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Mon-Af-Or4

Development of Vacuum Pressure Impregnation (VPI) for Central Solenoid of JT-60SA

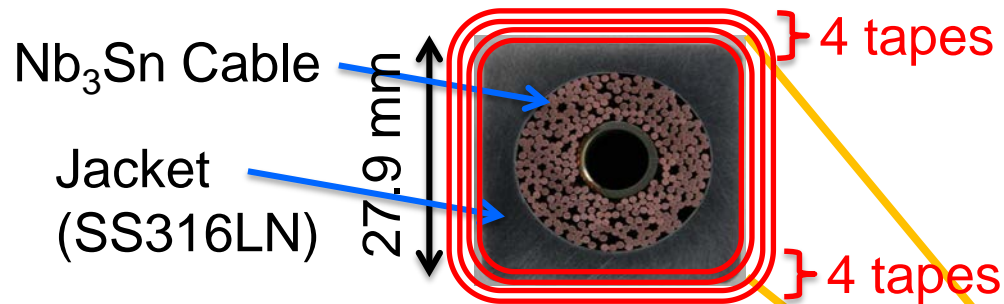
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28 Aug 2017, Amsterdam, The Netherlands

1. Operation Condition

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



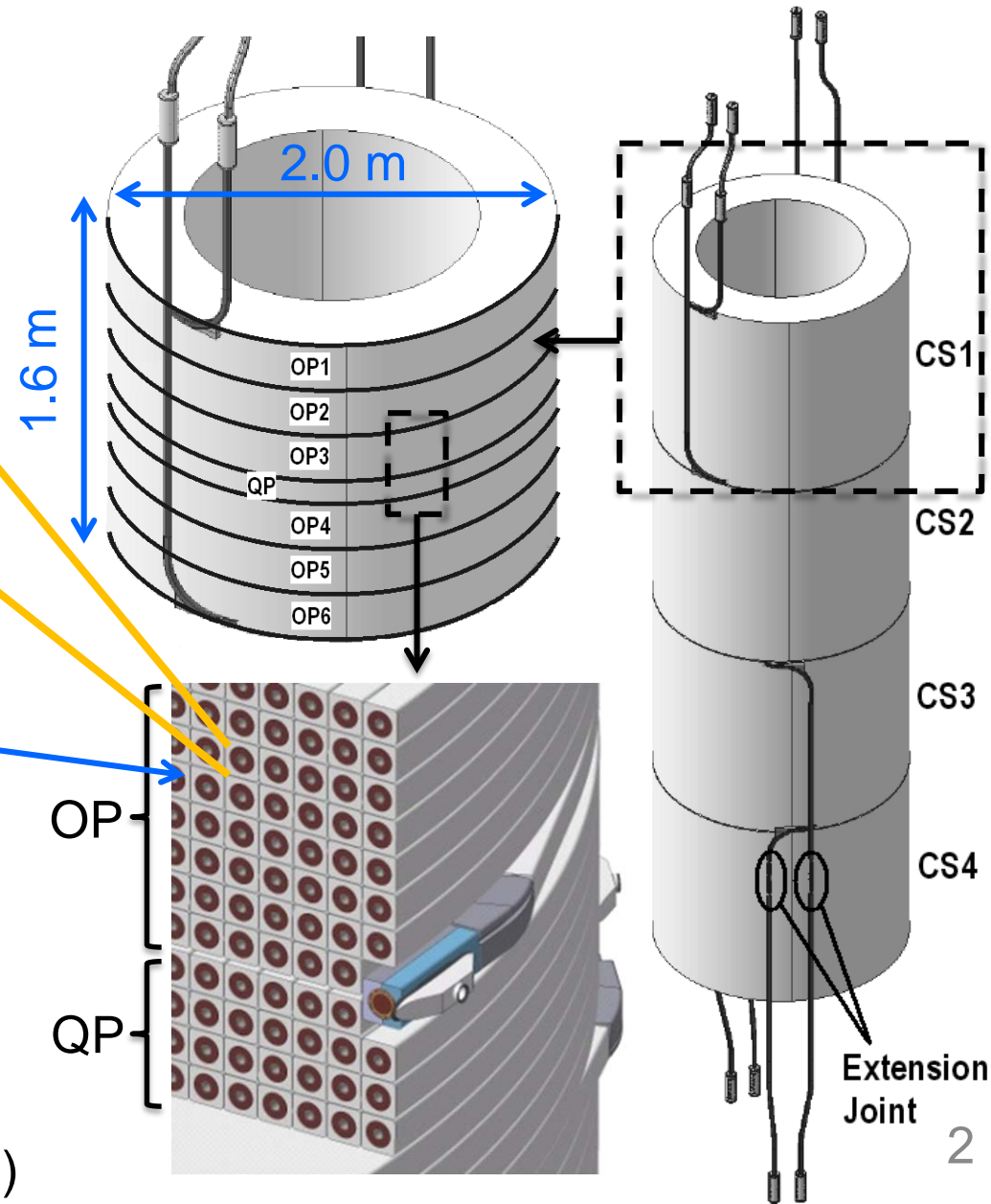
2. Magnet Design

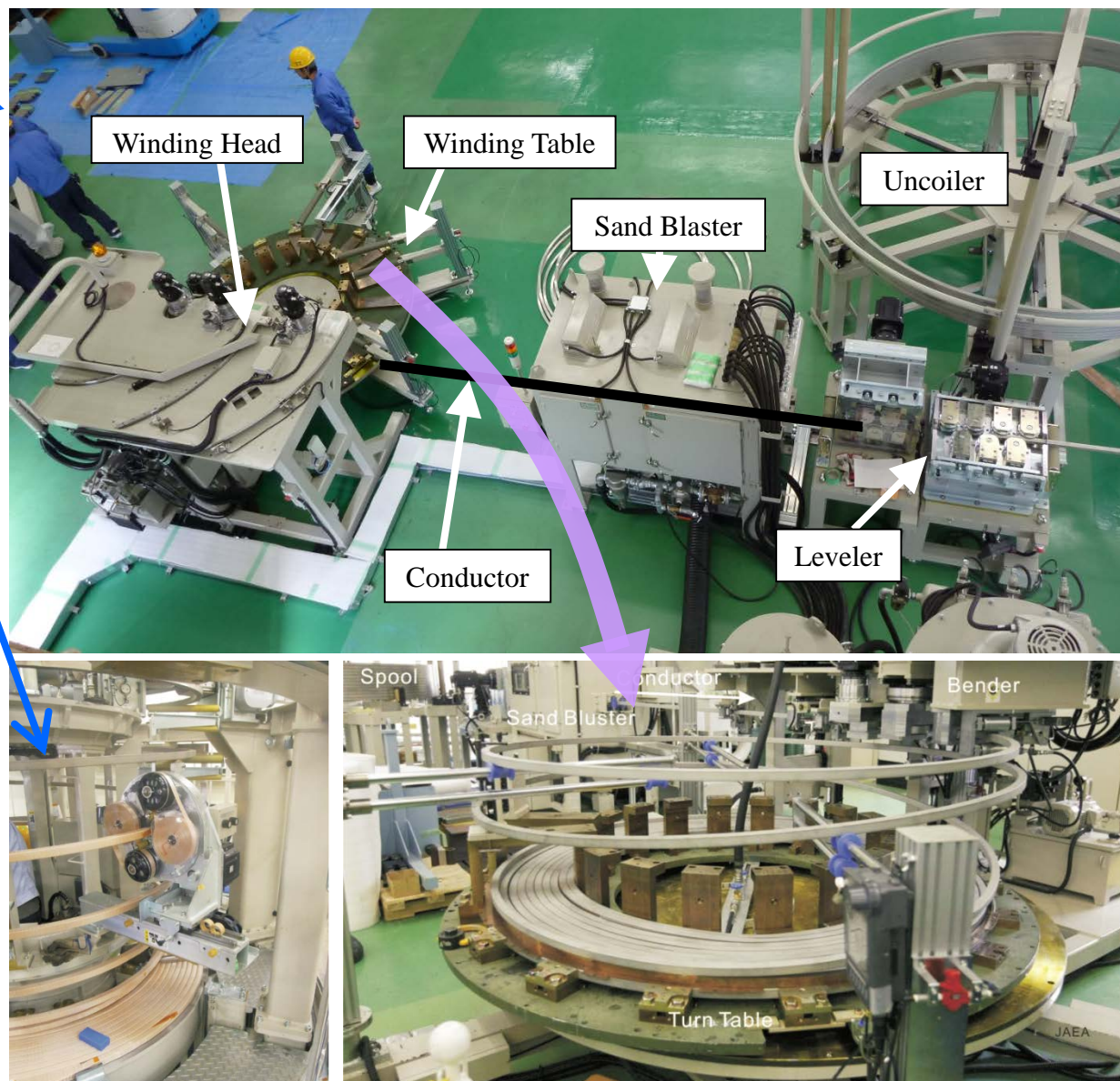
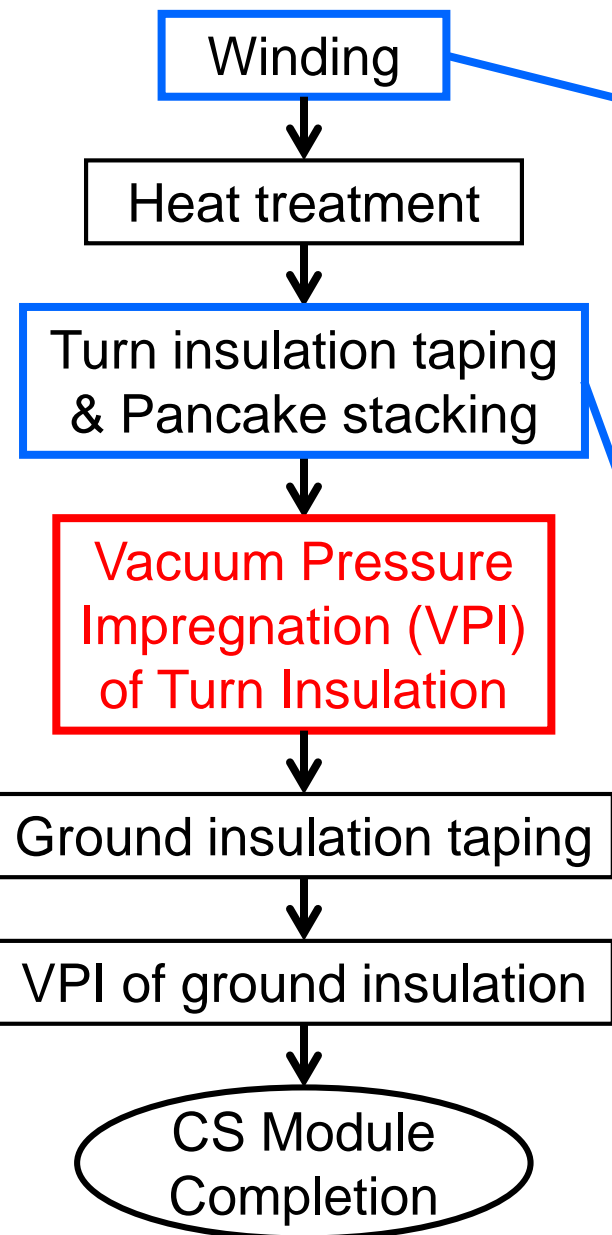
- CS system has 4 modules.
- Each module consists 52 layers
 - 6 Octa-Pancake (OP : 8 layer)
 - 1 Quad-Pancake (QP : 4 layer)
- Conductors are electrically insulated by GKG (Glass-Kapton-Glass) tape with epoxy resin. ($V_{\text{layer}}=1.8$ kV)

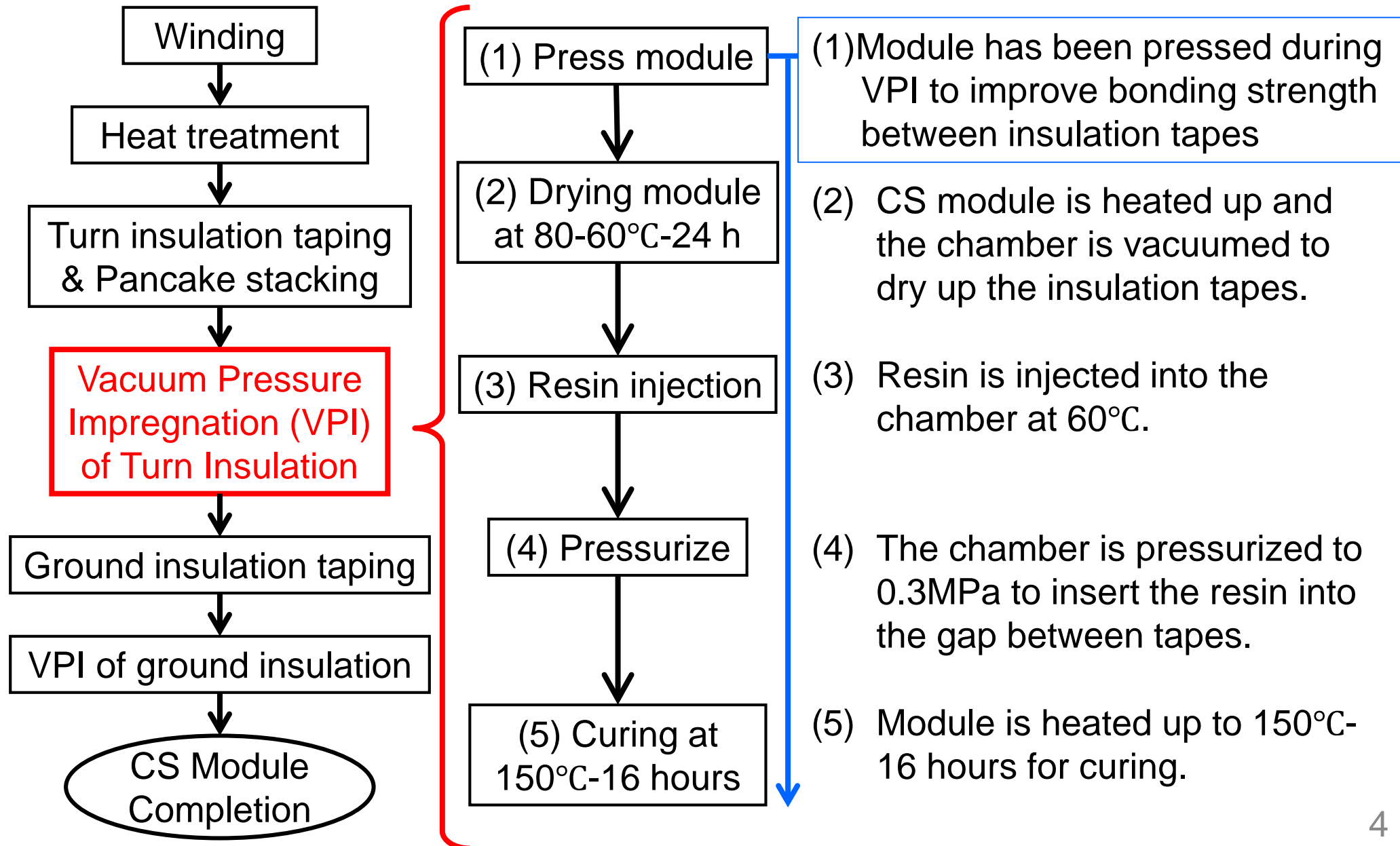
Half lap x 2 times
(total : 416 tapes)

Total thickness of turn insulation
(GKG tape) is about 70 mm

(0.165 mm x 416 tapes)







Basic design of VPI jigs

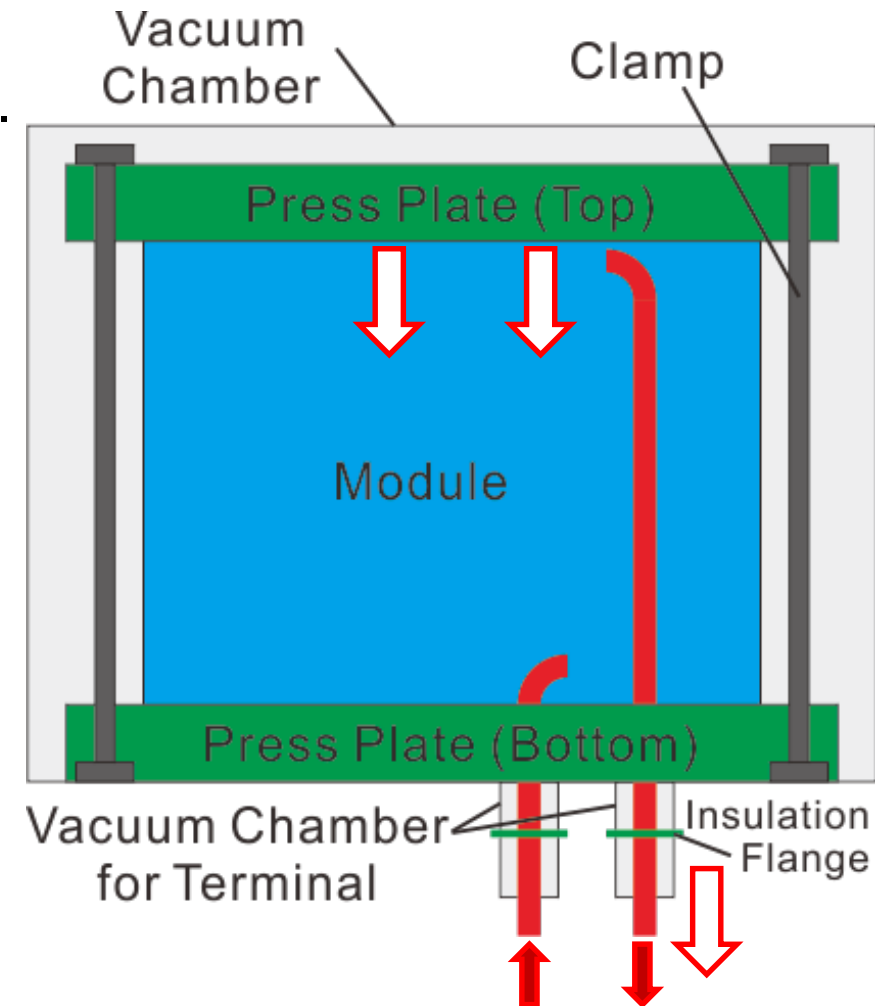
- Module is pressed by press plates and clamps.
- Module, press plates and clamps are installed into vacuum chamber.
- Insulation flanges are inserted to separate between terminals and vacuum chamber.

Insulation tapes of 70 mm thickness may be deformed by pressing and heating

- Pressing load may be released.
- Insulation flange may be broken.

Improved VPI jigs should be developed

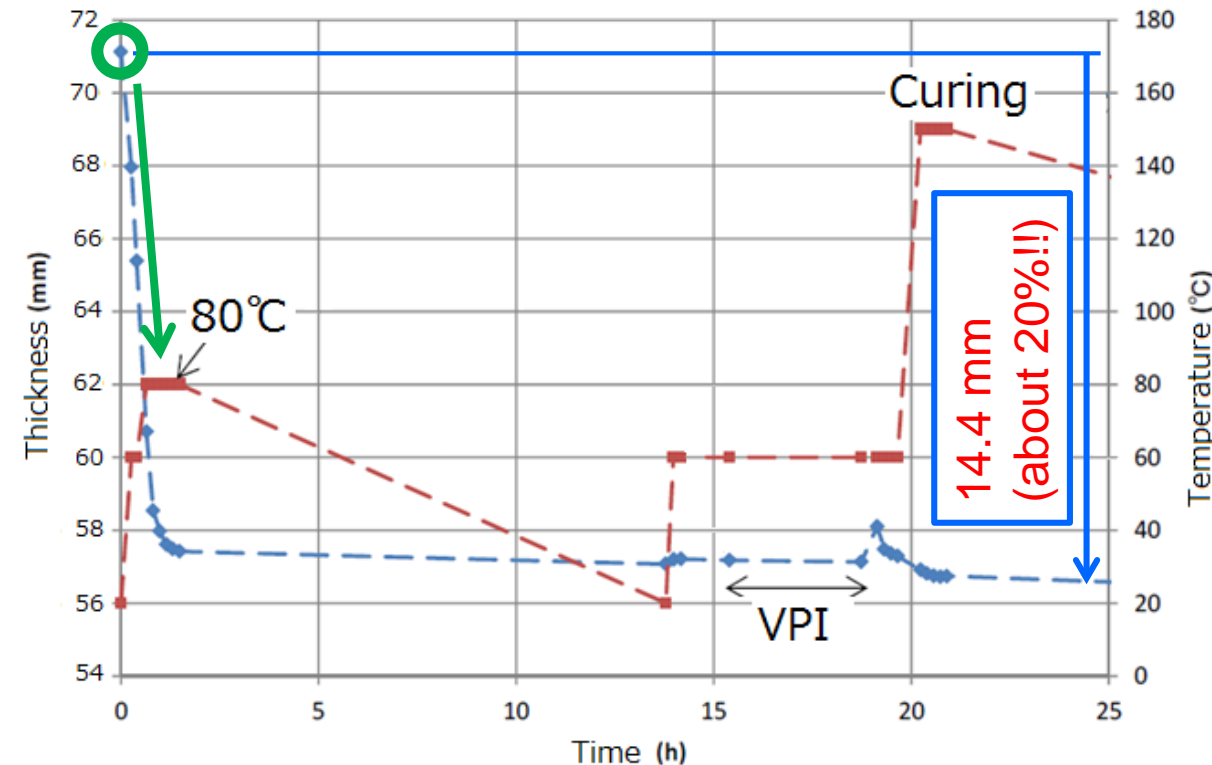
- (1) Amount of shrinkage was evaluated by preproduction VPI test.
- (2) Pressing mechanism is changed.
- (3) Vacuum chamber for terminal is changed.



CS module is energized to heat up itself during VPI process

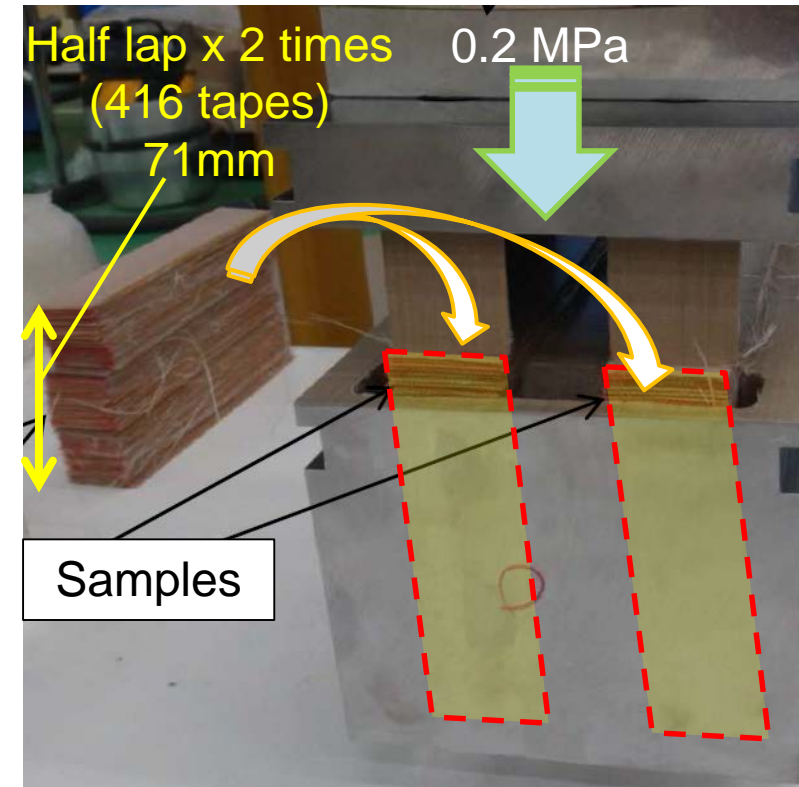
VPI Test of Insulation

416 layers stacked GKG tape was tested to measure the amount of shrinkage during VPI.



Insulation was not shrunk by only pressing at RT.
Thickness were decreasing with increasing temperature.

71 mm insulation tape was shrunk by 14.4mm

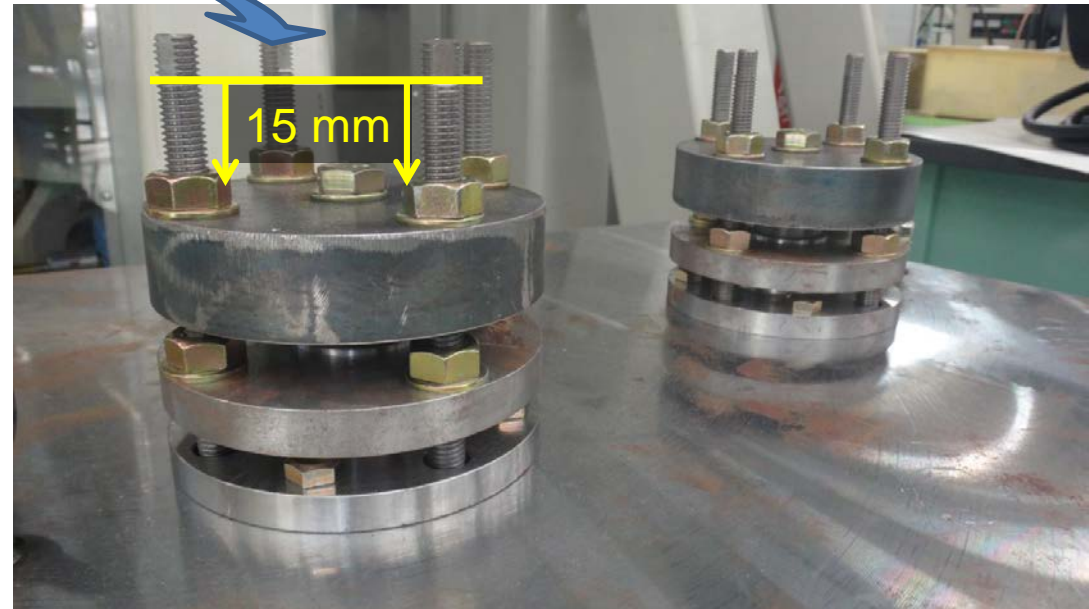
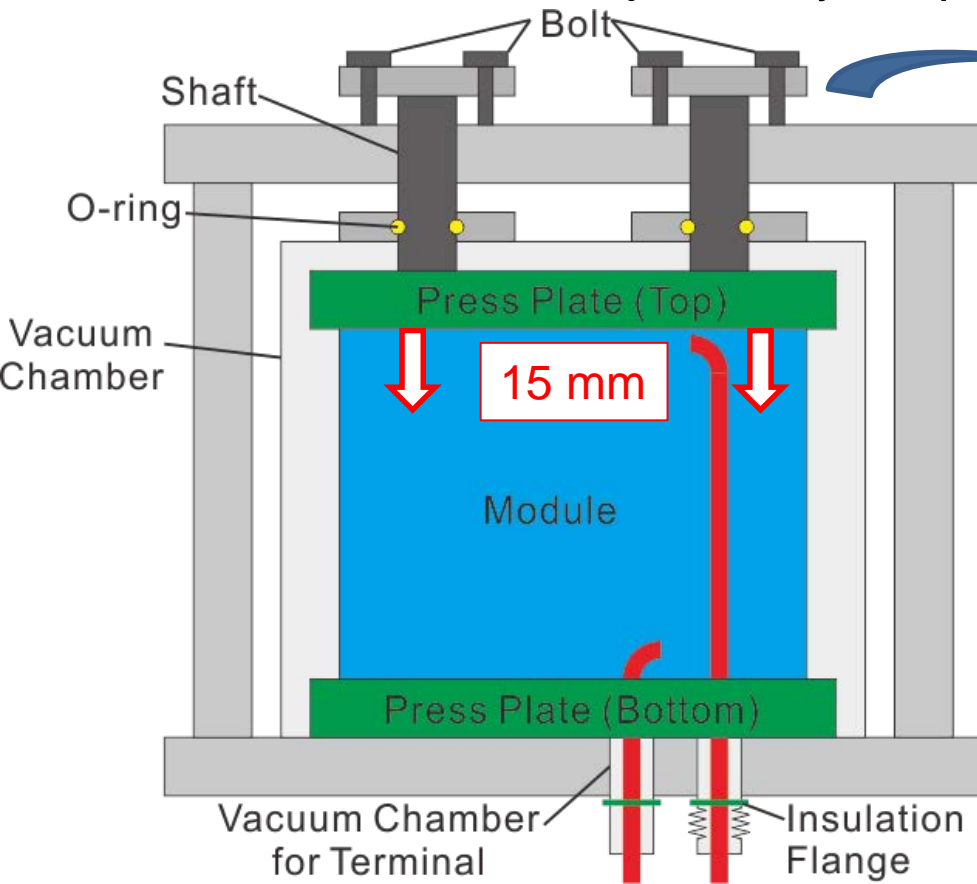


Requirement of displacement

Improved VPI jigs can be used even if module is shrunk about 15 mm.

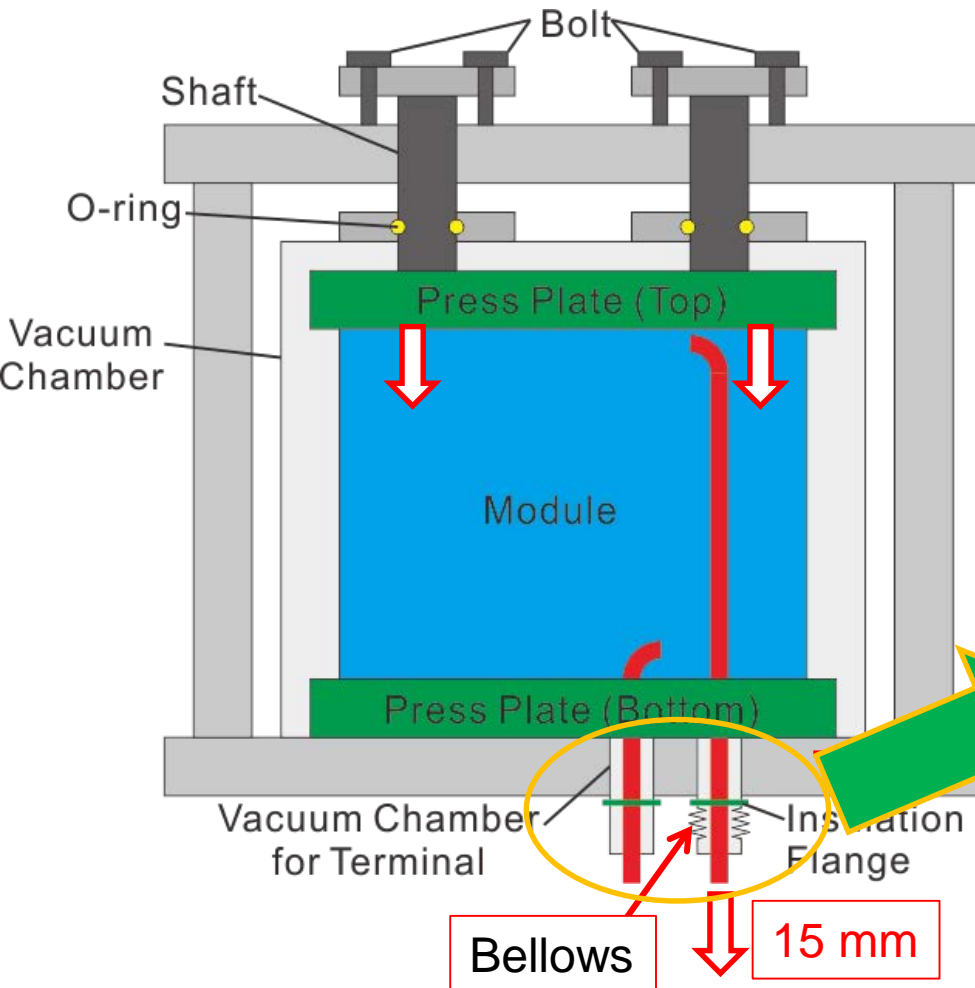
Pressing mechanism

- O-ring was used to be able to press the module after shrinking in vacuum.
- Press load can be adjusted by torque control.

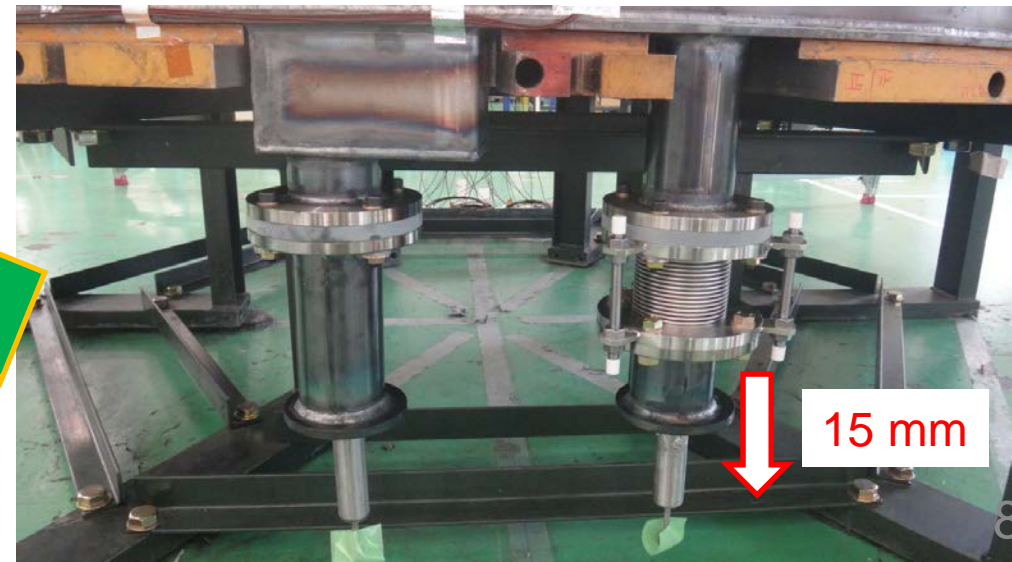
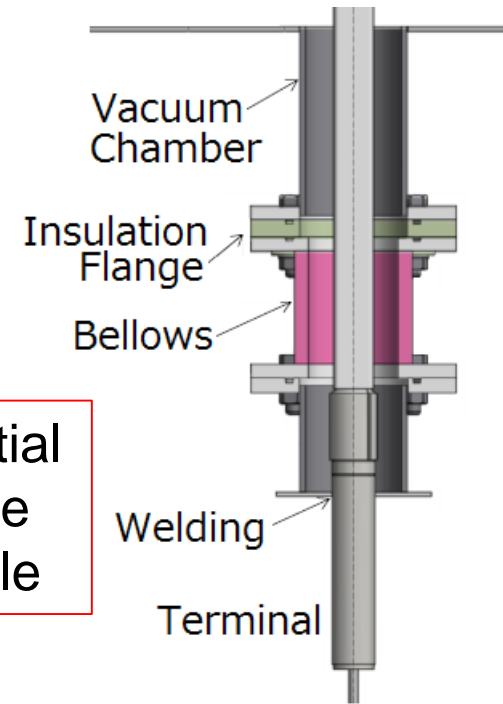


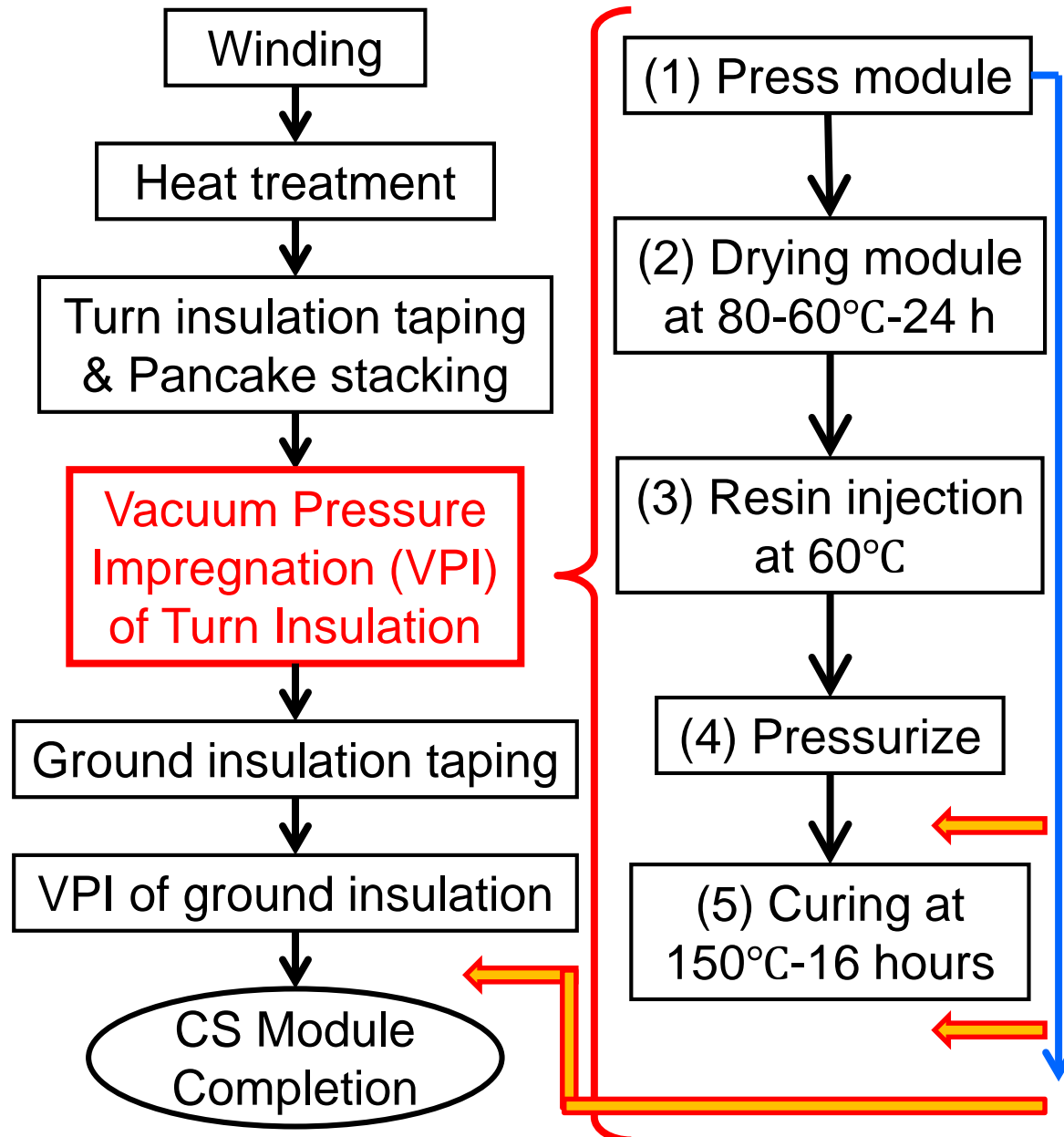
Vacuum seal of terminal part

Bellows is inserted between terminal and vacuum chamber to be able to move with module shrinkage.



Bellows is cooled at initial step of curing not to be solidified before module





Visual check was performed after injection process for first module

Impulse test (1.8kV/layer)

High voltage test (21kV)

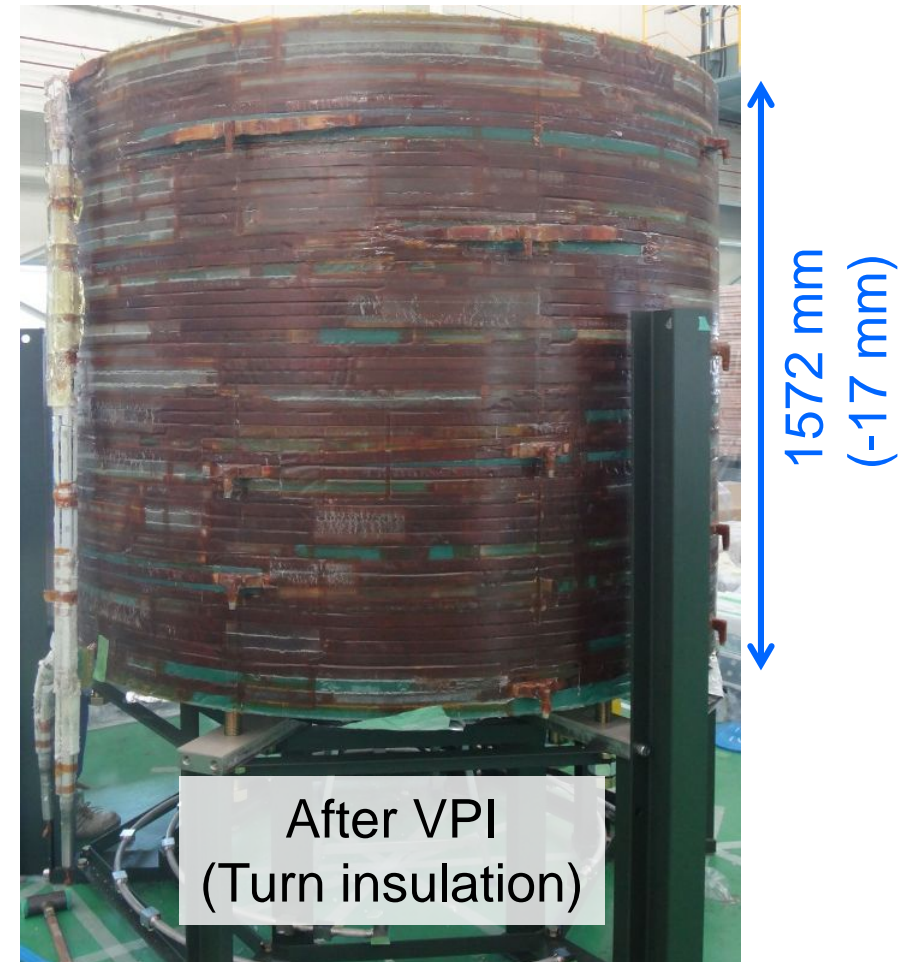
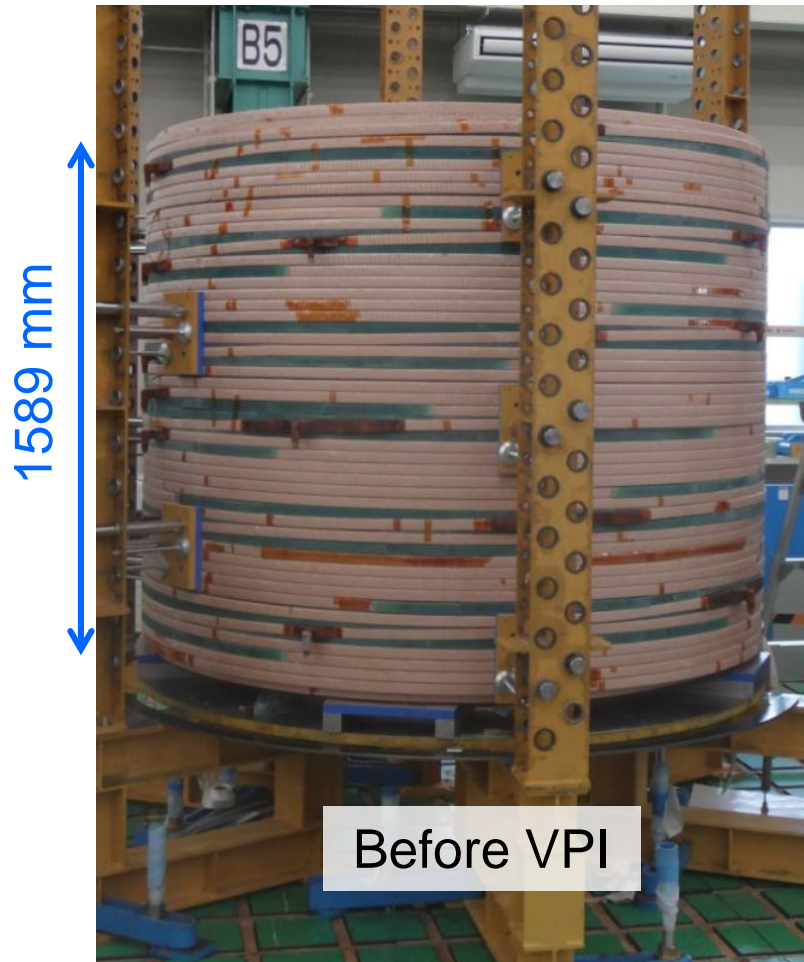
Visual check after injection process

Vacuum chamber was disassembled after resin injection for first module.

No void was observed



Impulse test (1.8kV / layer) for turn insulation and high voltage test (21kV) for ground insulation were conducted after VPI and **all insulations passed the test.**



The vacuum impregnation procedure was established.

- 1) The height of CS module after vacuum impregnation process is reduced due to the shrinkage of insulation thickness.
- 2) The displacement of this shrinkage were evaluated by preproduction test.
 - (a) The shrinkage measurement of the insulation (GKG tape) was performed under the same pressing load as actual vacuum impregnation process.
 - (b) Insulation thickness was reduced by 20% during VPI process.
- 3) We developed the jigs taking into account this shrinkage.
 - (a) O-ring was used for pressing jigs to be able to press module after shrinking.
 - (b) Bellows and insulation flanges were used for vacuum seal of terminal part.
- 4) VPI was successfully performed validated by visual check and impulse test.

The vacuum impregnation procedure was established.