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Low-resistance Joint Development for Segment-fabrication of High-temperature Superconducting Fusion Magnets

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ABSTRACT

Two designs have been proposed as segment-fabrication of the HTS helical coils in FFHR-d1 helical fusion reactor, joint-winding of the HTS coils wound by connecting conductor segments, and the “remountable” HTS magnet (here “remountable” means being able to mounted and demounted repeatedly) assembled from coil segments with remountable joints. Bridge-type mechanical lap joint and mechanical edge joint are planned to be applied to those two designs, respectively.

This poster presents progress in electrical and mechanical performances of the mechanical joints of high-temperature superconducting (HTS) conductors and methods to evaluate those quality for segment-fabrication of HTS helical coil. R&D of Joint performance have been progressed during this decade and it shows acceptable performance for the HTS helical coils. Contact-probing CTL method and X-ray CT scan are promising for quality assessment of the joints and HTS tapes.

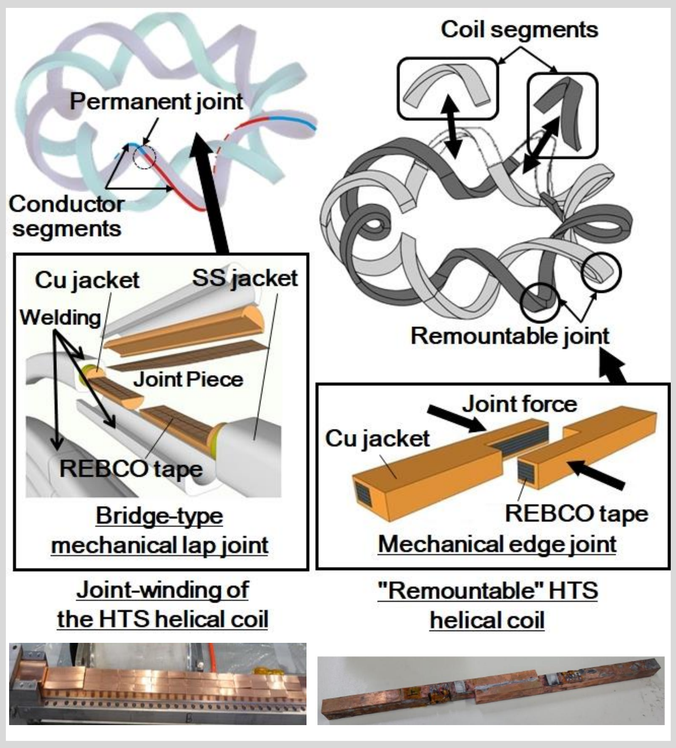
1. INTRODUCTION

Two designs of **segment-fabrication of HTS helical coils**

(1) Joint-winding [1,2]
- Feature: Simplify construction
- Joint: **Bridge-type mechanical lap joint**

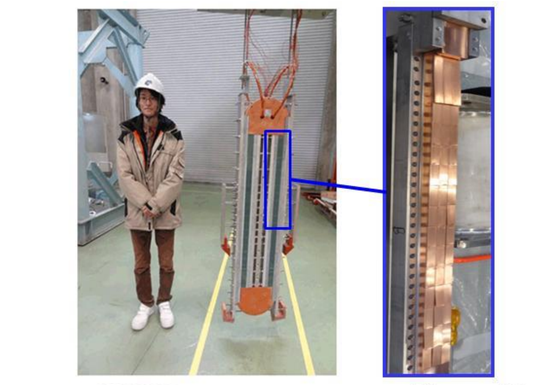
(2) Remountable magnet [3-5]
- Feature: Simplify construction
  Enable to replace failed segments
- Joint: **Mechanical edge joint**

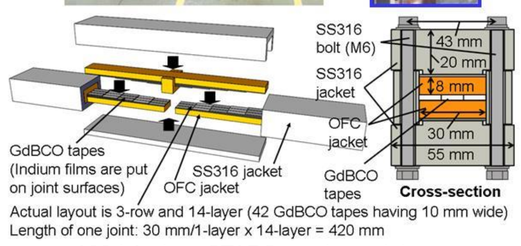
- Indium foil is inserted between joint surfaces to increase real contact area.
- The **electric and mechanical performances** of the joints and those **quality assessment** are important technical issues for the designs.



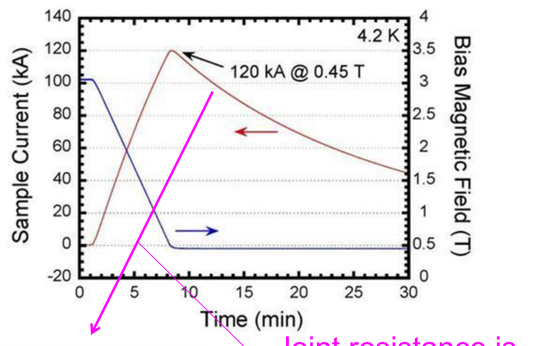
2. ELECTRIC PERFORMANCE OF JOINT

Bridge-type mechanical lap joint [5,6]





100-kA-class STARS conductor joint

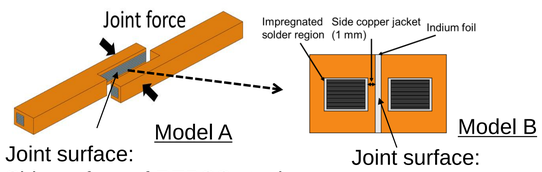


1.8 nΩ at 100 kA
~10 pΩm² (~100 nΩcm²)

Joint resistance is evaluated by decay time constant

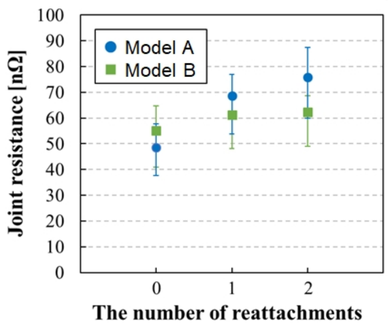
Integrated joint piece + low-temp. heat treatment
<3 hours for joining process, ~3 pΩm²

Mechanical edge joint [7,8]



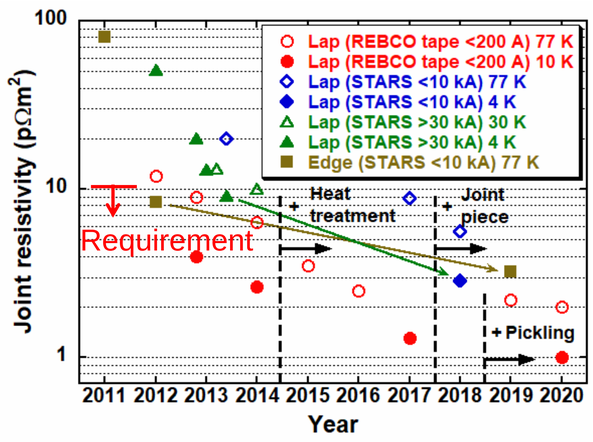
Joint surface: Side surface of REBCO stacks

Joint surface: Copper jacket



Joint resistanc kept to be alm constant wit Model B

Joint resistance as a function of the number of reattachments



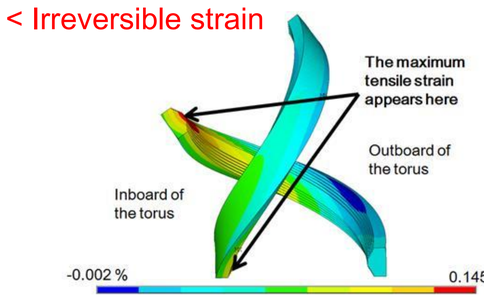
Progress in development of joint for the last decade based on joint resistivity

The achieved joint resistivity satisfies the required performance.

3. MECHANICAL PERFORMANCE OF JOINT

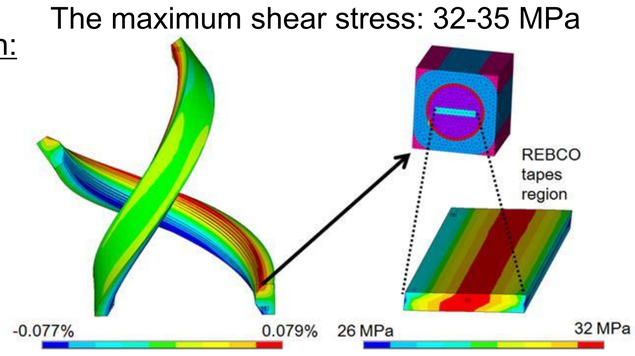
Structural Analysis [5,9,10]

• Normal strain along the winding direction:
The maximum tensile strain: 0.145%
< Irreversible strain



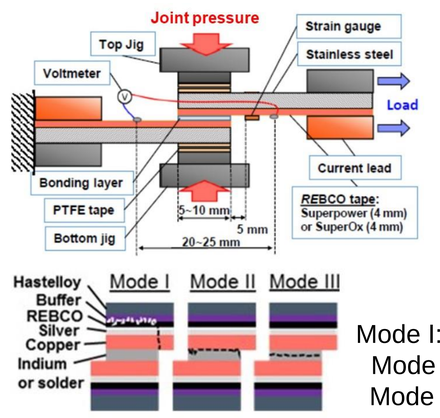
Normal strain distribution along the winding direction of the Helical coils (HCs).

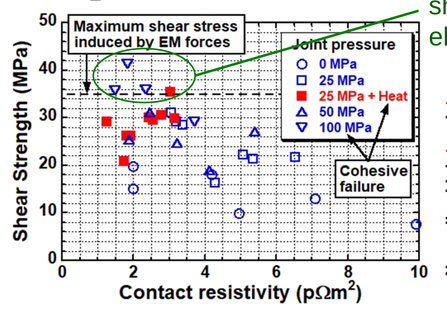
• Shear stress in the REBCO tapes region:
The maximum shear stress: 32-35 MPa



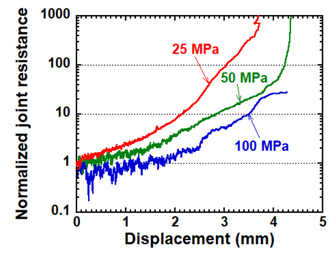
Distribution of in-plane shear strain in HCs (left figure) and distribution of *xy* component of shear strain in REBCO tape region (right figure).

Tensile shear testing [5,9,11]





Larger than maximum in-plane shear stress induced by electromagnetic forces

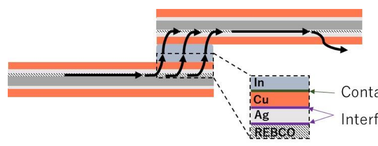


Mode I: REBCO tape failure
Mode II: Interfacial failure
Mode III: Cohesive failure

Mechanical joint with indium insertion can keep joint resistance after cohesive failure.
Displacement is limited due to the presence of the jackets.

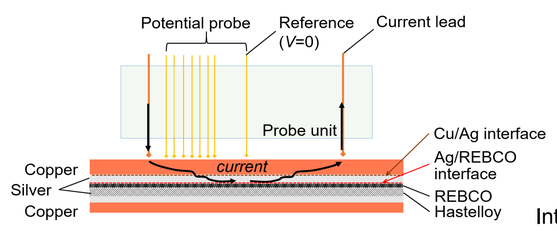
4. QUALITY ASSESSMENT OF JOINT

Evaluation of interface resistance of REBCO tape [12]

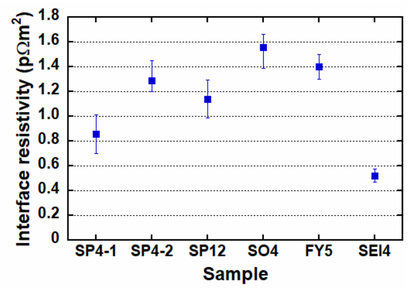


- Contact resistance: controlled by joining process
- Interface resistance: varied depending on batch of REBCO tape

Contact-probing current transfer length method



Schematic illustration of the contact-probing CTL method

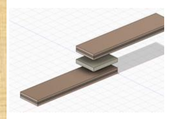


- SP4-1, SP4-2: SuperPower, 4 mm
- SP12: SuperPower, 12 mm
- SO4: SuperOx Japan, 4 mm
- FY5: Fujikura, 5 mm
- SEI4: Sumitomo, 4 mm

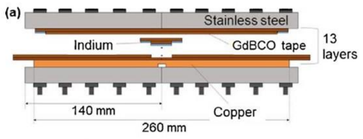
Interface resistivity of various REBCO tapes evaluated at 77 K

REBCO tape can be sort out before conductor segment fabrication based on nondestructive interface resistance evaluation.

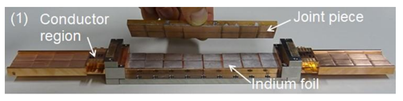
Evaluation of contact area based on X-ray CT scan [13,14]



Single lap joint

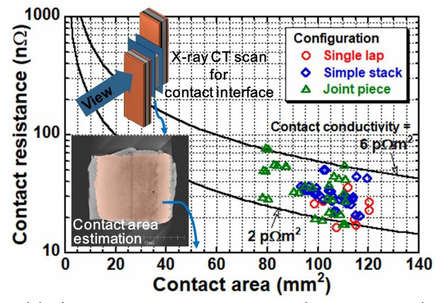


Bridge-type mechanical lap joint of HTS conductors with “Simple stack” method



Bridge-type mechanical lap joint of HTS conductors with “Joint piece”

All joints were fabricated with low-temperature heat treatment



Relationship between contact area and contact resistance based on X-ray CT scan for three joint configurations

Range of contact resistance can be predicted from contact area using X-ray CT scan

5. CONCLUSION

(i) Joint resistance for bridge-type mechanical lap joint and mechanical edge joint have been reduced to be acceptable value for HTS helical coils in FFHR-d1 helical fusion reactor.

(ii) The bridge-type mechanical lap joint with indium insertion is preferable for use in joint-winding of the HTS helical coil because of its mechanical behavior.

(iii) X-ray CT scan and contact-probing CTL method are promising to predict joint resistance, and quality control of the joints during fabrication process at room temperature before applying current.

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