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Mechanical Compress Process for Pre-compression of JT-60SA Central Solenoid

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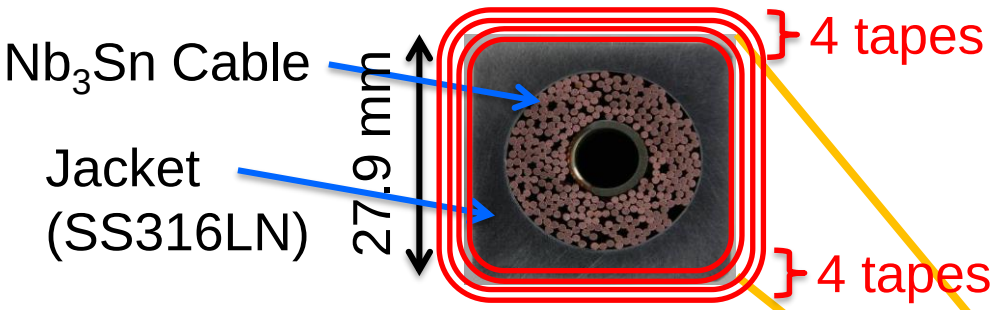
Central Solenoid

1. Operation Condition

Current : 20 kA, B_{max} : 8.9 T

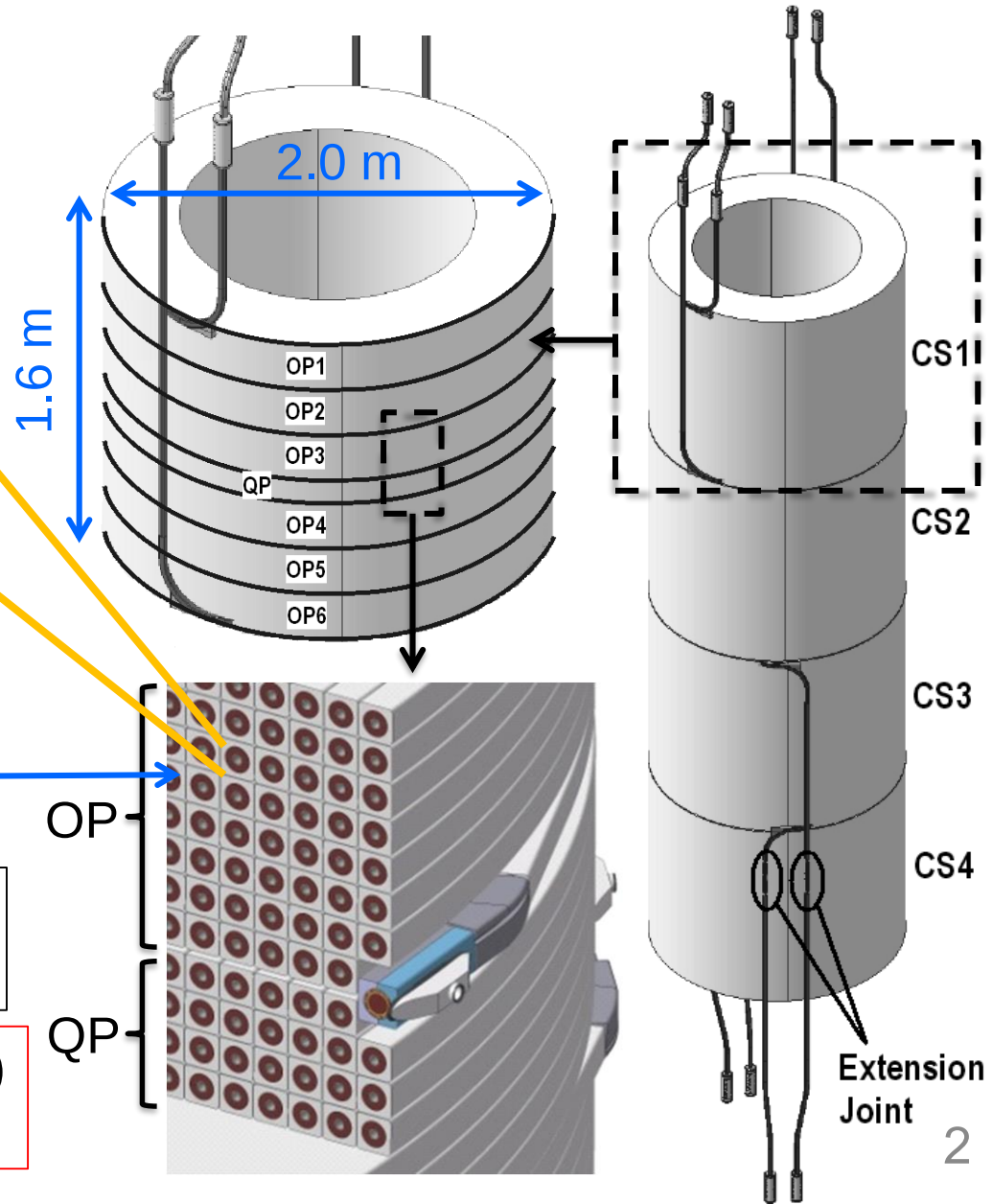


2. Magnet Design

- CS system has 4 modules.
- Each module consists 52 layers
  - 6 Octa-Pancake (OP : 8 layer)
  - 1 Quad-Pancake (QP : 4 layer)
- Conductors are electrically insulated by GKG (Glass-Kapton-Glass) tape with epoxy resin. (V_{layer}=1.8 kV)

Half lap x 2 times
(416 tapes/module)

Total thickness of insulation (GKG tape) is more than 300 mm for 4 modules



CS Precompress

＜CS Precompress＞

Stacked 4 CS modules need to be fixed each other by 9 sets of tie plate (SS316LN) with large compress load.

＜Compress load＞

・Sufficient compress load, considering cool down and operation, need to be subjected to modules.

・The compress load had been estimated by FEM analysis.

Inner：2.11 MN±10%

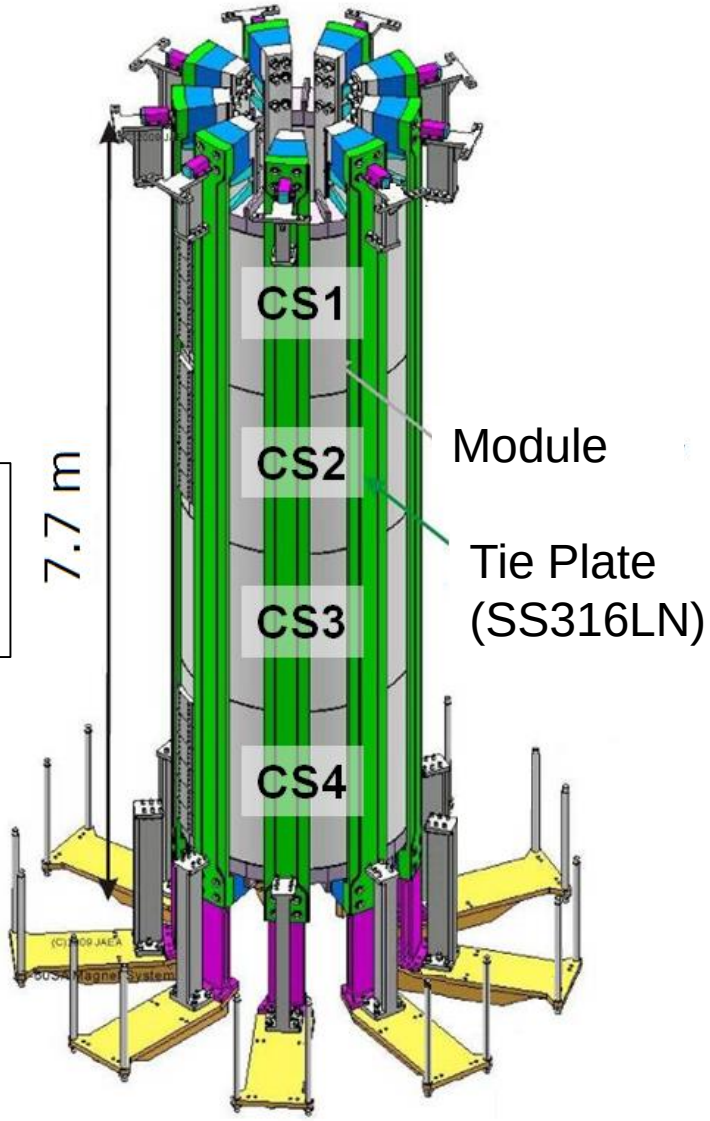
Outer：2.05 MN±10%

Total ：More than 4.16 MN

for each tie plate.

(There are 9 sets of tie plate in total)

K. Tsuchiya, K. Kizu, H. Murakami et al, "Design of the Precompression Mechanism and Gravity Support for the Central Solenoid Assembly in the JT-60SA Tokamak", IEEE transactions on plasma science, Vol. 42, No. 4, pp. 1042-1046)



＜Main topic of this presentation＞

How to conduct precompress actually.

・Design of compress jigs

・Analysis of compress jigs

・Procedure and measurement of precompress

・Result of precompress

Precompress load

Temperature	Electro magnetic force	Axial force		
		Tie plate		Inter module
		Inner	Outer	Minimum
		MN	MN	MN
RT	---	19.0	18.5	37.6
4K	---	11.3	10.9	22.2
	Repulsion	10.6	10.4	15.0
	Attraction	2.9	12.2	2.4

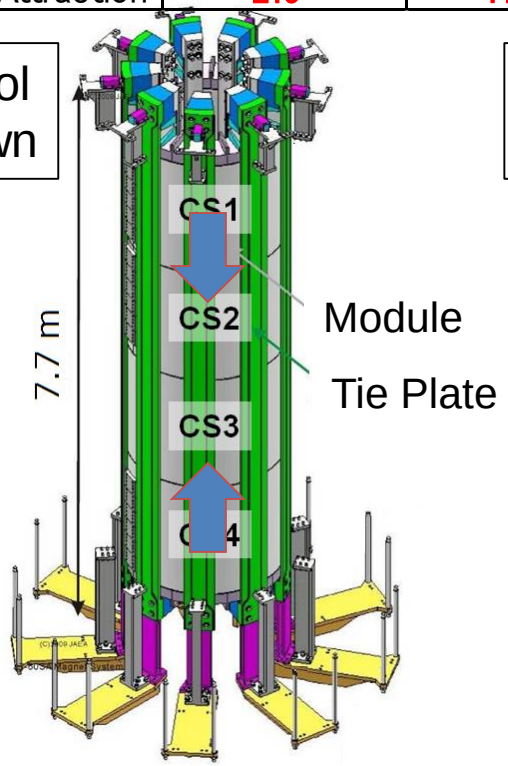
2.11 MN × 9 tieplates

2.05 MN × 9 tieplates

Compress load is reduced by cool down

Compress load is reduced during operation
（Contact area is more than 50% in any case)

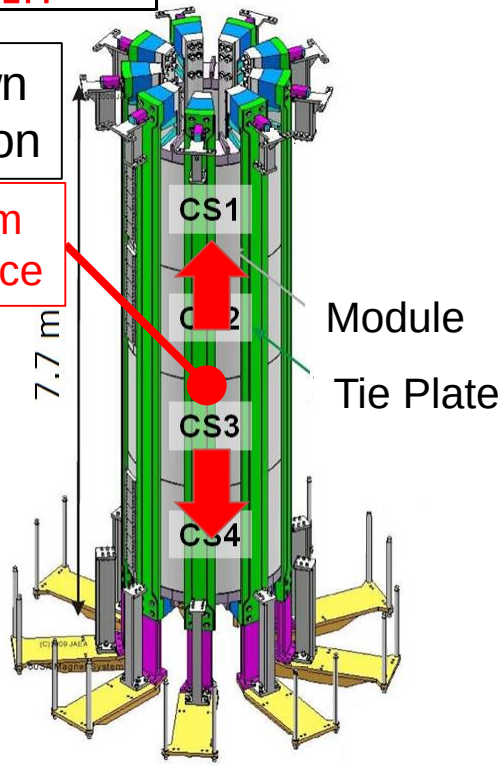
Cool down



Thermal shrinkage

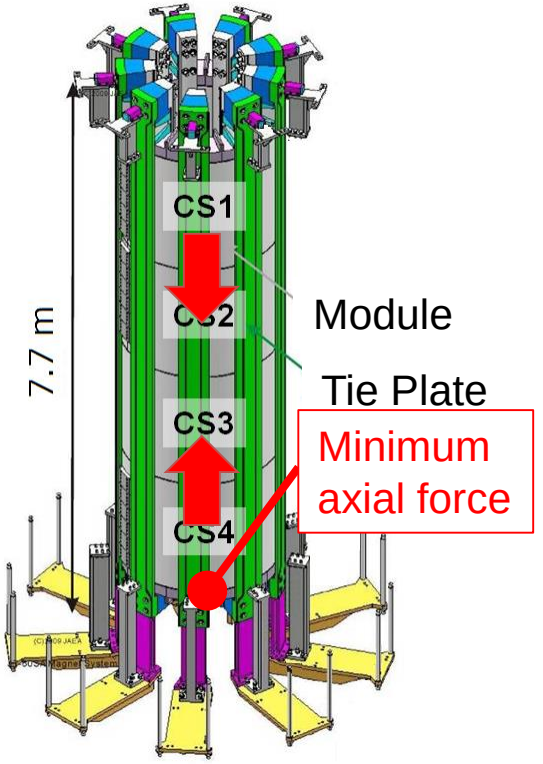
Module＞Tieplate (SS)
→Compress load is reduced

Cool down + Operation



Repulsion EMF

Minimum axial force is between CS2 and CS3



Attraction EMF

Minimum axial force is bottom of CS modules

Design of precompress jigs

＜Precompress method＞

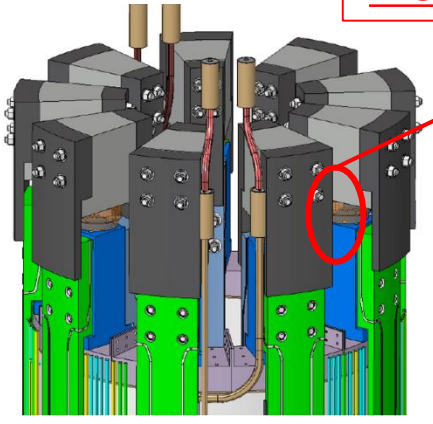
- **Shrink fit by using heaters (80℃ heating is estimated to get sufficient load)**
  Simple jigs and simple procedure ←→ Difficult to adjust precompress load after setting.
- **Mechanical pulling by jacks**
  Large jigs and complex procedure ←→ Easy to adjust precompress load after setting.

Creeping amount of thick insulation is unknown

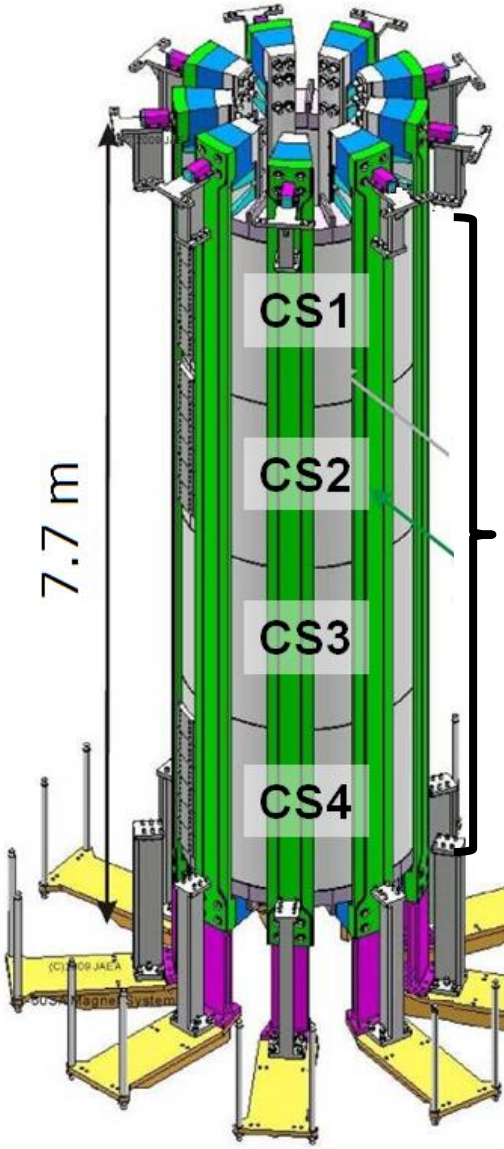
Mechanical loading process was selected

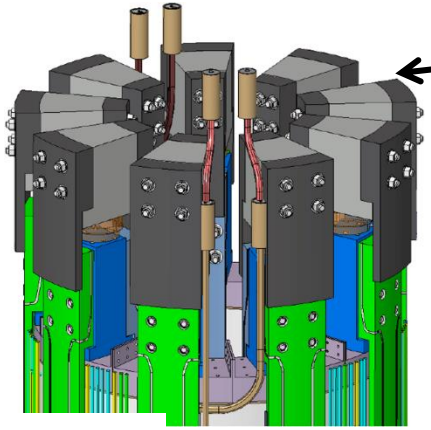
→We can retighten after creeping

Precompress Jigs



Analysis model for jigs



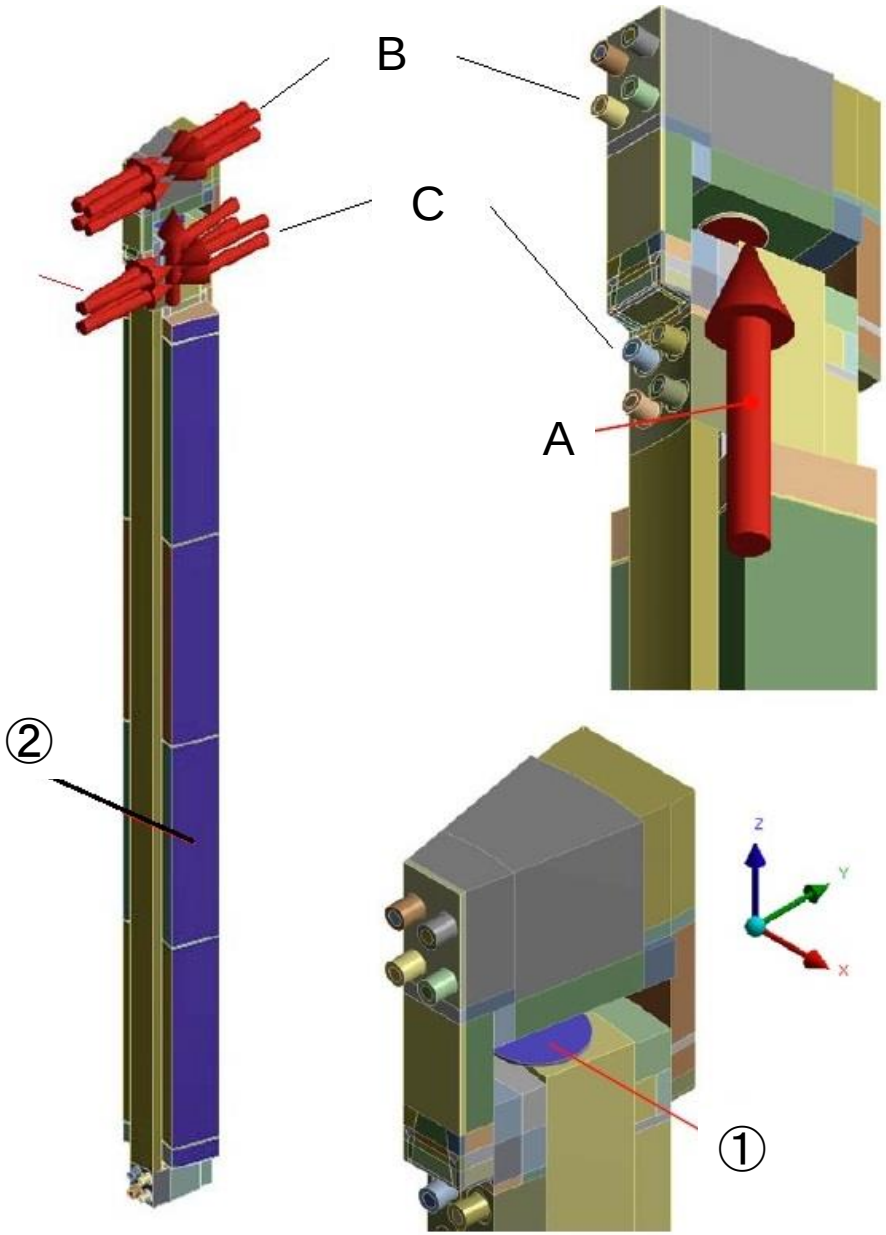


＜Validation for precompress jig part＞
Precompress jigs are validated by analysis considering plastic deformation.
→The number of applied load is only a few times for initial precompress and retightening (if needed).

＜Validation for tie plate main part＞
＜Validation for gravity support structure for CS＞
The structures have been validated by analysis considering repeated load based on JSME code.
(Cool down : 100 times, Operation load : 36,000 times)

K. Tsuchiya, K. Kizu, H. Murakami et al, "Design of the Precompression Mechanism and Gravity Support for the Central Solenoid Assembly in the JT-60SA Tokamak", IEEE transactions on plasma science, Vol. 42, No. 4, pp. 1042-1046)

Analysis model for jigs



＜Analysis model＞

・Module, tieplate and jigs are modeled.

・40 degree symmetrical model

＜Boundary condition＞

①Bottom surface of jack is fixed.

②Side surface is symmetrical condition.

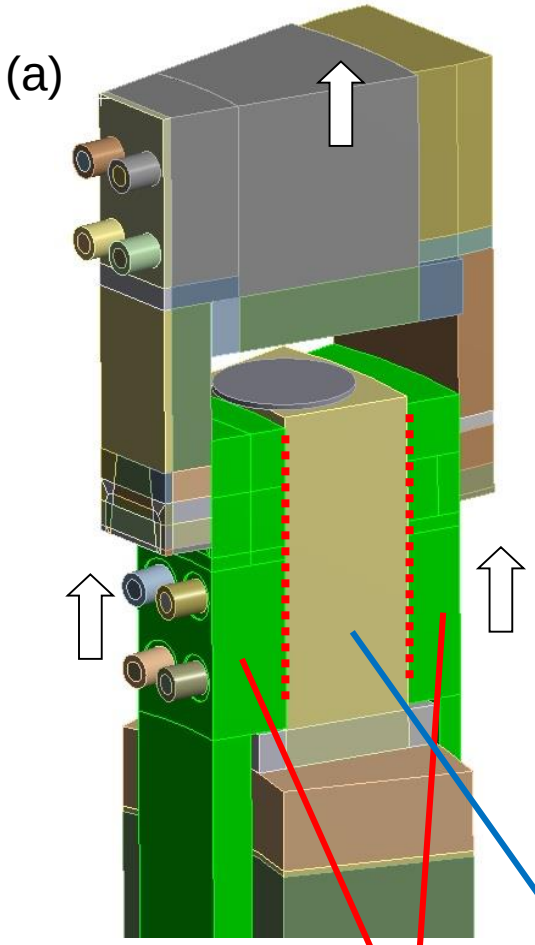
＜Load condition＞

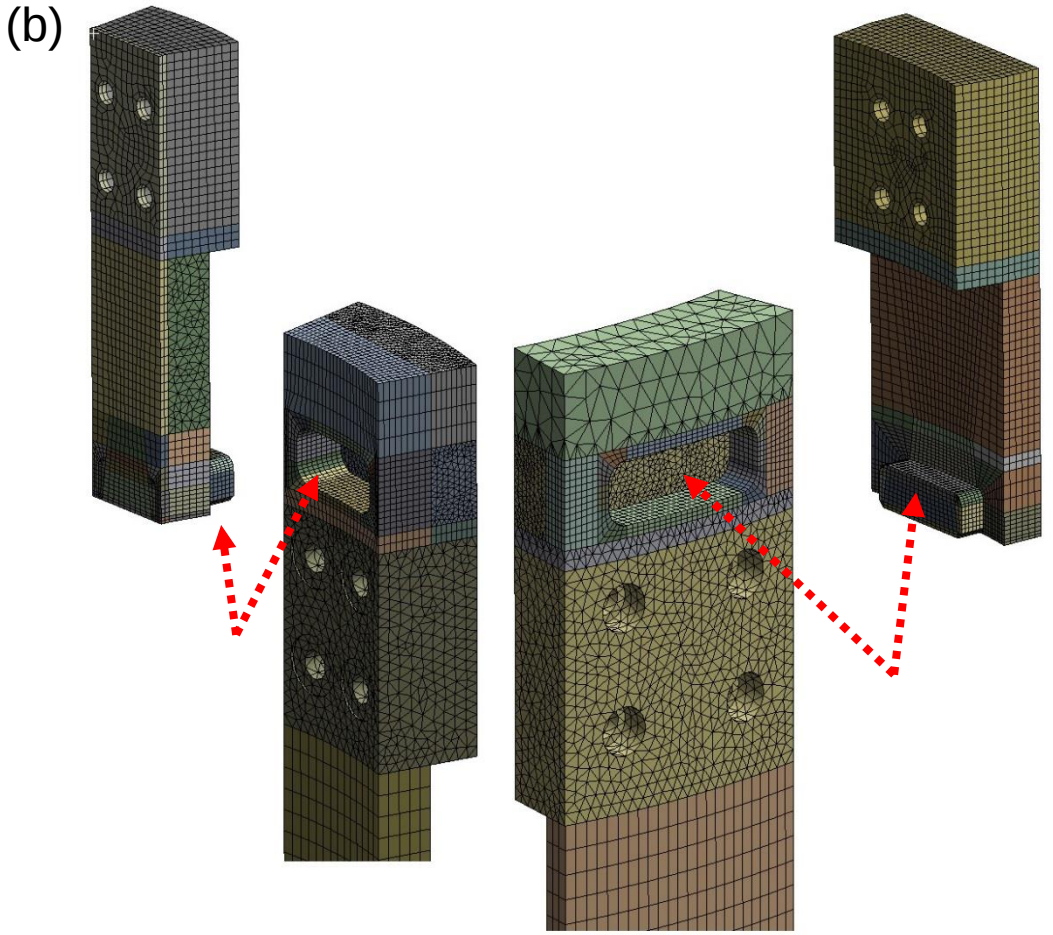
A. Vertical load is applied to upper surface of jack.
→Applied load is up to 160% of rated value.

B. Bolts of jigs are tightened by rated value of class 8.8 bolt.

C. Bolts of jigs are tightened by 10 % of rated value of class 8.8 bolt.
→Tieplate need to be slided.

Analysis model for jigs





＜Contact condition＞

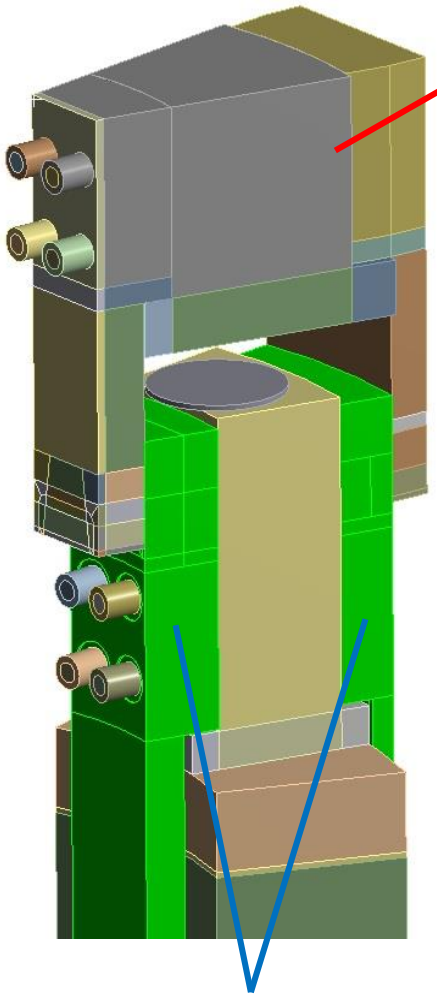
a. Contact surface of tieplate and key block

b. Contact surface of tieplate and jigs

→These surface have 0.2 of coefficient of friction.

→All other surfaces are bonded condition.

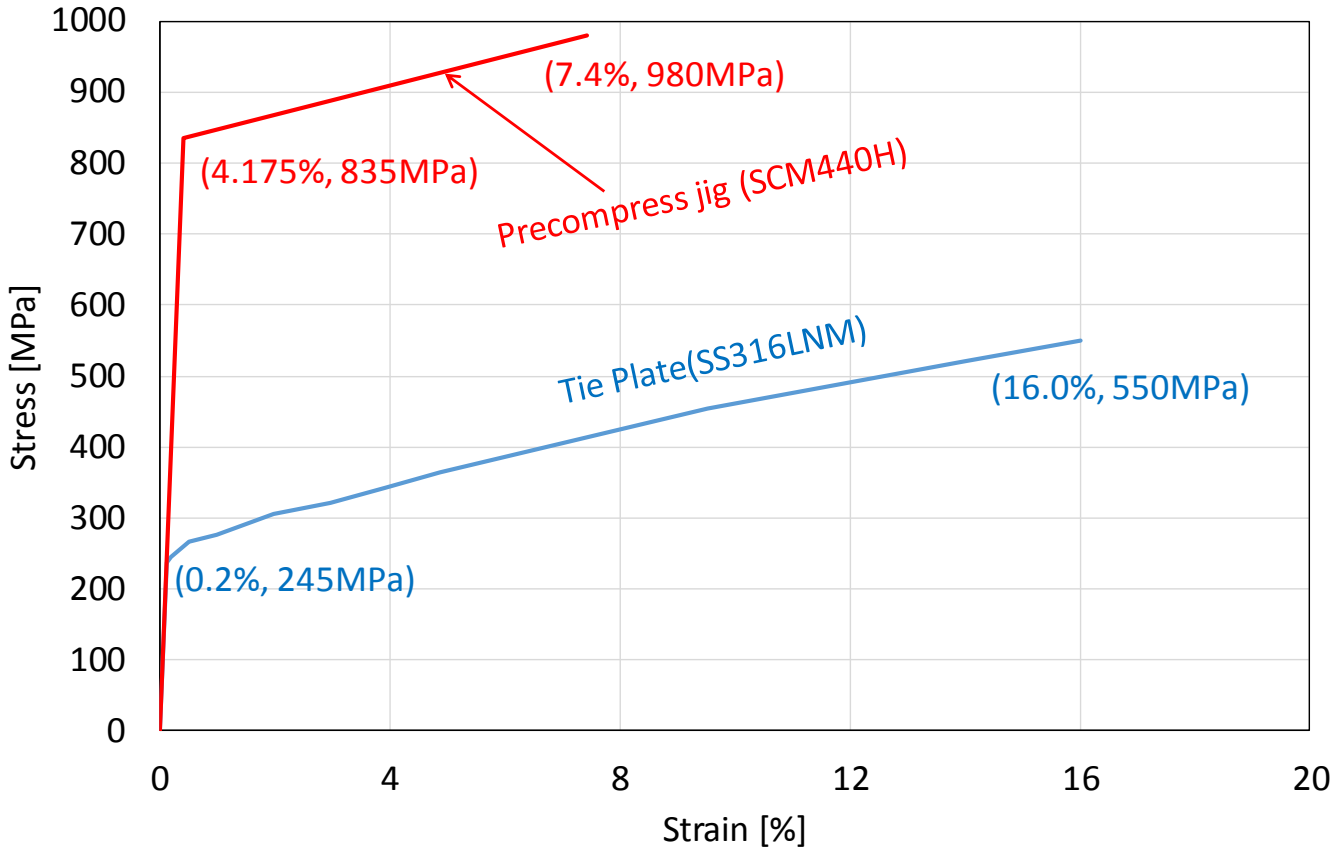
Stress-strain curve



Precompress jig (SCM440H)

↑Cr–Mo alloy steel

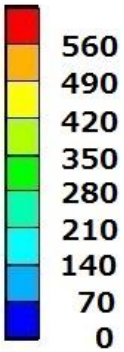
Tie plate (SS316LNM)



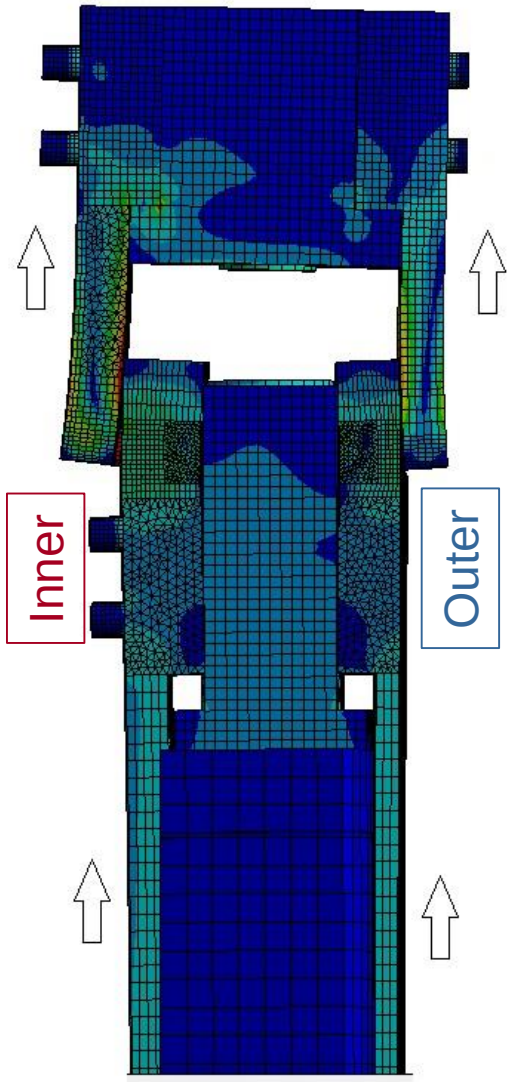
Structure become broken at
Strain > Ultimate strain
(SCM440H:7.4%、SS316LNM:16.0%)

Analysis Result

Mises stress (MPa)



Deformation ×5



Precompress Load Target ×120%

＜Analysis Result＞ (Rated load : 4.16 MN)

- Strain is less than ultimate strain even under the load condition as 160% of rated load.
- Plastic deformation occurs in very local area.

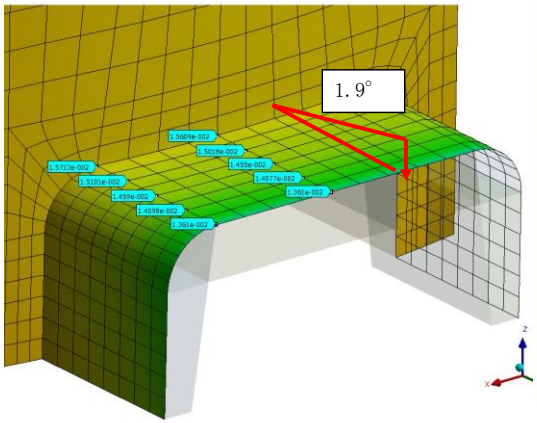
→Jigs can be used in safe

Arms of jigs tend to open.

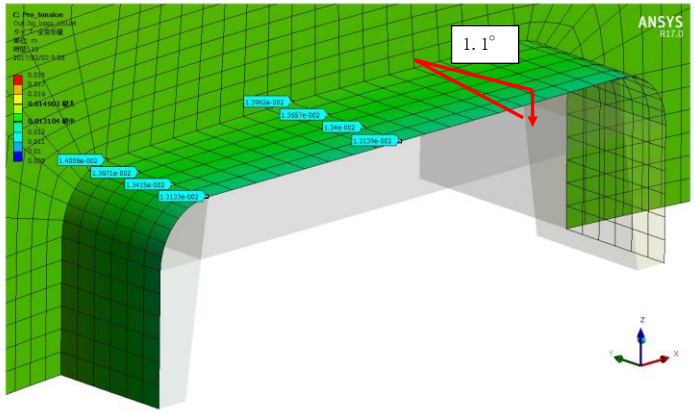
→1~2 degree under 120% of rated load.

→Opening prevention plate is added for actual precompress jigs to reduce plastic deformation.

Inner : 1.9°



Outer : 1.1°

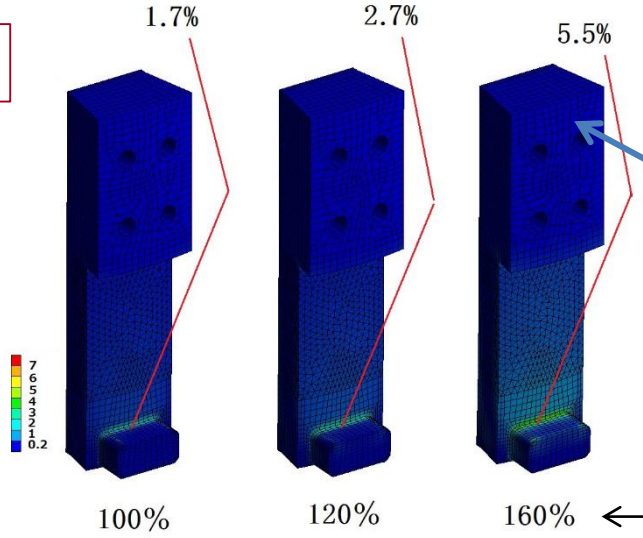


Analysis Result (Strain)

JT-60SA
Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

Precompress jig (Ultimate strain : 7.4%)

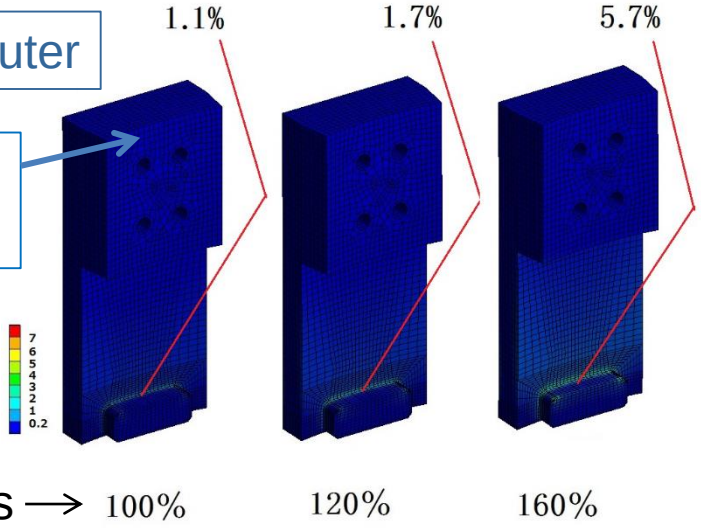
Inner



Blue area = Elastic area

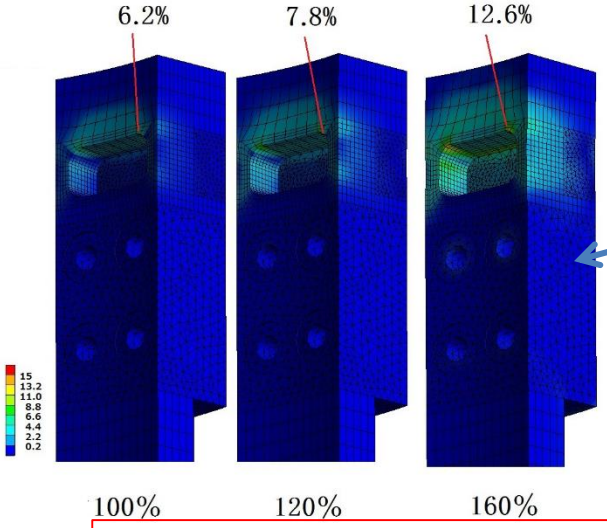
Maximum strain

Outer



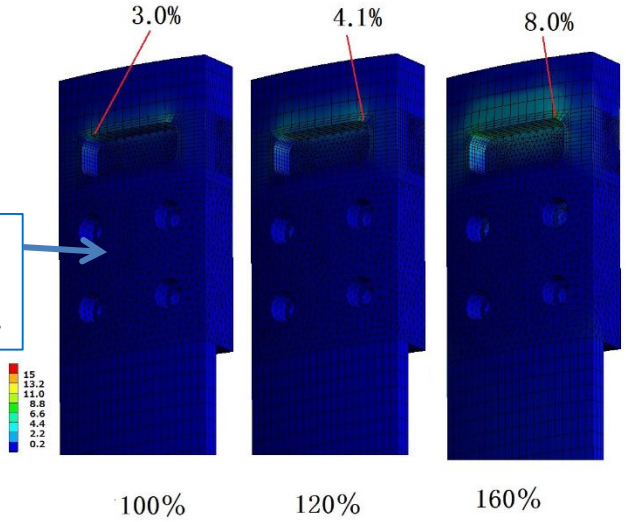
← Precompress → Load

Tie plate (Ultimate strain : 16.0%)



Blue area = Elastic area

Maximum strain



Maximum strain is less than ultimate strain up to 160% load

Precompress procedure

JT-60SA
Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

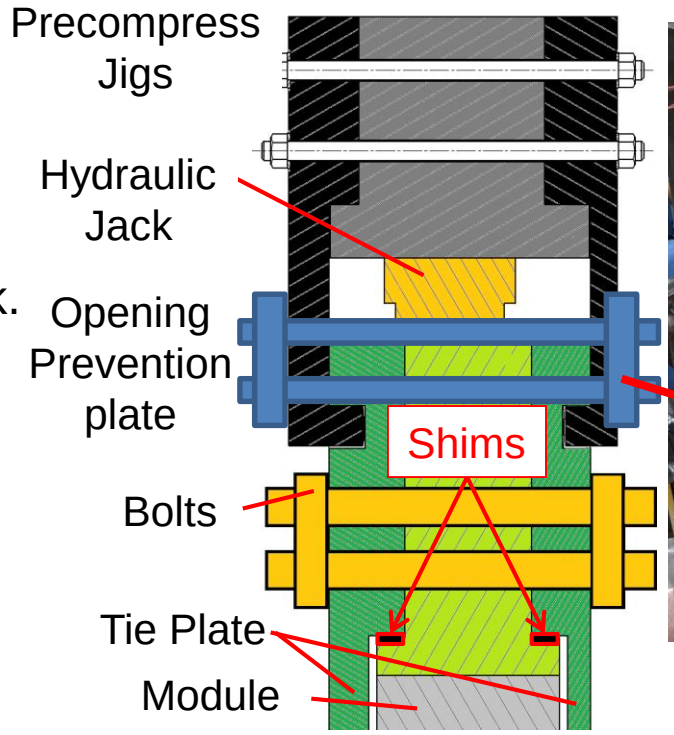
＜Setting Jigs＞

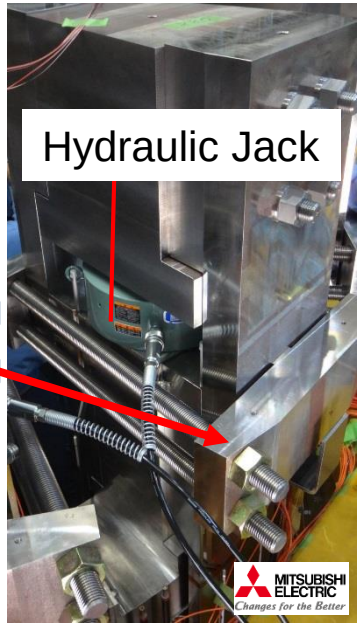
- Hydraulic jack and pump is separately installed to each sector to control precompress load individually.
- Strain gauges are attached to both surface of tie plate.
- Precompress load is evaluated by the measured tie plate strain and Young's modulus of 200GPa.
- Opening prevention plate is added for actual jigs.

＜Procedure＞

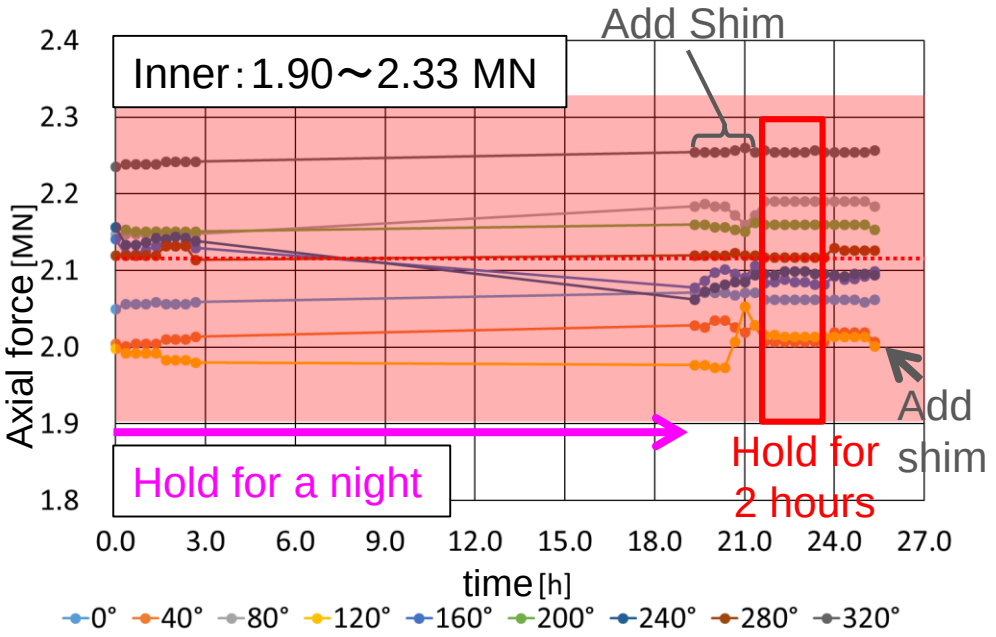
- Precompress load is gradually increased. (e.g. 20%→50% →80%→90% of target load)
- Check the proportionality of precompress load and hydraulic pressure (Plastic deformation)
- Adjust insertion shims by 0.1 mm thickness to get target load after unloading of hydraulic jack.
- Holding load for a night after loading.

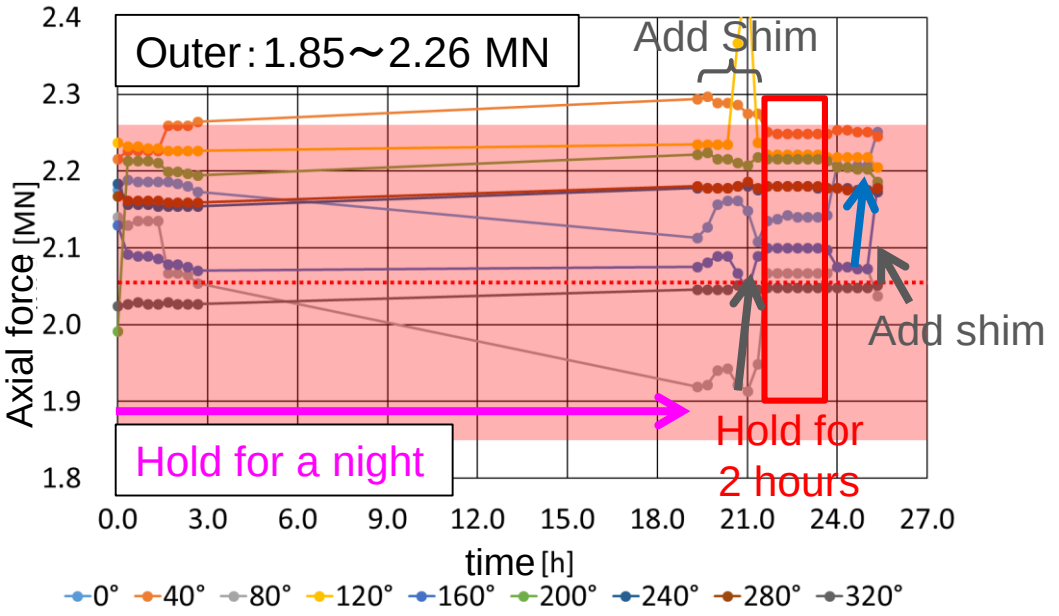
	Target	Result
Inner	1.90～2.33MN	2.00～2.27MN
Outer	1.85～2.26MN	2.05～2.25MN
Total	More than 4.17MN	4.25～4.35MN

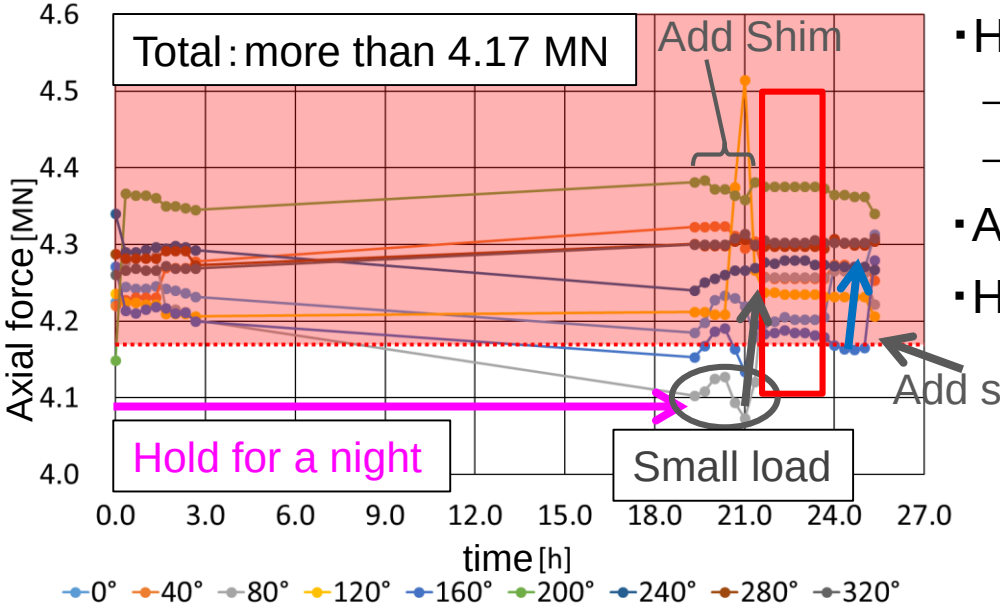




Result of precompress







- Hold precompress load for a night after first loading
  → Load changes by insulation creeping.
  → Amount of change differ from sector to sector.
- Additional shims were inserted for small load sector.
- Hold for 2 hours to check no additional creeping.

Retightening can be conducted until finish of creeping by using mechanical loading method

Precompress was successfully performed

Summary

1) The mechanical loading technology has been developed for CS precompress.
It can adjust precompress load easily after tie plate setting.

2) Precompress jigs were designed by using plastic mechanical analysis.
   (a) Maximum strain is less than ultimate strain up to 160% load.
   (b) Arm of precompress jigs tend to open by 1~2° at 120% load.
   →Opening prevention plate is added to reduce plastic deformation.

3) Precompress was performed using developed jigs.
   (a) Hold precompress load for a night after first loading.
   →Precompress load changes by insulation creeping and amount of change differ from sector to sector.
   → Additional shims were inserted for small load sector.
   (b) Finally, precompress load of all tie plate is within target range.

Precompress was successfully performed using developed jigs