Design of Superconducting Coil System for remodeling JT-60 (JT-60SC)

**T. Ando, S. Ishida, T. Kato, M. Kikuchi, K. Kizu, M. Matsukawa,
Y. Miura, H. Nakajima, A. Sakasai, and K. Tsuchiya**

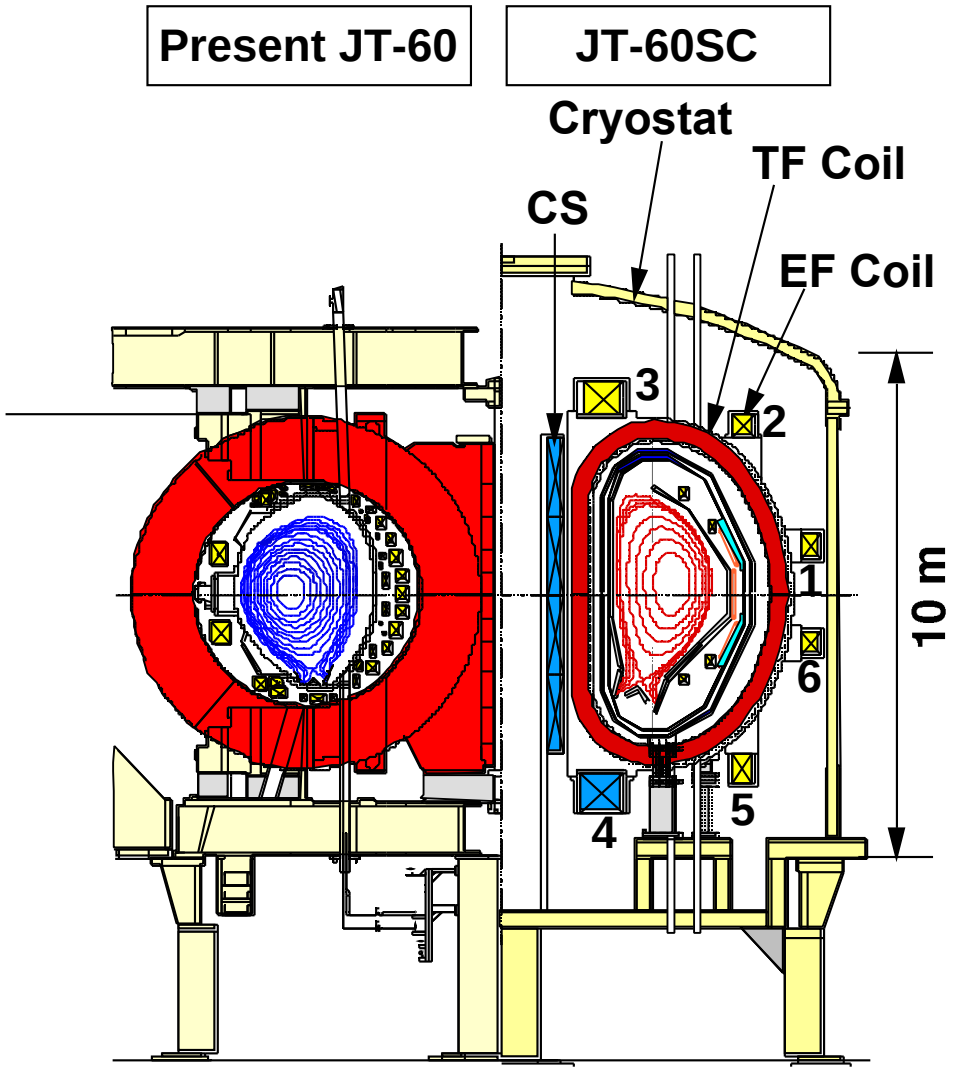
JAERI

Contents

1. **Purpose of JT-60SC and Outline of its Superconding Coil Design**
2. **Nb_3Al Conductor Development for TF Coil**
3. **AC Loss Reduction Technique for Conductor of Cetral Solenoid**
4. **Joint Design**
5. **Conclusion**

Configuration of JT - 60SC Coil System

JT-60 SC JAERI



Total weight : 2000 tons

Main parameters of the TF coil

Overall Height / Width	6.0 m / 3.7 m
Number of Coils	18
Max. Magnetic Field	7.4 T
Total Stored Energy	1.7 GJ
Centering Force per Coil	33.6 MN
Weight per Coil	23.5 ton

Main parameters of the CS

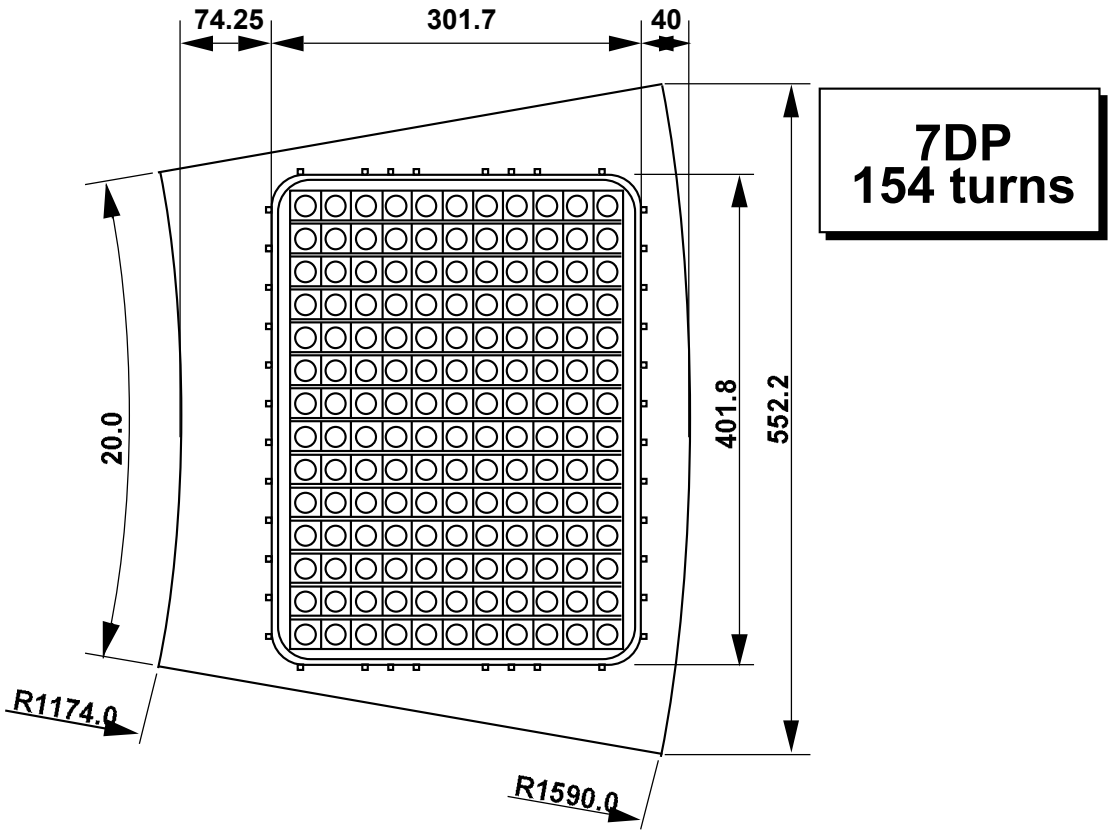
Height of Winding	5.4 m
Inner Diameter of Winding	1.6 m
Outer Diameter of Winding	2.1 m
Number of Coils	4
Max. Magnetic Field	7.4 T

Main parametcrs of the EF

Number of Coils	6
Max. Diameter of Winding	10.6 m
Max. Magnetic Field	5 T

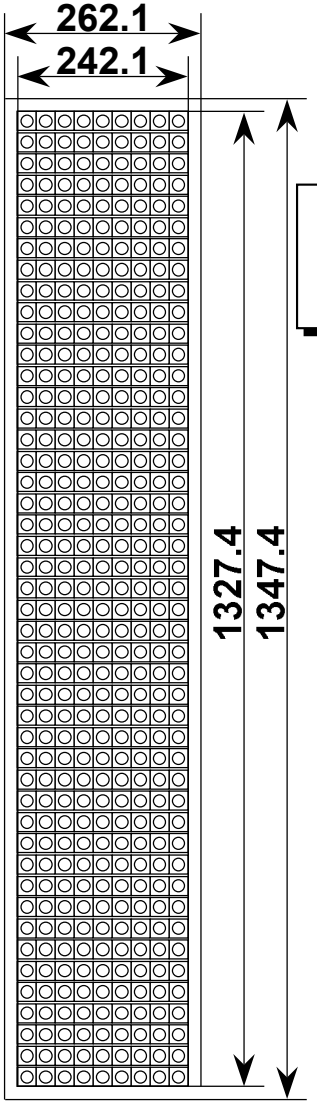
Winding Configuration of TF coil and CS JT-60 SC JAERI

TF coil



7DP
154 turns

Central Solenoid

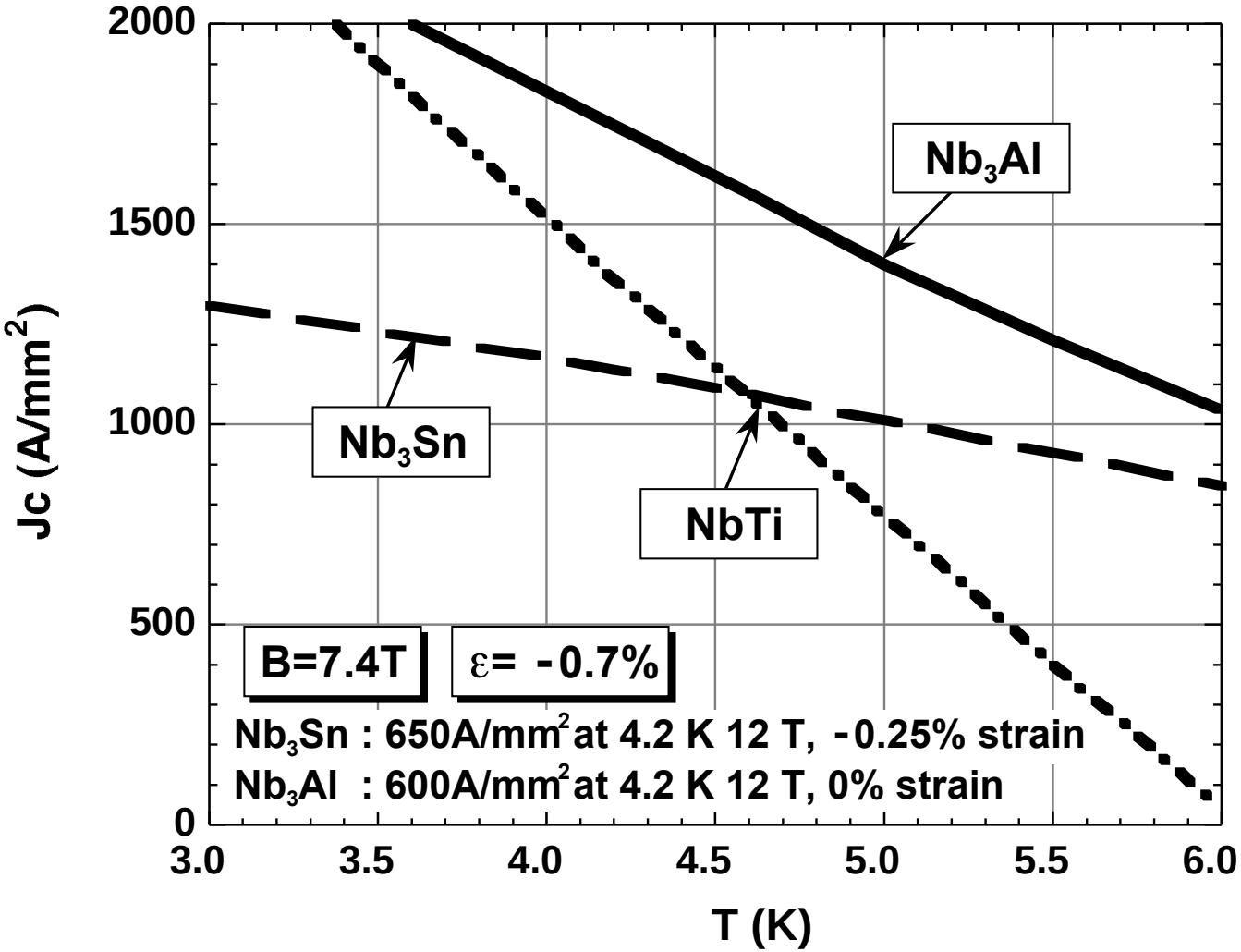


23DP
414 turns

M010911c_T.A

Selection of Superconductor for TF Coil JT-60 SC JAERI

NbTi, Nb_3Sn and Nb_3Al strands compared in Jc performance with stainless steel conduit.



Development of Nb_3Al conductor (II)

JT-60 SC JAERI

30m length full size conductor fabrication

- Cable fabrication : use of a 11 km Nb_3Al strand and a capper wire

  Pattern : 3 x 3 x 3 x 3 x 4 = 324

  Final stage twist pitch = 350 mm

- Conduit fabrication

  Material : 316 LN

  Shape : Square conduit with a circular hole

  Unit length : 10m (Hot extrusion and cold work)

  30 m conduit : 2 butt weldings with 3 unit conduits

- Conductor fabrication

  Cable was inserted into the 30 m length conduit and then it was drawn down to the nominal size

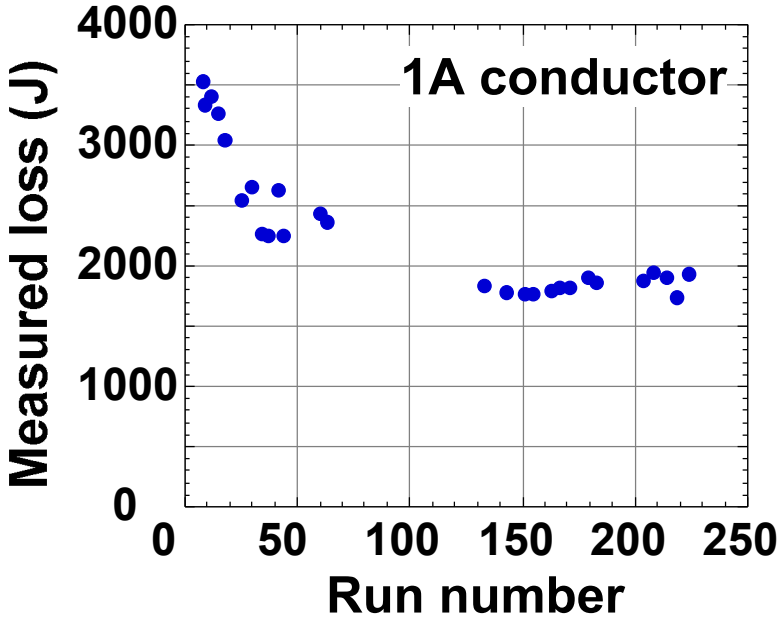
A 30 m Nb_3Al full size conductor was completed

AC Loss Reduction Technique for the conductor of CS (I)

JT-60 SC JAERI

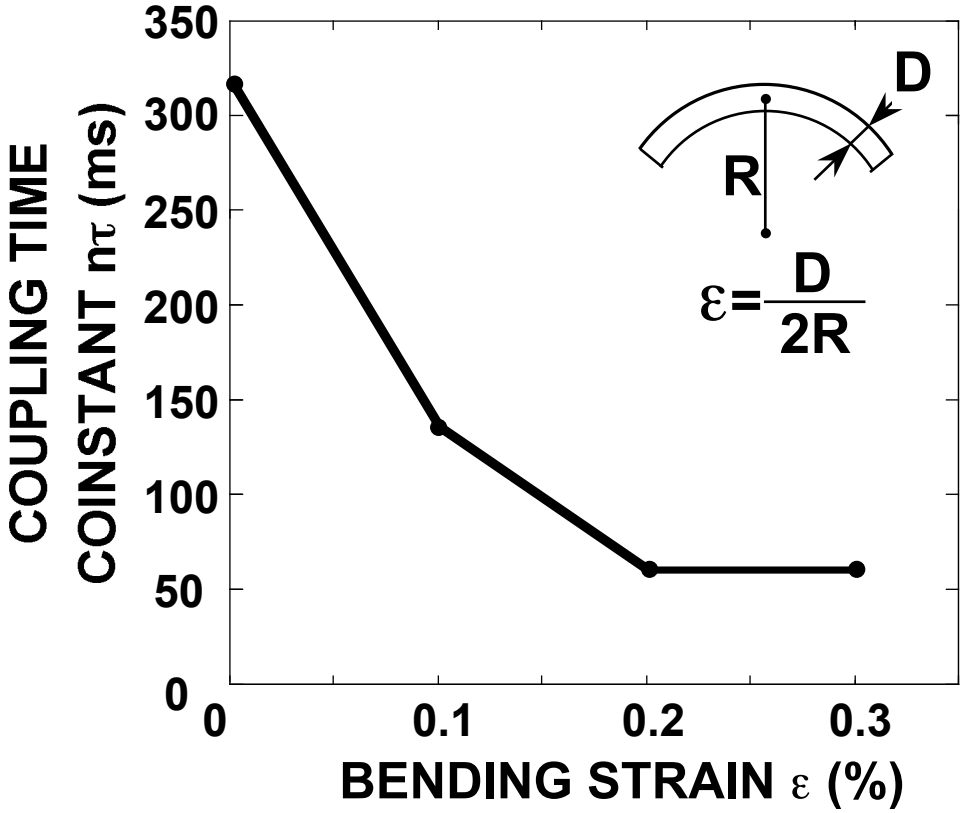
Conductor for CS and EF 4 coil requires low coupling loss of 50 ms level.

Dependence of coil operation frequency on coupling loss was measured in ITER - CSMC test.



This shows that the sintering between strands is broken by electro - magnetic force during coil operation and ac loss is decreased because the resistance between strands is inceased.

To break the sintering at room temperature, the application of bending strain to a full size conductor sample was tried and ac loss was measured.



M010911a_T.A

Joint Structure

Operation Condition

- Max. Transport Current : 20 kA
- Max. Magnetic Field : 4.8 T
- Max. Changing Field Rate : 2.0 T/s
- Operating life : 10 years
- Fatigue life : 18000 times

Design

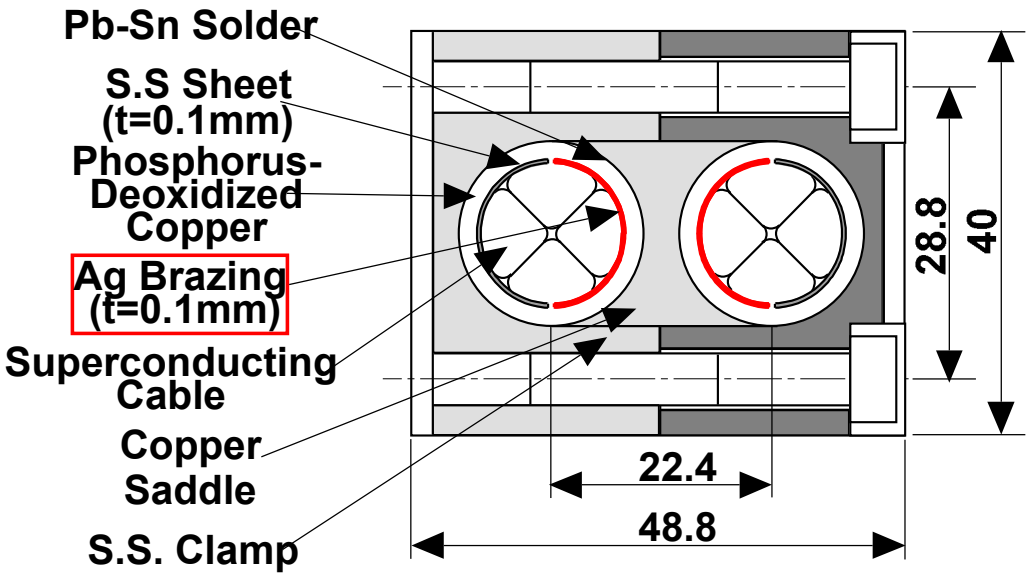
- Lap type
- Use of Ag brazing for contact between cable and Cu pipe
- Cable void fraction of 25 %

Requirements

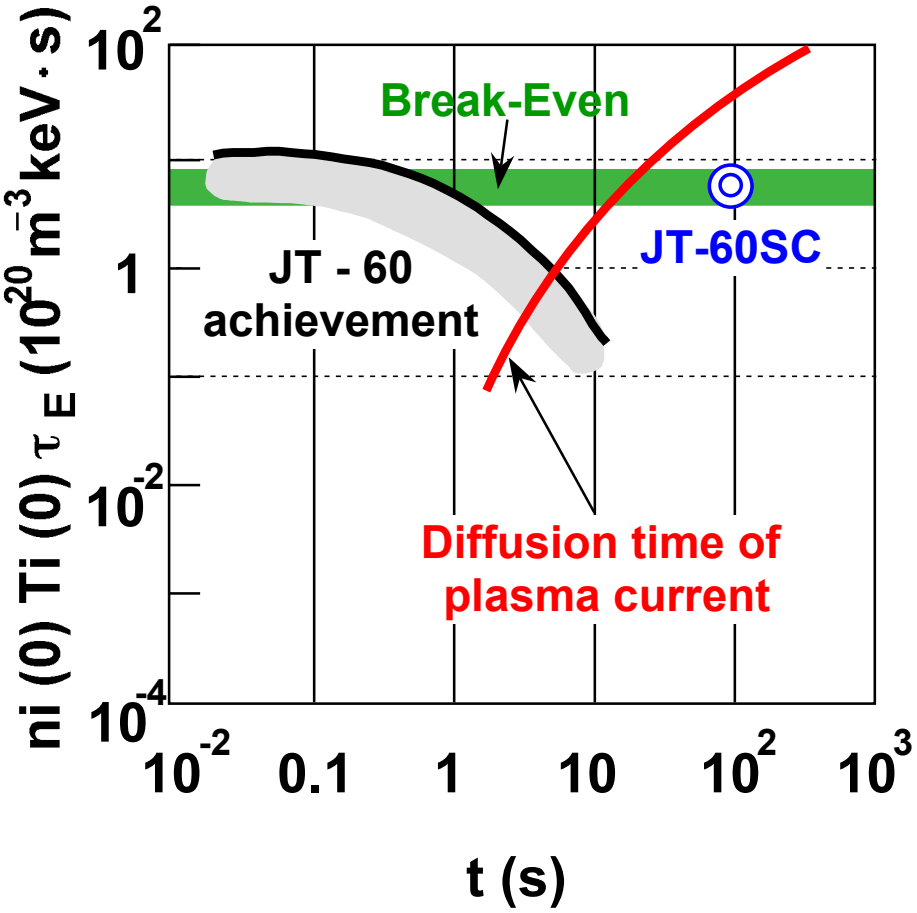
- Resistance : < 7nΩ
- Time constant of coupling current : < 1s
- Temperature margin : < 1K

↓

To realize these high endurance and low ac loss the following joint structure is designed.



The Need of JT-60 remodeling with superconducting coil



Investigation of plasma performance in the region beyond the diffusion time of plasma current at the break-even level.

↓

Long Pulse Operation

↓

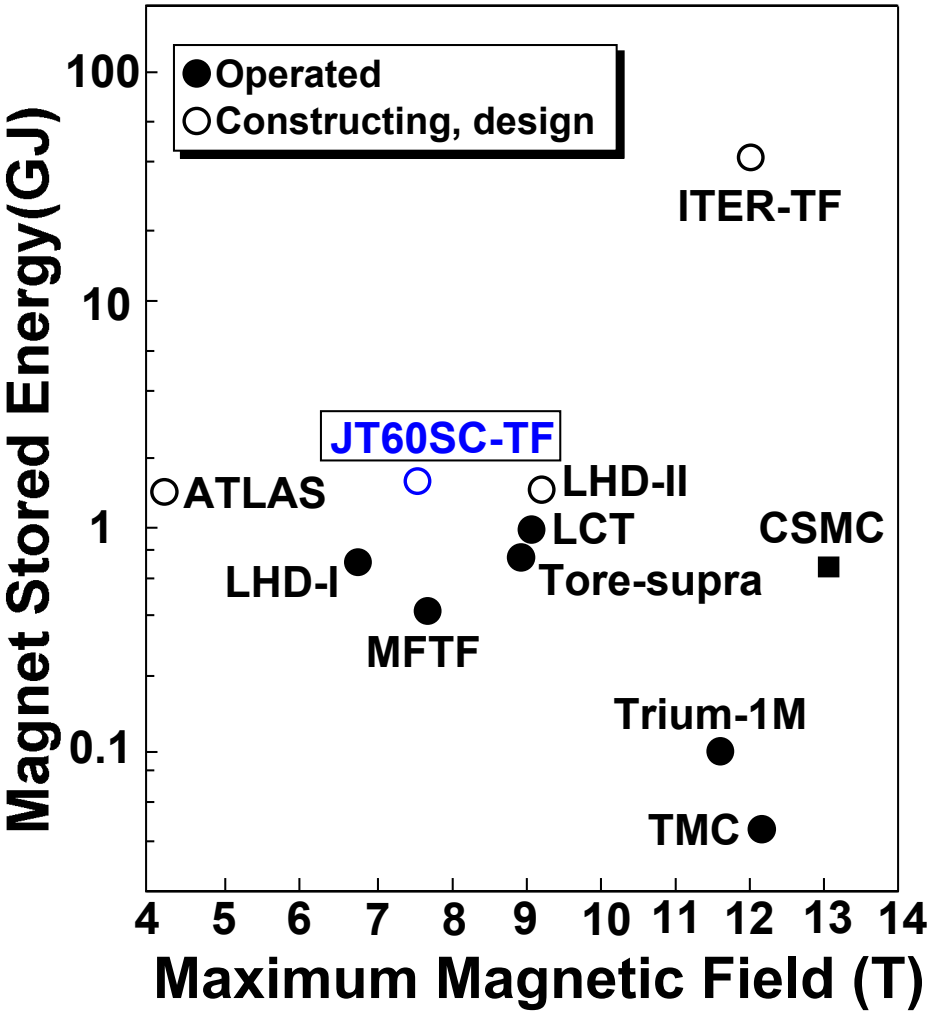
Use of Superconducting Coil

PRINCIPAL PARAMETERS OF JT - 60SC

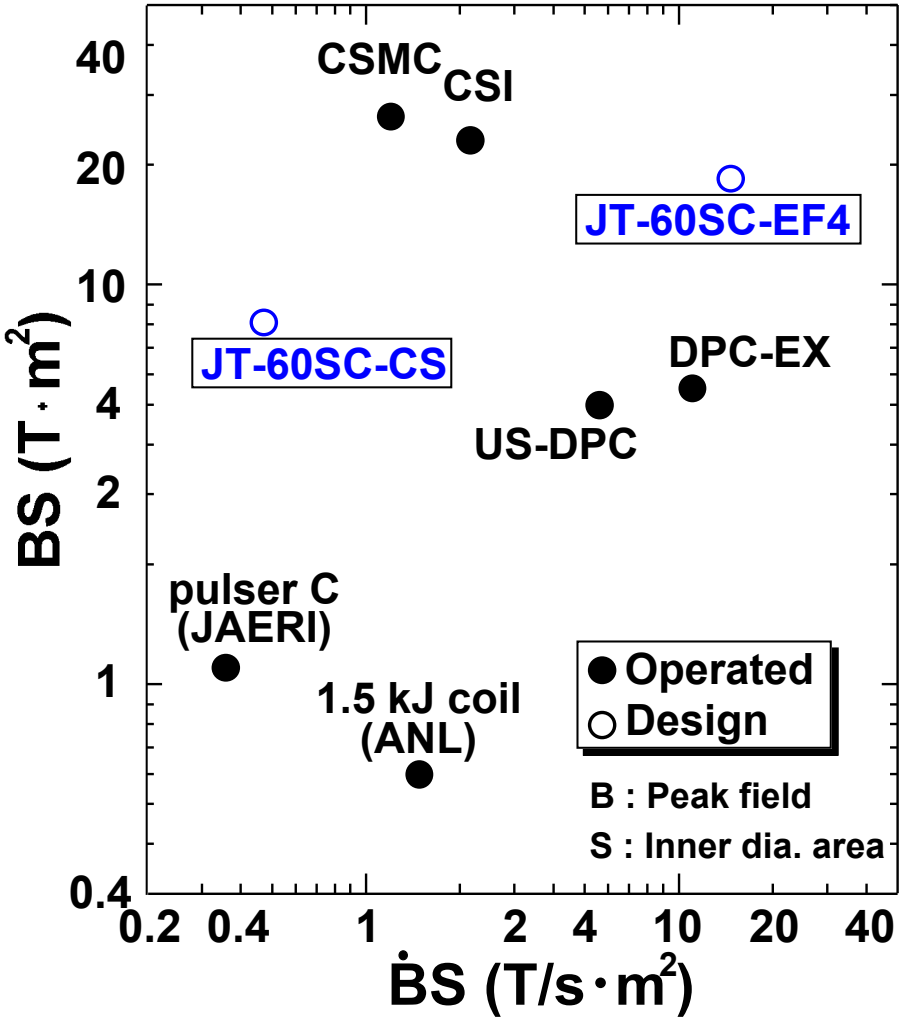
Plasma Current	4 MA
Flat Top Plasma Current	100 s
Plasma Major Redius	2.8 m
Plasma Minor Radius (maximum)	0.8 m
Plasma Elongation	1.8
Triangularity	0.35
Divertor Configuration	Single Null
Toroidal Field at the Major Radius	3.8 T

Size of the JT-60SC Superconucting Coil JT-60 SC JAERI

TF Coil (Steady operation)



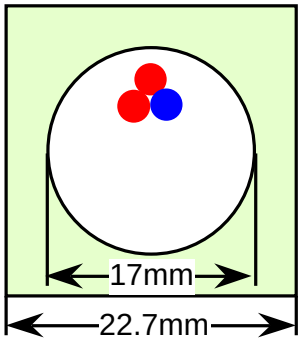
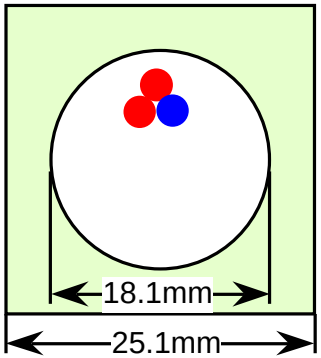
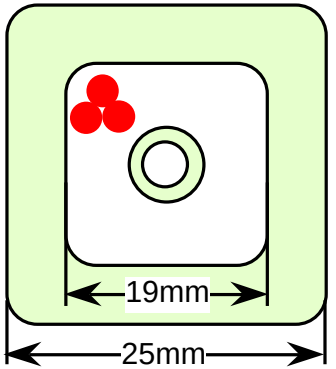
CS and EF Coil (Pulsed operation)



M010911d_T.A

Conductors for TF coil, CS and EF coil

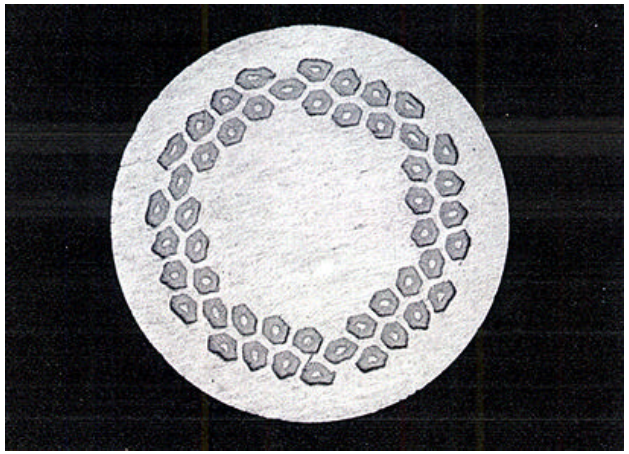
JT-60 SC JAERI

	for TF coil	for CS and EF4 coil	for EF coil
Structure 316 LN Superconducting Strand Pure copper wire			
Max. Magnetic Field	7.4 T	7.4 T	5 T
Nominal Current	19.4 kA	20 kA	20 kA
Operating Temp	4.6 K	5.0 K	4.8 K
SC Material	Nb_3Al(or Nb_3Sn)	Nb_3Sn	NbTi
Coating Material	Cr	Cr	Ni
No. of Total Strands	324	324	486
No. of SC Strands	216	216	486
No. of Cu Wires	108	108	0
Cu/non Cu Ratio	4	2.3	7
Strand Diameter	0.74 mm	0.78 mm	0.70 mm
Void Fraction	36 %	36 %	36 %
Weight of SC strand	32 ton	13 ton	40 ton

Development of Nb_3Al conductor (I)

Nb_3Al strand development

Strand diameter	: 0.74 mm
Cu non Cu ratio	: 4
Filamentary diameter	: 55 μm
Jc at 12 T and 4.2 K	: 600 A/mm^2
n value	: 45



High quality jelly - roll preparation

↓

A Nb_3Al strand of 11 km length was successfully fabrication with no breakage

R & D of React and Wind Technique

Using the 30 m length full size Nb_3Al conductor the following R &Ds are planned :

1. A two turns coil is fabricated and tested
   - Verification test of React and Wind technique

     Application of same strain as a real TF coil conductor to a two turns coil conductor

2. Short Sample test
   - Conductor performance measurement

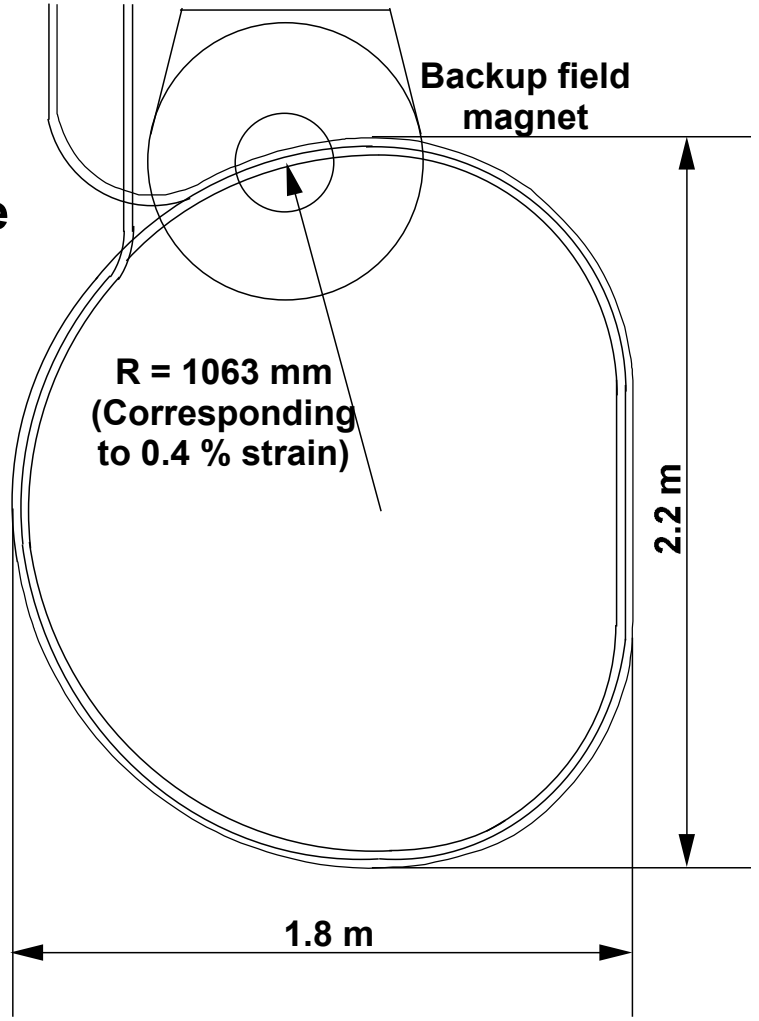
     Ic - B - T

     AC loss
   - Joint performance measurement

     Ic - B - T

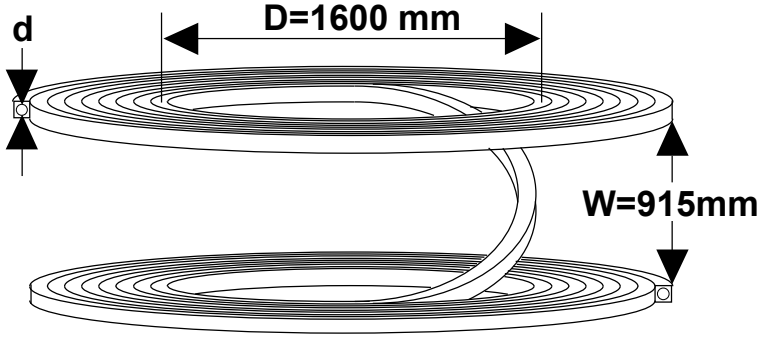
     Joule loss

     AC loss



AC Loss Reduction Technique for conductor of CS (II)

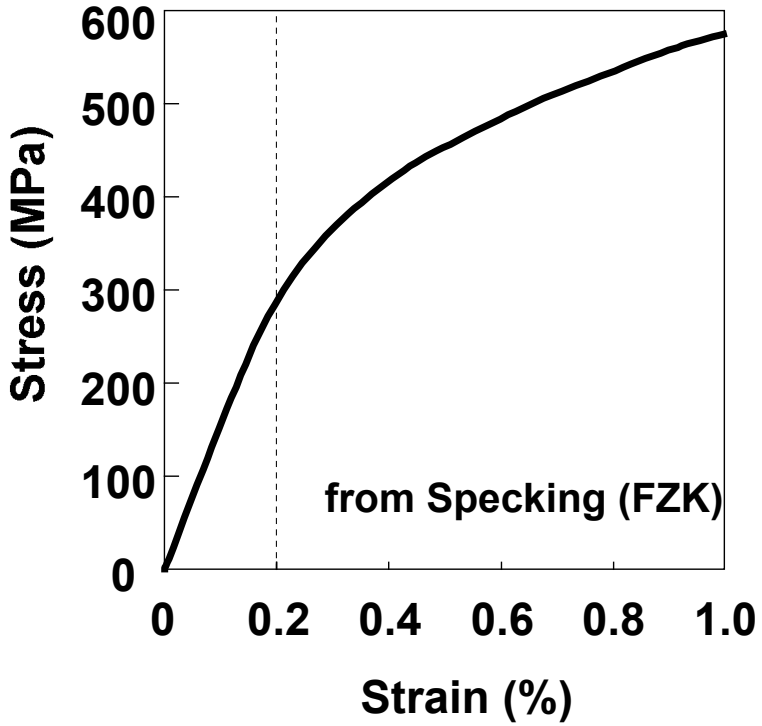
Method to apply 0.2 % strain to the conductors of CS.



$$\varepsilon_t = \frac{W.d}{\pi D^2}$$

0.2% strain is applied to conductors due to expanding the space between the pancakes after heat treatment of the double pancakes. At that time, turn insulation work is carried out.

0.2 % strain is within the region of elastic on the stress - strain curve of a CIC conductor.



Conclusion

The Design of JT-60 remodeling with a superconducting system has been carried out with new technologies to perform the extensive plasma experiment.
The features of this system are as follows:

1. The TF coil has a magnetic stored energy of 1.7 GJ that is the largest in superconducting coil constructed so far.

2. High copper ratio strands (4 for Nb_3Al and 2.3 for Nb_3Sn) were developed to realize high current density in winding and coil fabrication with low cost.

3. A Nb_3Al cable-in-conduit conductor with s.s.conduit is considered to be applied to the TF coil, which enable it to make with a react-and-winding technique.

4. In order to decrease inter strand coupling loss in CS conductor, a bending strain technique was considered.

5. Joints between pancakes use brazing between cable and copper tube to get strongly mechanical contact.