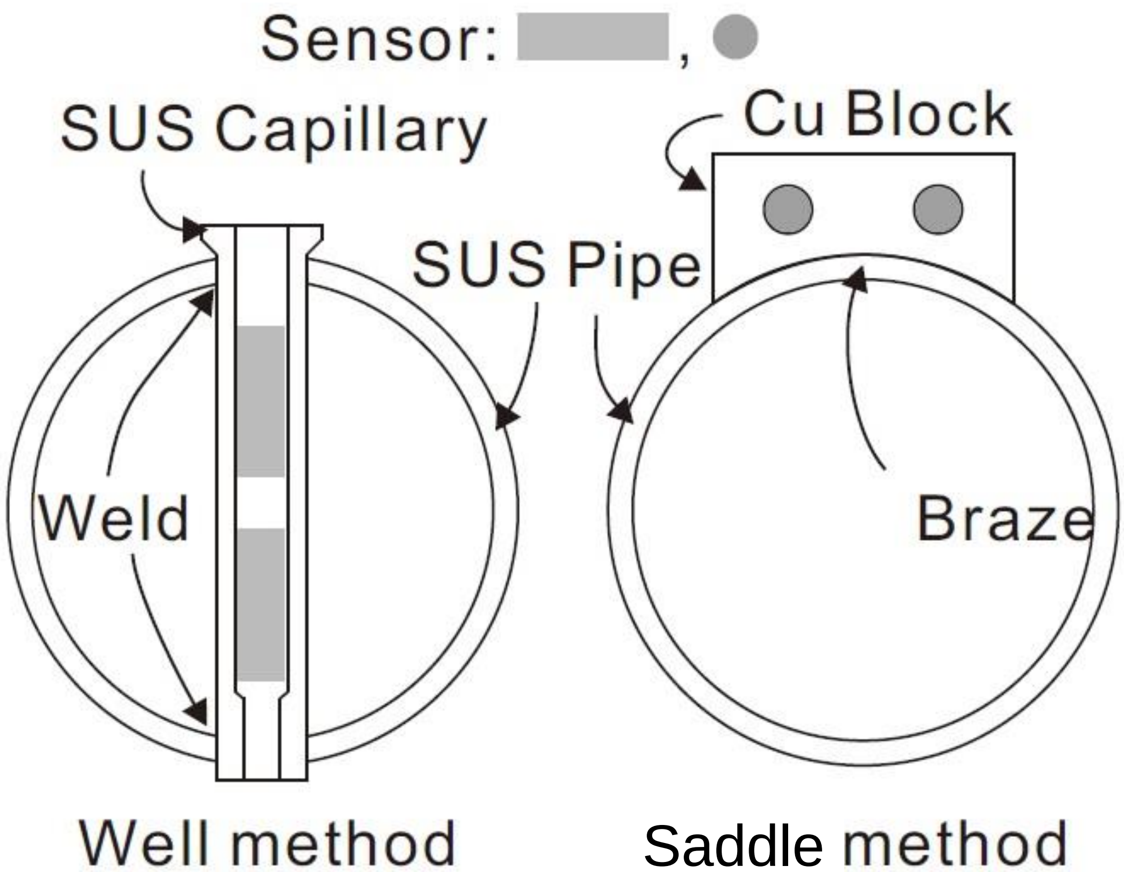
Cold Component	TFC	PFC	TS	HTSCL	CryoPump
Temperature (K)	4.4	4.4	80	50	3.7
Pressure (MPa)	0.40	0.40	1.35	0.40	0.5
Flow rate (g/s)	876	960	404	30	270
Pressure loss (MPa)	0.13	0.08	0.13	0.30	0.1
Heat load (W)	1794	1850	42,000	-	1400
Mass (Ton)	370	206	96	-	-

Temperature Measurement

About 300 thermometers are attached on distribution pipes and thermal shield (TS). They are mainly installed on pipes beside flow meters in Valve boxes (VBs) and Coil Terminal Boxes (CTBs) in order to adjust flow rate of refrigerant to cold components.



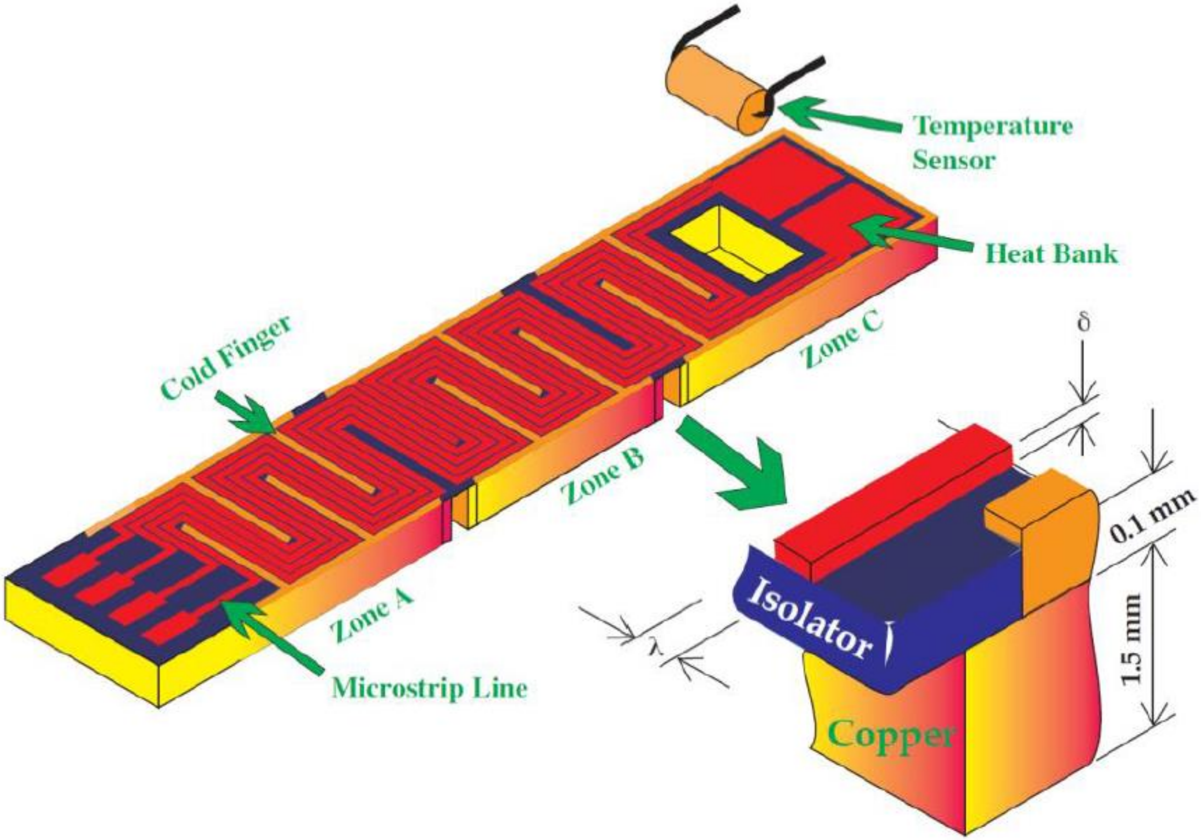
How to install on refrigerant pipe?



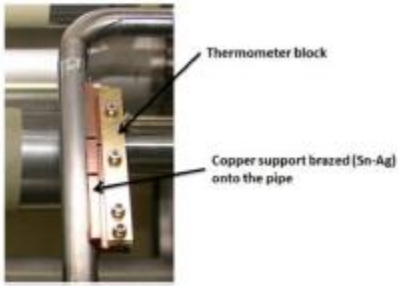
- Well Method
  - Higher accuracy*
  - Lower productivity
  - Leak tightness and proof pressure test are imposed.
- Saddle Method
  - Lower accuracy*
  - Higher productivity
  - Specific inspection is not imposed.

*Main factor : ("Cooling power from sensor" – "Heat load to sensor")

Reference：A thermometry for LHC at CERN



- Dimention:
  100 × 10 × 2 (mm)
- Temperature ~1.8 K
- When the temperature of the terminal of Microstrip Line is 80 K, the accuracy is ±100 mK.
- The similar method will be adopted for ITER*.



“Industrial-type cryogenic thermometer with built-in heat interception”, C. Balle and J. Casas: Advances in Cryogenic Engineering 41 (1996) pp1715-1721.

Requirement accuracy

JT-60SA comply with ITER requirement*

Temperature	Precision
T at 4.2 K : used in magnet coil temperature control loops	±0.1 K
T < 10 K	±0.2 K
10 K < T < 80 K	±0.3 K
80 K < T	±0.5 K

: The temperature acquisition period per thermometer should be less than 2 seconds.

*DDD11-9: Instrumentation and controls
DDD: Design Description Document

Objective

- To decide the thermometry method for Helium in pipes.
  - comparing two sensor attachment methods
    : Well method and Saddle method
  - comparing two sensors: Cernox™ and TVO
  - comparing two wire anchoring methods
    : Print-Circuit Board (PCB) and CuNi wire with Stycast 2850FT
  - comparing two sensor fixation materials
    : Apiezon N grease and Stycast 2850FT

in terms of accuracy and productivity.

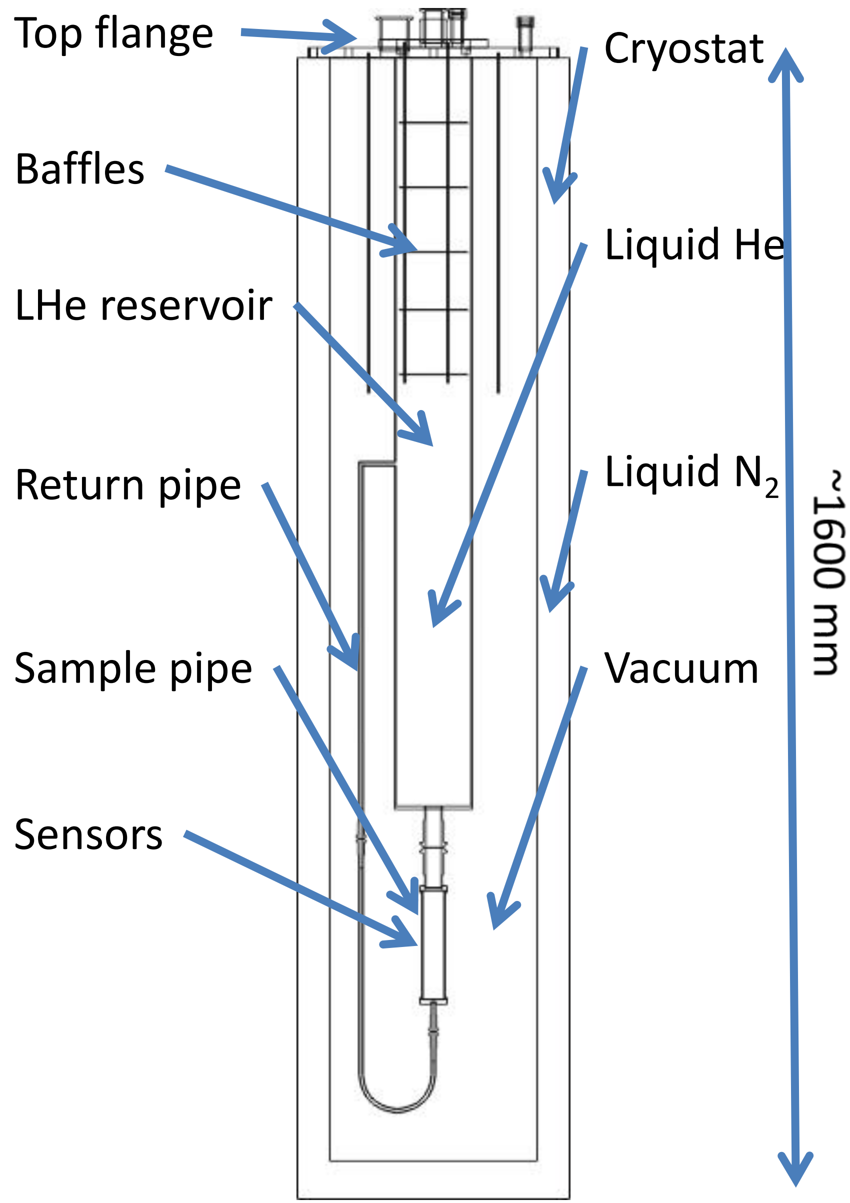
If the accuracies of both choices are satisfied the requirement, higher productivity one is adopted.

Sensor attachment		Sensors		Wire anchoring method		Sensor fixation material	
Well method		Cernox		Print-Circuit Board (PCB)		Apiezon N grease	
Saddle method		TVO		CuNi wire with Stycast		Stycast 2850FT	

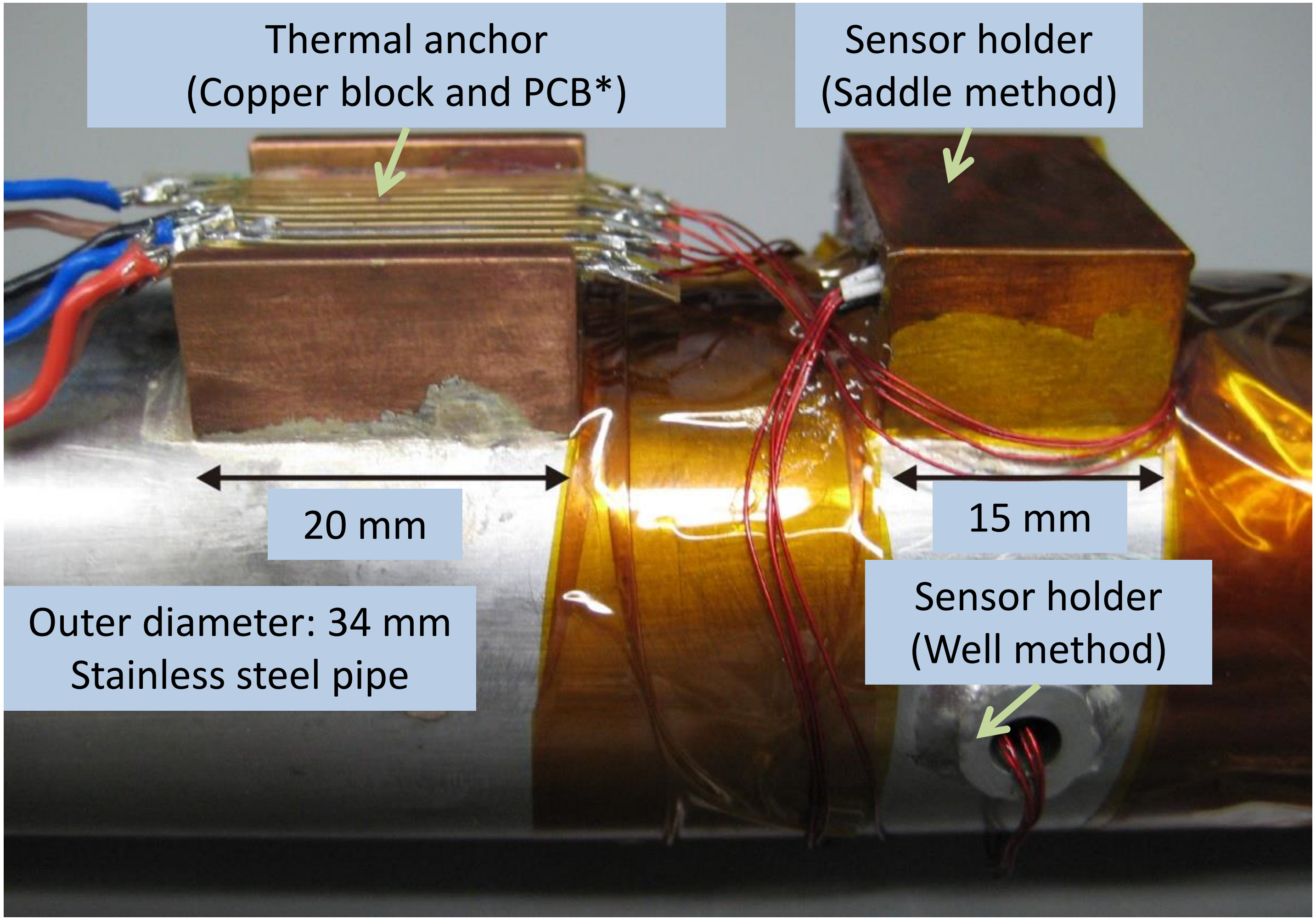
Experimental apparatus

The sample pipe is installed in vacuum and filled with liquid Helium (LHe). The temperature of LHe is shifted by pressurized or depressurized.

A temperature sensor is directly immersed in LHe in the pipe as the reference sensor. The sensor accuracies attached on the pipe are evaluated using this reference sensor.

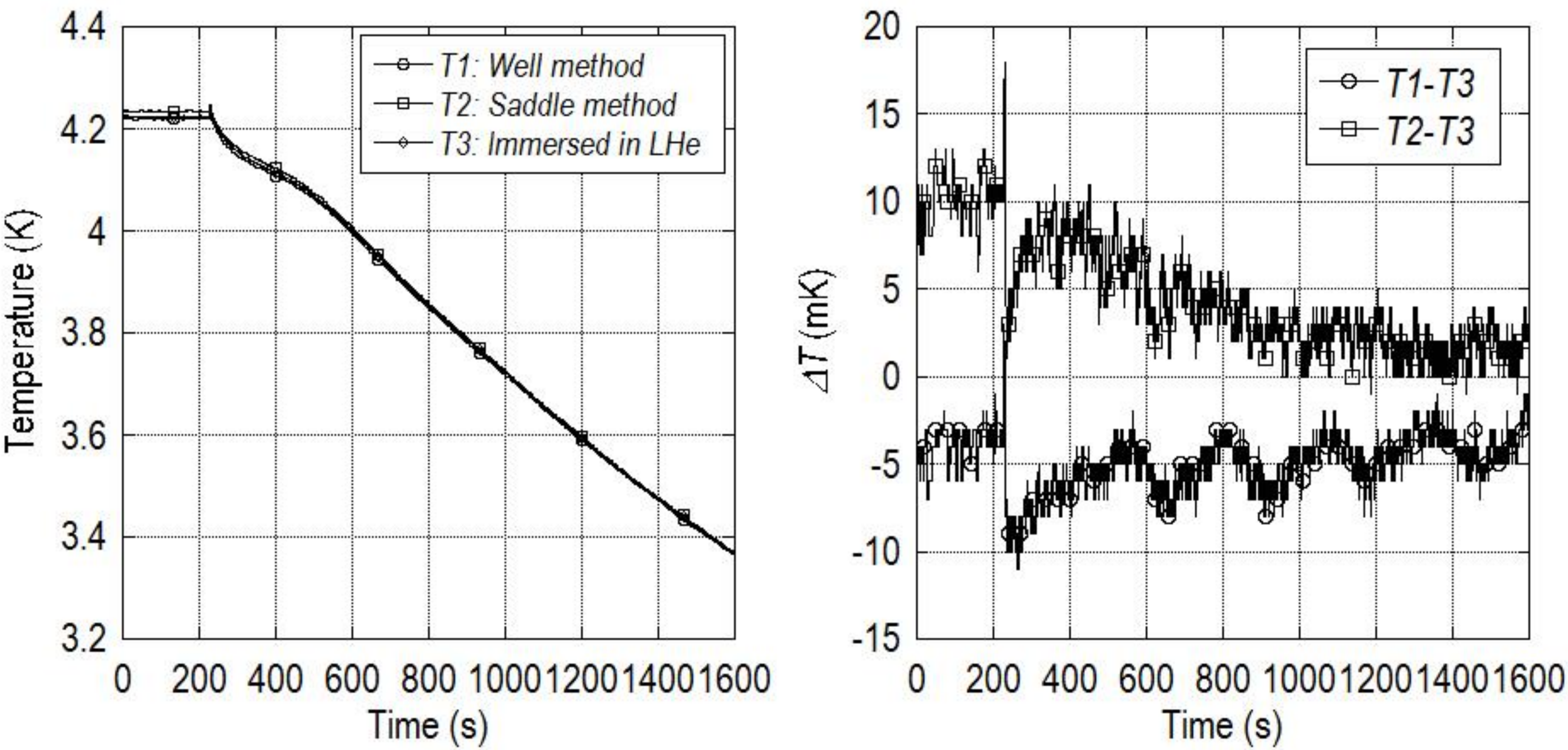


1. Two attachment methods tested at the same time using Cernox anchoring with PCB



*PCB: Printed-Circuit Board

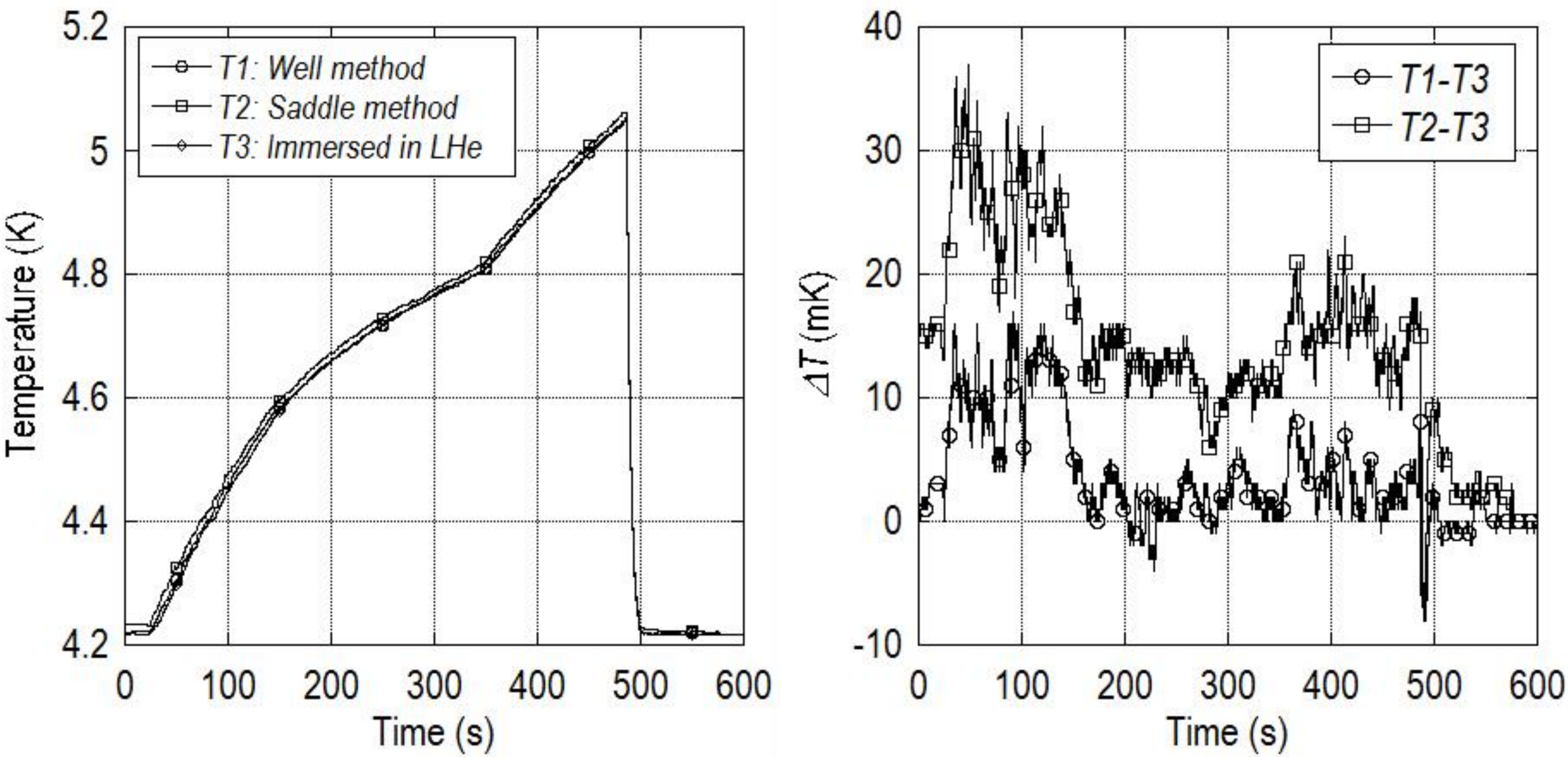
Comparison of the well and the saddle methods at 3.37-4.22 K



Both differences from the reference sensor are allowable

*The calibrated accuracy of the bare chip of Cernox^{TM} is ±5 mK
(*Temperature Measurement and Control Catalog*, Lake Shore Cryotronics, Inc.)

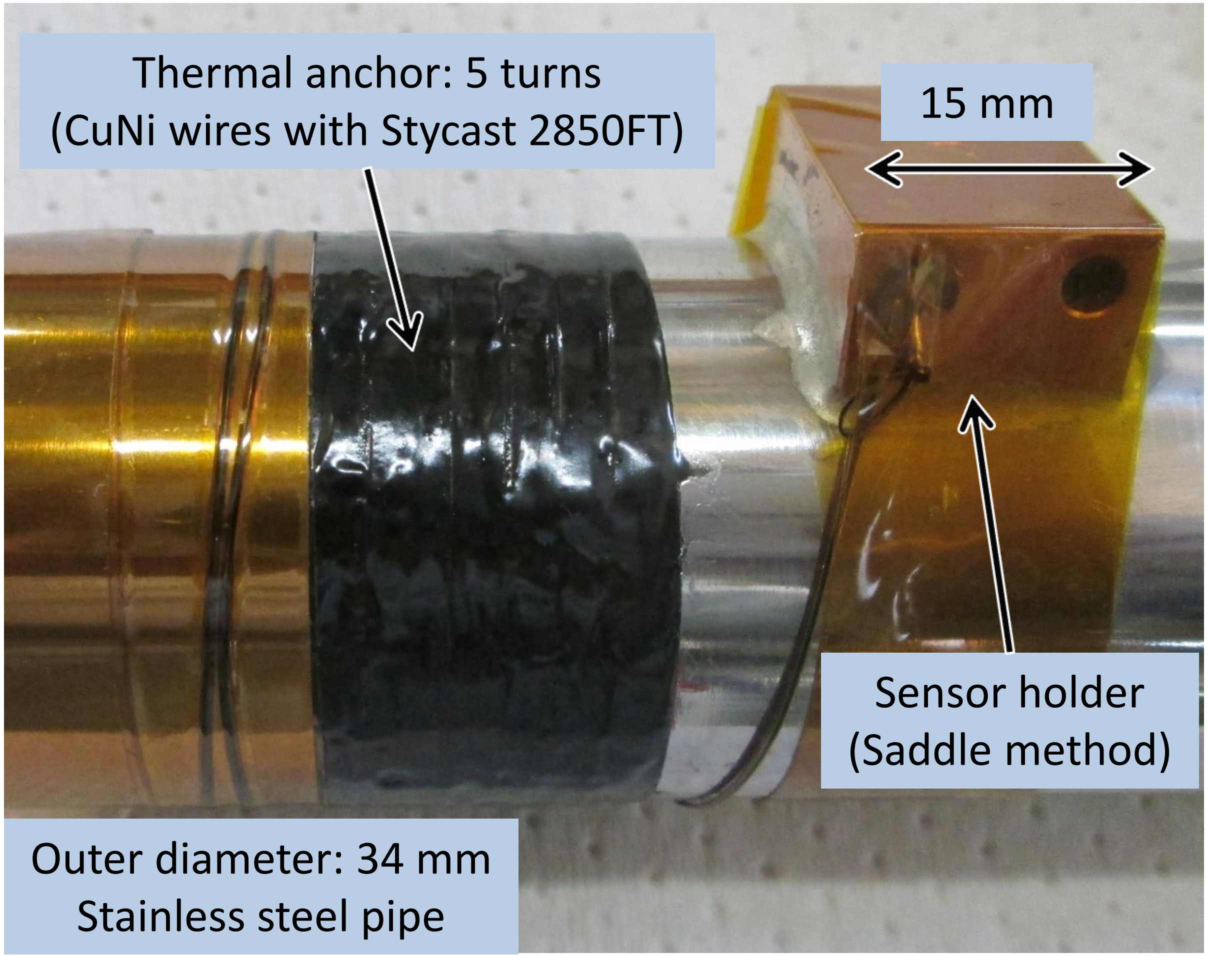
Comparison of the well and the saddle methods at 4.22-5.06 K



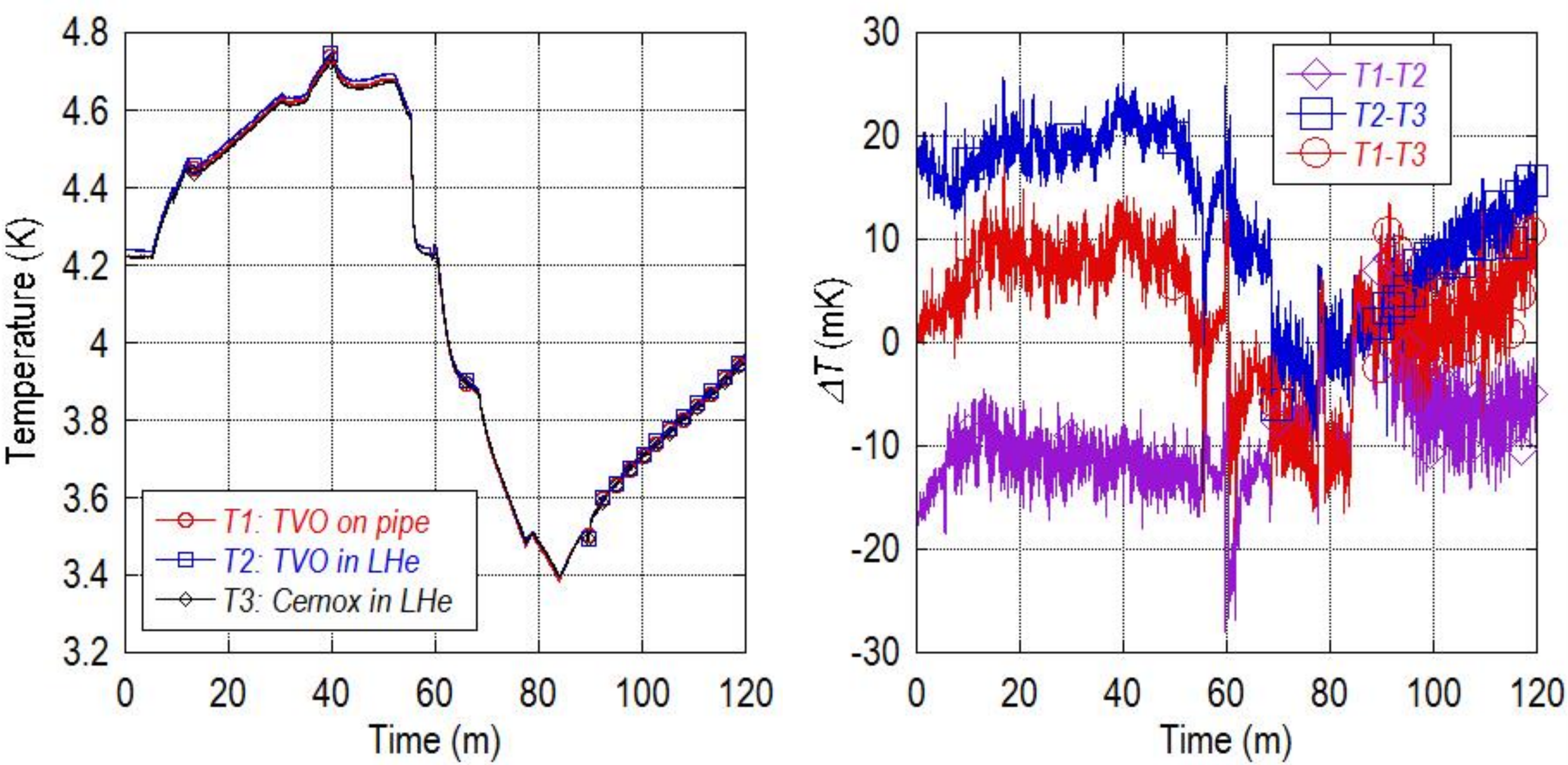
Both differences from the reference sensor are allowable

*The calibrated accuracy of the bare chip of Cernox^{TM} is ±5 mK
(*Temperature Measurement and Control Catalog*, Lake Shore Cryotronics, Inc.)

2. Cernox and TVO immersed in Liquid He tested
3. The saddle method TVO anchoring CuNi wires with Stycast 2850FT tested



Comparison of Cernox and TVO at 3.40-4.73 K

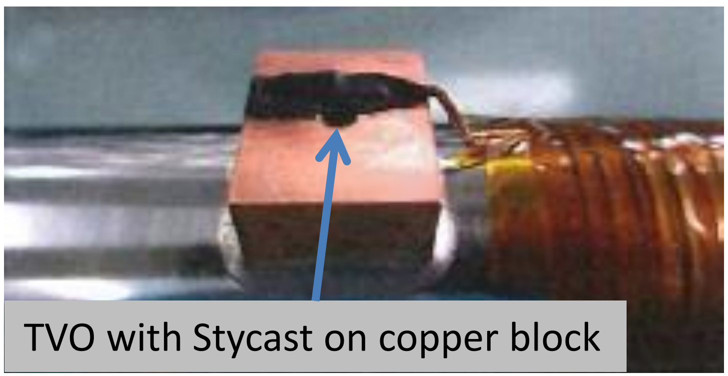


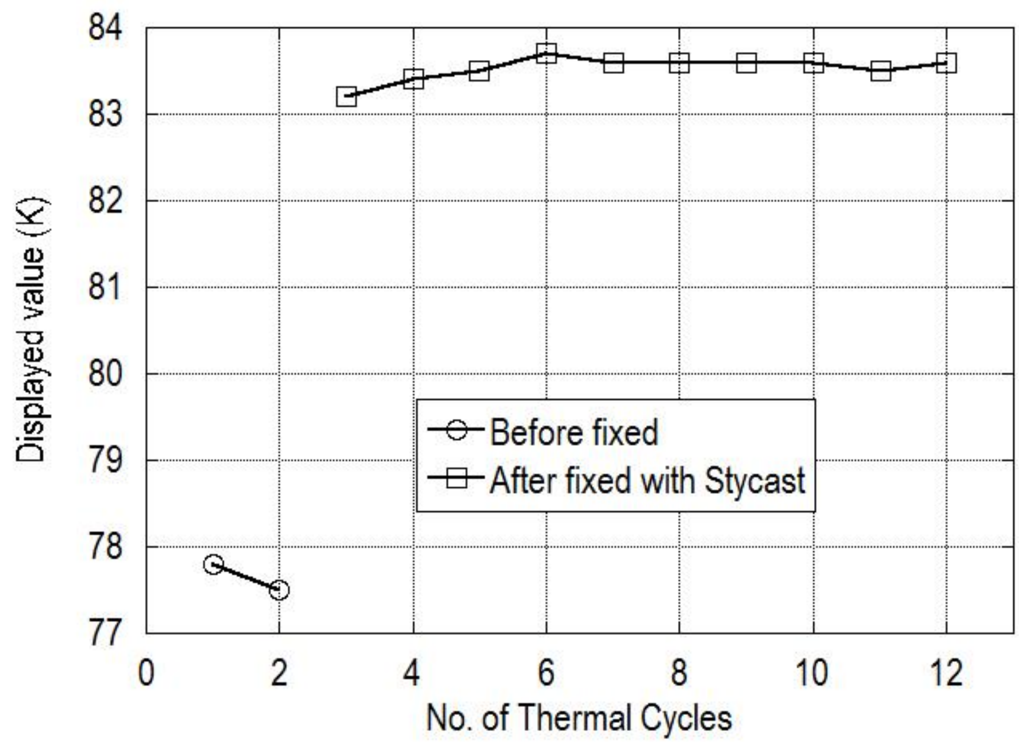
Any differences between two sensors are less than 30 mK

4. Thermal Cycle test of a sensor fixed with Stycast

The displayed temperature increase after the sensor is fixed with the Stycast and cooled down by LN2.

TVO is attached on the copper holder with Stycast 2850 FT instead of being inserted in a hole with Apiezon N grease





Degradation of sensor is caused by the thermal contraction of the Stycast.

Summary of experimental results

- The differences of measured value between attached thermometers and directly immersed one at 3.34-5.06 K are:
  - Well Method ~15 mK
  - Saddle Method ~35 mK
- The difference of measured value between Cernox and TVO at 3.40-4.73 K is: ~25 mK
- The thermal anchoring of measurement wire made of CuNi with Stycast 2850FT is applicable.
- The fixing TVO with Stycast 2850FT is not applicable because of the degradation by the thermal contract.

Conclusion

TVO sensors will be used for the thermometry of almost all refrigerant distribution lines of JT-60SA. The saddle method, CuNi wire with Stycast, and Apiezon N grease will be adopted as sensor attachment method, wire anchoring method, and sensor fixation material, respectively.

Cernox sensors attached by the well method are used for the lines beside Poloidal Field Coils because the temperature should be measured more precisely there (~20 measurement points).

Sensor attachment		Sensors		Wire anchoring method		Sensor fixation material	
Well method	✓	Cernox	✓	Print-Circuit Board (PCB)		Apiezon N grease	✓
Saddle method	✓	TVO	✓	CuNi wire with Stycast	✓	Stycast 2850FT	