Recent status of Fujikura's 2G HTS wire

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Fujikura

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Outline

- Introduction
- Recent progress of 2G HTS wires at Fujikura
- Evaluation of the mechanical properties of 2G HTS wires
- HTS magnets
- Summary

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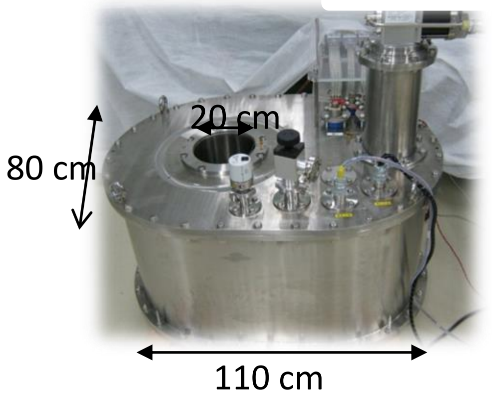
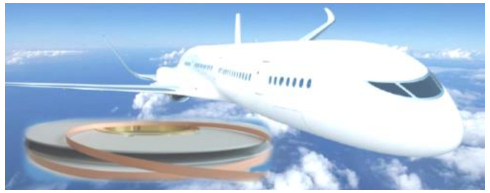
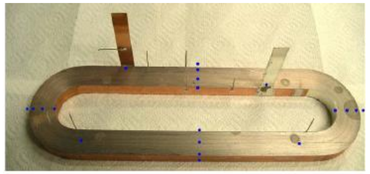
Recent shipment of Fujikura's RE-based HTS tapes

- 5T cryocooled magnet with 20 cm RT bore by Fujikura (2012)



- NEDO MRI program (2016-2018)
- TELOS Project (2016-2019)

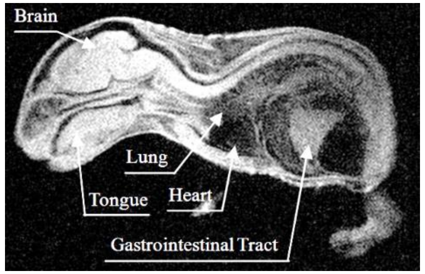


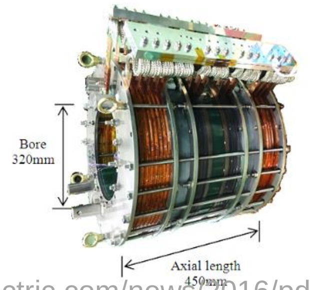


Presented at EUCAS 2019

Airbus, KIT, Siemens

- Worlds 1st 3T MRI by Mitsubishi Electric (2015)

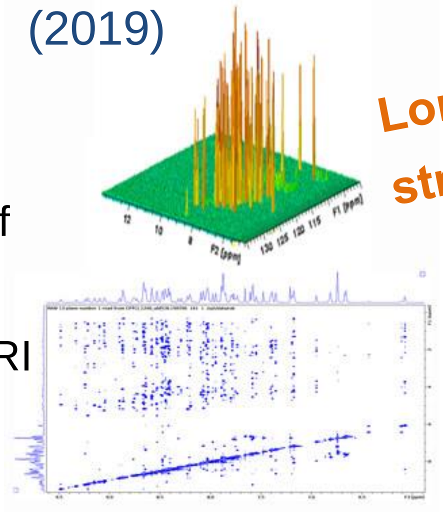




1/3 demo of drive mode 3T class MRI

http://www.mitsubishielectric.com/news/2016/pdf/0524.pdf
http://www.nedo.go.jp/english/news/AA5en_100071.html

- Bruker 1.2 GHz high field **NMR** system (2019)



Longitudinal uniformity strongly required

Worlds 1st 1.2 GHz NMR

28.2 T magnet with 54 mm bore RE-based HTS

https://ir.bruker.com/press-releases/press-release-details/2019/Bruker-Announces-Worlds-First-12-GHz-High-Resolution-Protein-NMR-Data/default.aspx

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Typical Specifications of RE-based HTS tape at Fujikura

Products	Width [mm]	Thickness [mm]	Substrate [µm]	Stabilizer [µm]	Critical Current [A] 77K, S.F.	Critical Current [A] 20K, 5T *3
FYSC-SCH04	4	0.13	75	20	≥ 165	368
FYSC-SCH12	12	0.13	75	20	≥ 550	1,104
FYSC-S12 *1	12	0.08	75	—	≥ 550	—
FESC-SCH02 *2	2	0.11	50	20	TBD	(257)
FESC-SCH03 *2	3	0.11	50	20	≥ 63	497
FESC-SCH04 *2	4	0.11	50	20	≥ 85	663
FESC-SCH12 *2	12	0.11	50	20	≥ 250	1,990
FESC-S12 *1,2	12	0.06	50	—	≥ 250	1,990

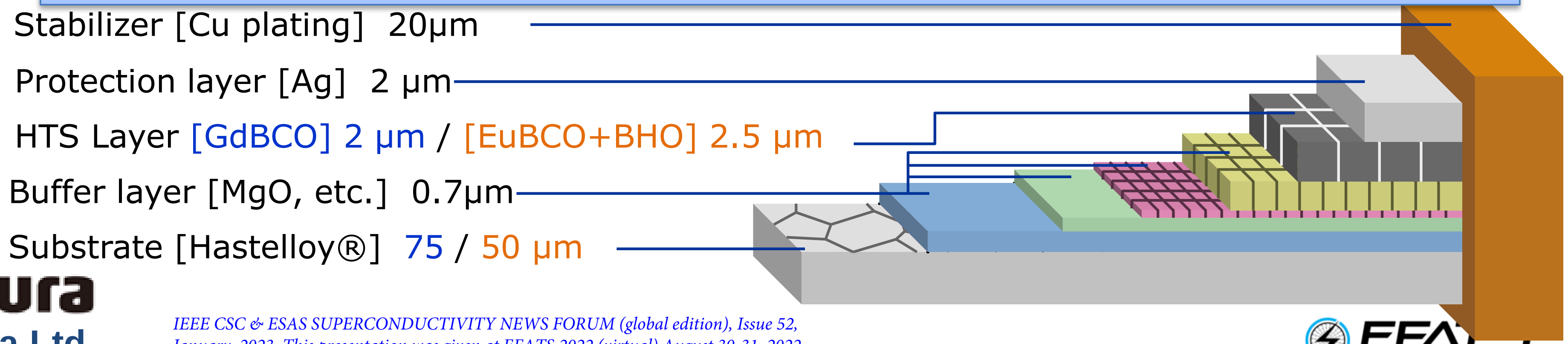
*1 Non-copper stabilizer specification is available in only 12mm-wide for current lead or low thermal conducting applications.

*2 Artificial pinning specification is mainly for use in magnet applications at low temperature and high magnetic field.

*3 Ic@20K, 5T is a reference value and no guarantee of the actual performance.

*4 If requested, an option customizing copper plating thickness is also available. (e.g., 5µm, 10µm or 40µm)

FYSC(Non-AP) is recommendable for use at relatively higher temperature.
FESC(AP) is recommendable for use in magnet applications at lower temp. and higher field.



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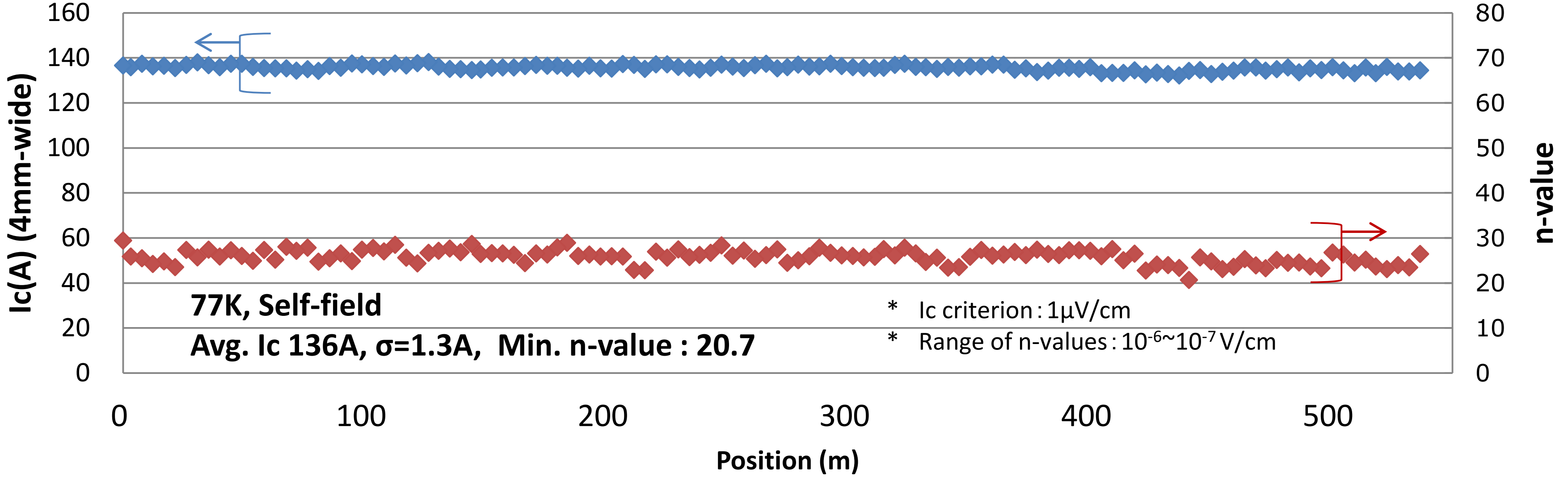
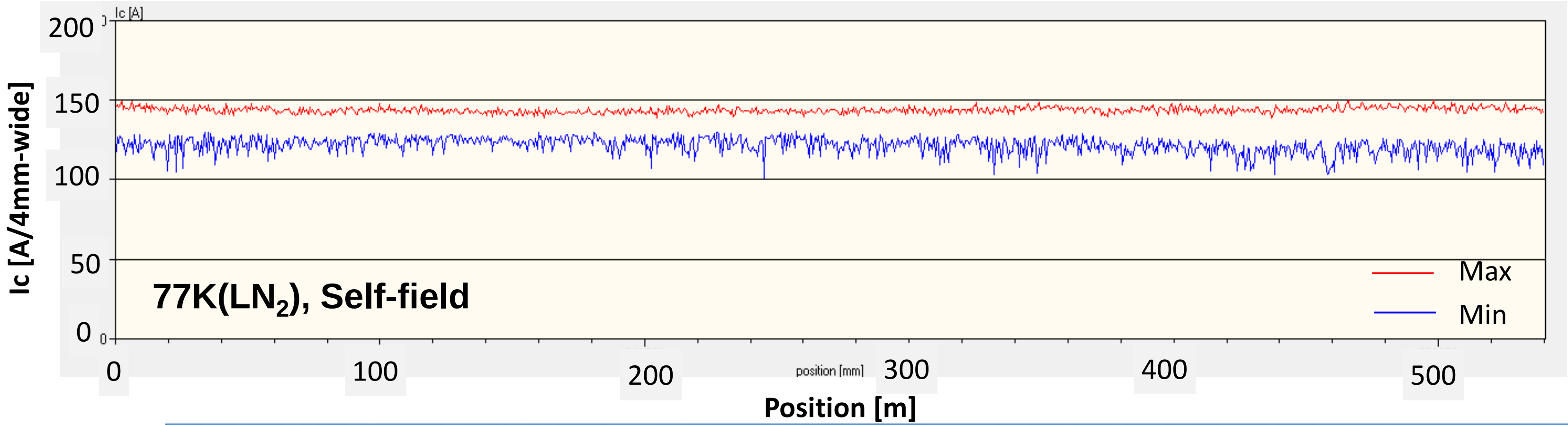
Example data of longitudinal I_c distribution of 4mm-wide tape

- **Measured by Current conduction measurement every 4.7 m (with AP / FESC-SCH04)**



- **Magnetic measurement @Tapestar™ (4mm-wide with AP / FESC-SCH04)**



quite uniform I_c with artificial pinning tape and over 500 m are obtained

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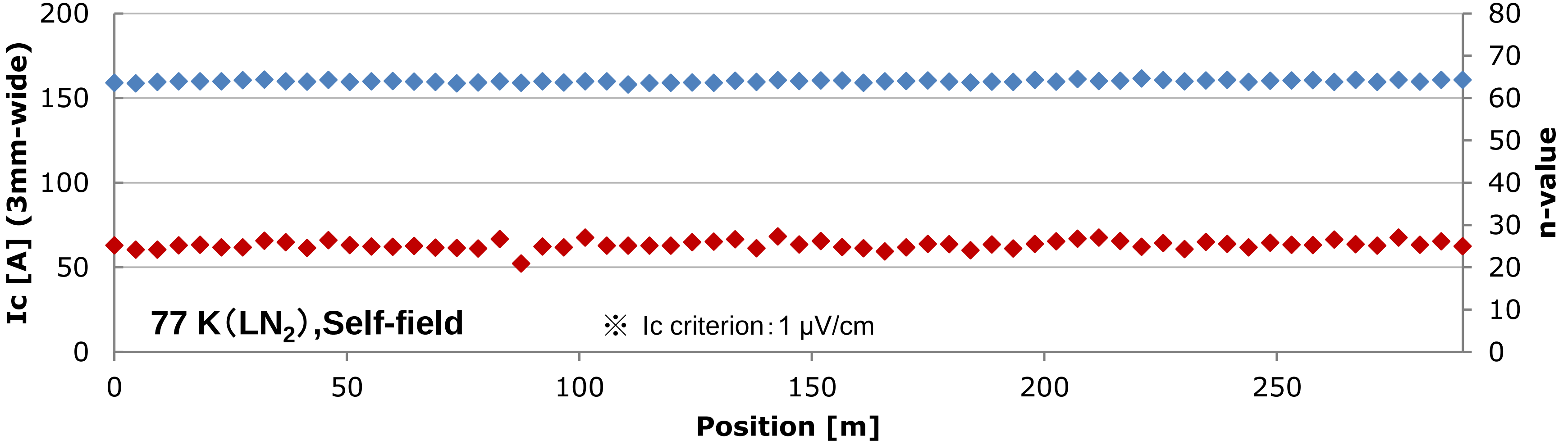
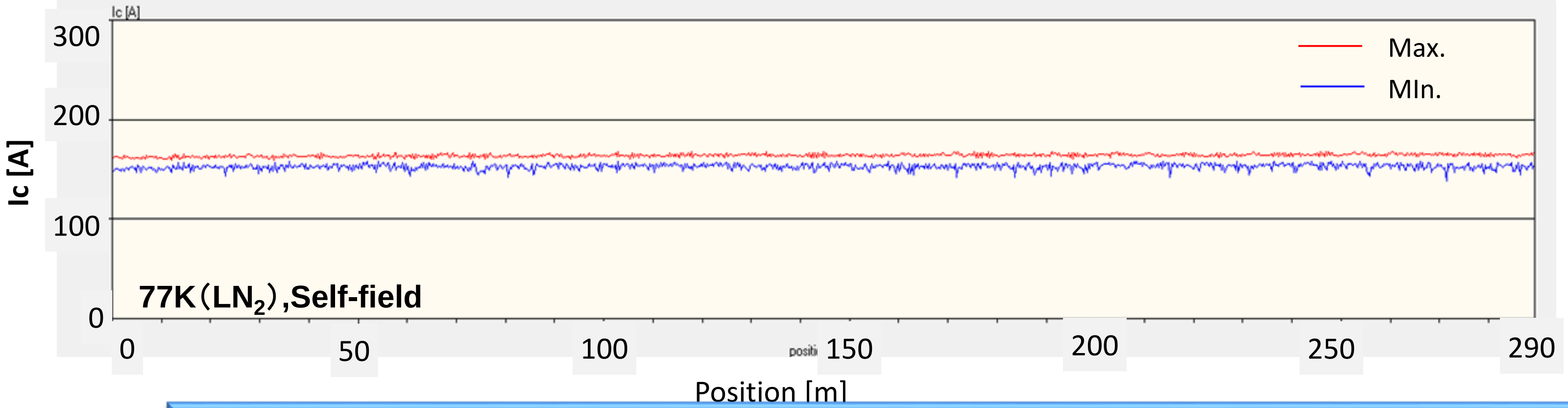
Example data of longitudinal I_c distribution of 3mm-wide tape

3 mm-wide tape: FESC-SCH03

- Measured by 4-terminal method current conduction measurement at every 4.7 m



- Magnetic measurement @Tapestar™ (3mm-wide with AP / FESC-SCH03(40))



Uniform I_c with artificial pinning and approx. 300m length tape are obtained

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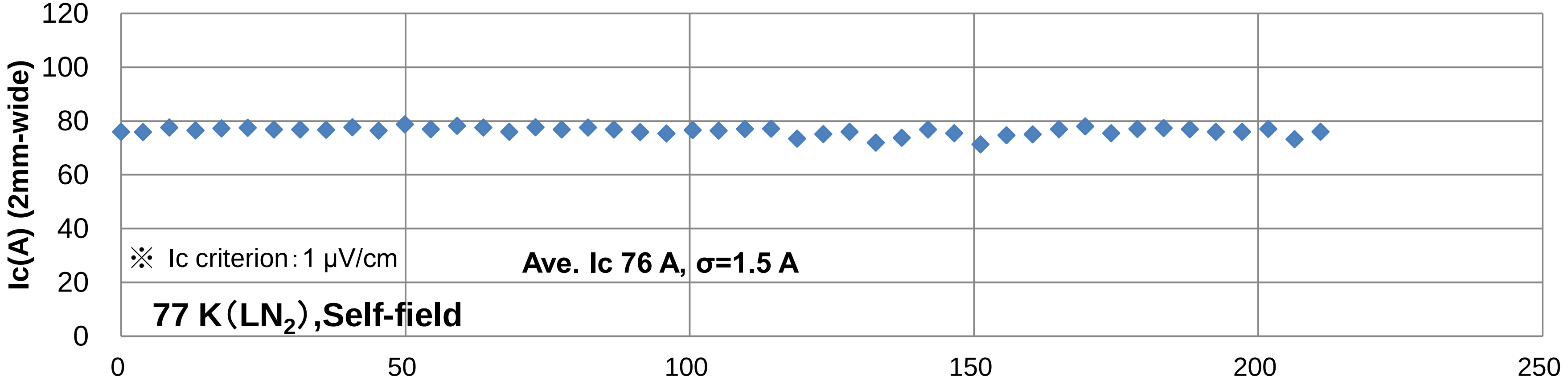
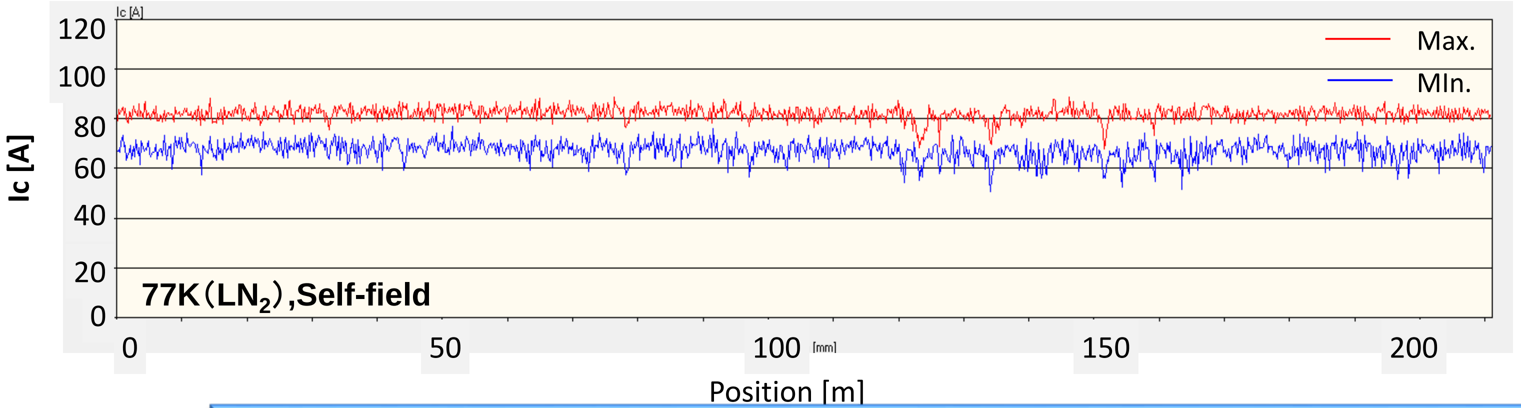
Example data of longitudinal I_c distribution of 2mm-wide tape

2 mm-wide tape: FESC-SCH02

- Measured by 4-terminal method current conduction measurement at every 4.7 m



- Magnetic measurement @Tapestar™ (2mm-wide with AP / FESC-SCH02)



Uniform I_c with artificial pinning tape are obtained even with 2 mm wide

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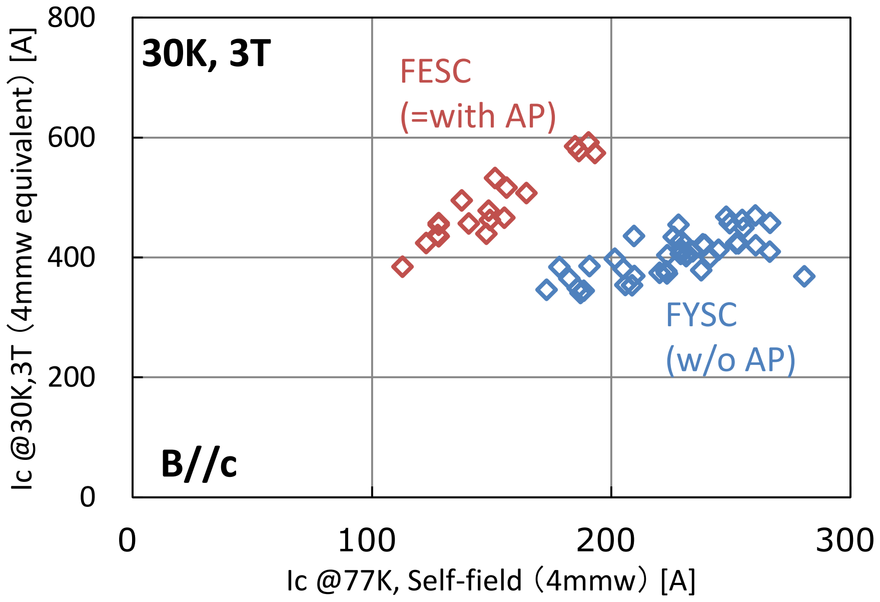
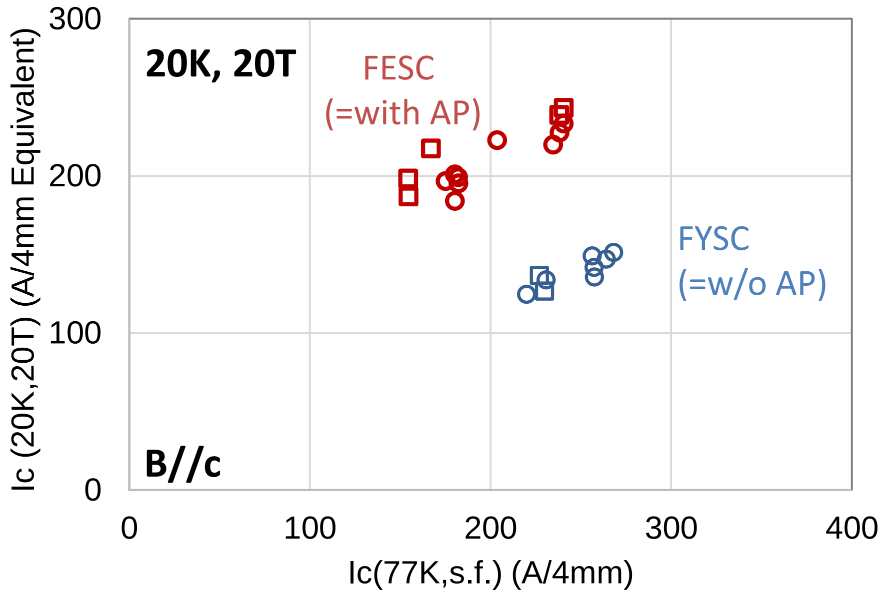
Evaluation of lot-to-lot variation of in-field I_c (1)

Evaluation results between Ic at 77K, self-field and in-field Ic, compared with conventional(w/o AP) tapes





Fujikura's tapes show very good correlation

◇ measured at Fujikura, and exploited values with Ic
□ in-field Ic measured at Tohoku university

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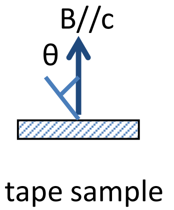
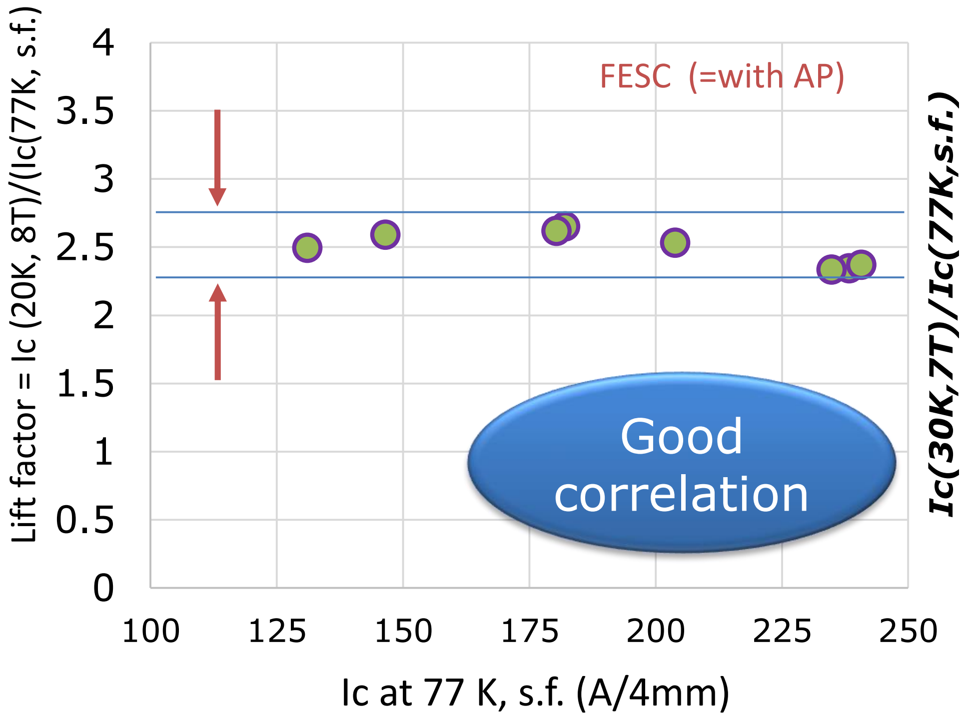
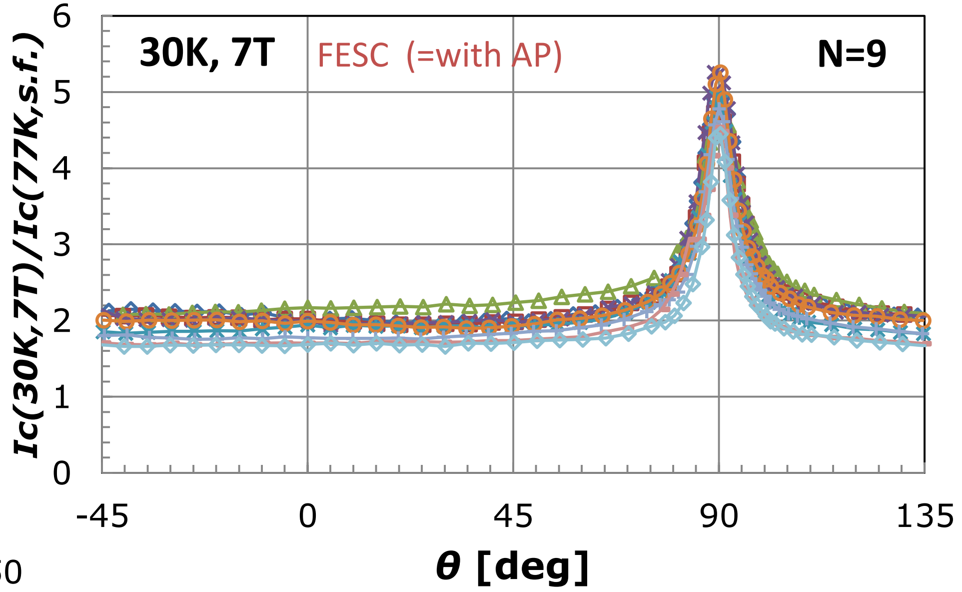
Evaluation of lot-to-lot variation of in-field I_c (2)

Narrow width indicates small variation of in-field Ic





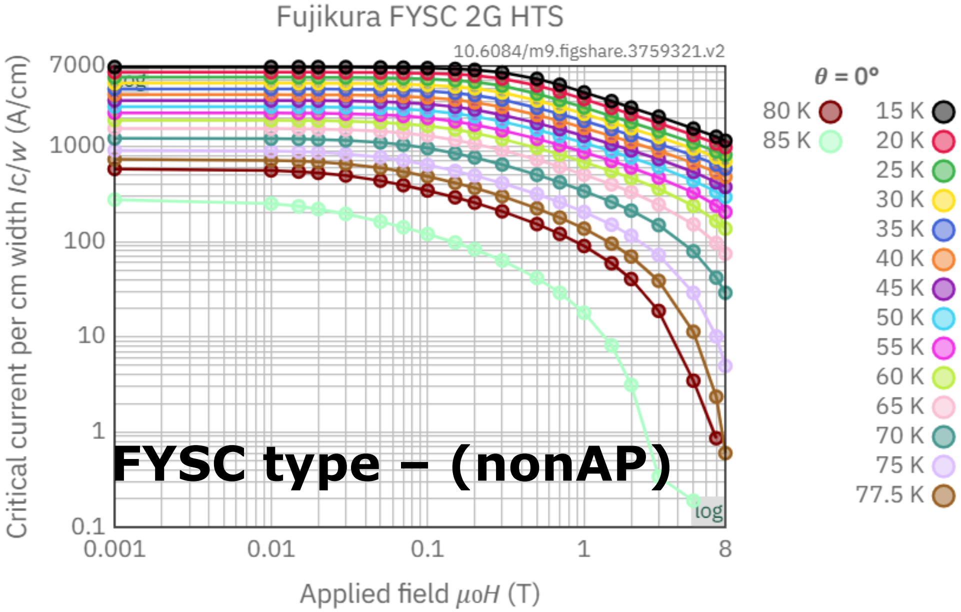


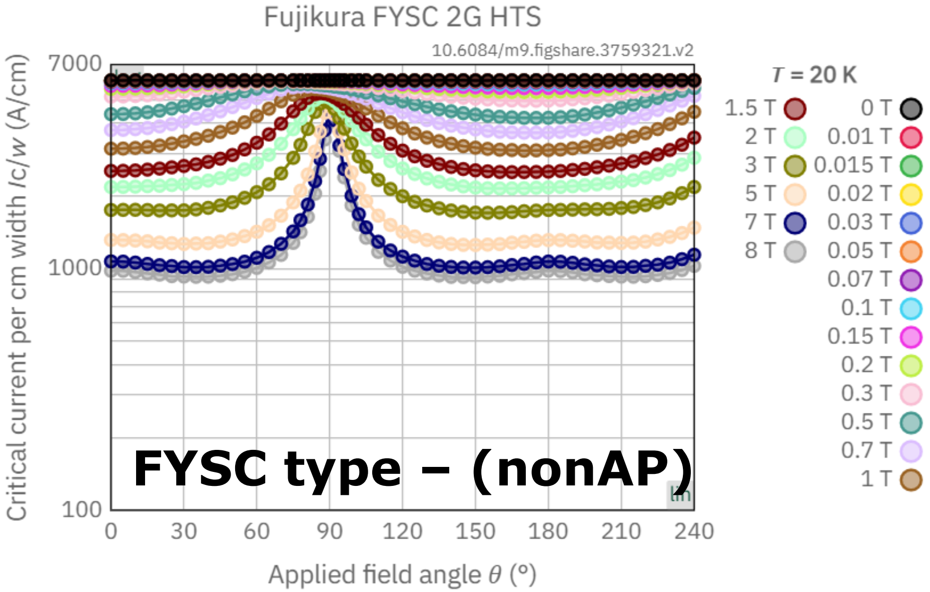
Fujikura's tapes perform very good reproducibility

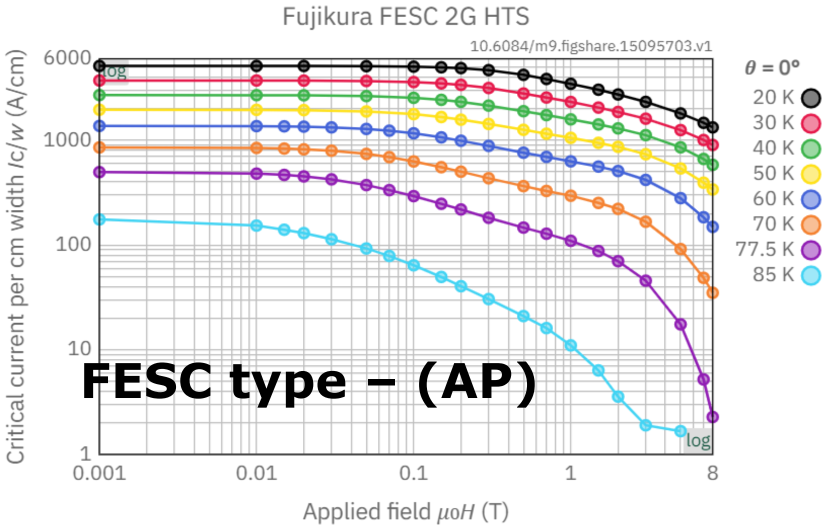
Typical data measured in RRI(robinson research institute)

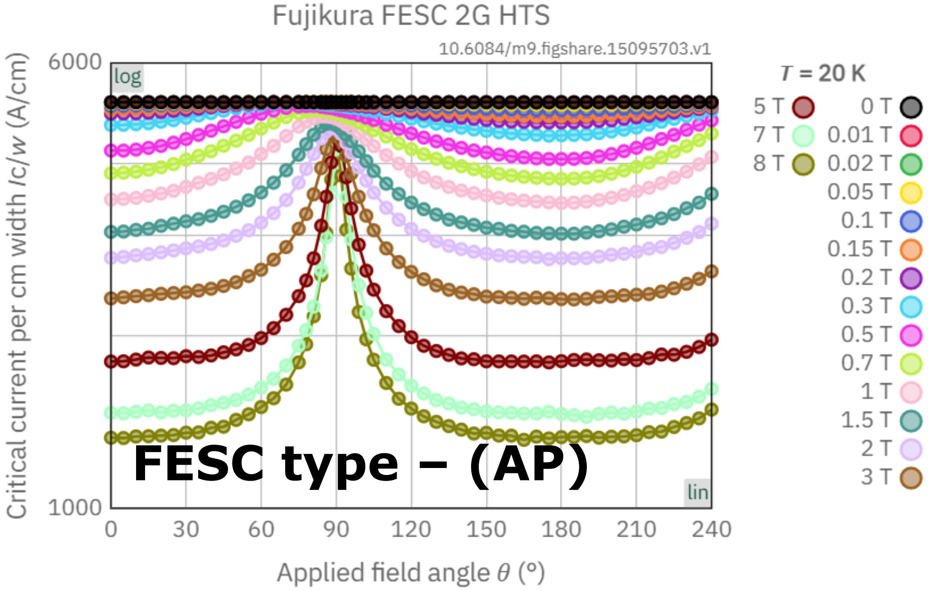
You can see the data at "http://htsdb.wimbush.eu"

Temperatures, fields and angles can be changed.









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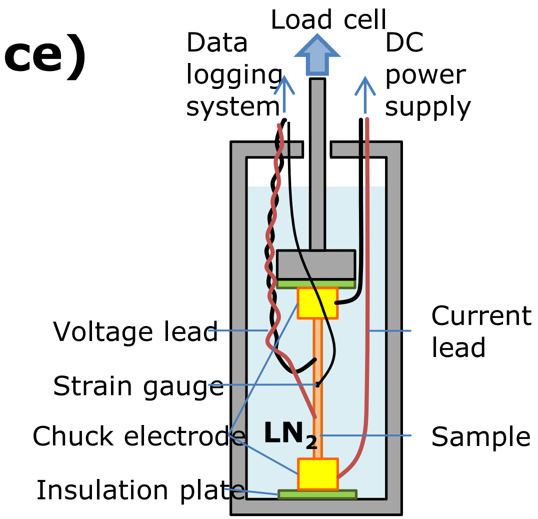
Tensile Stress

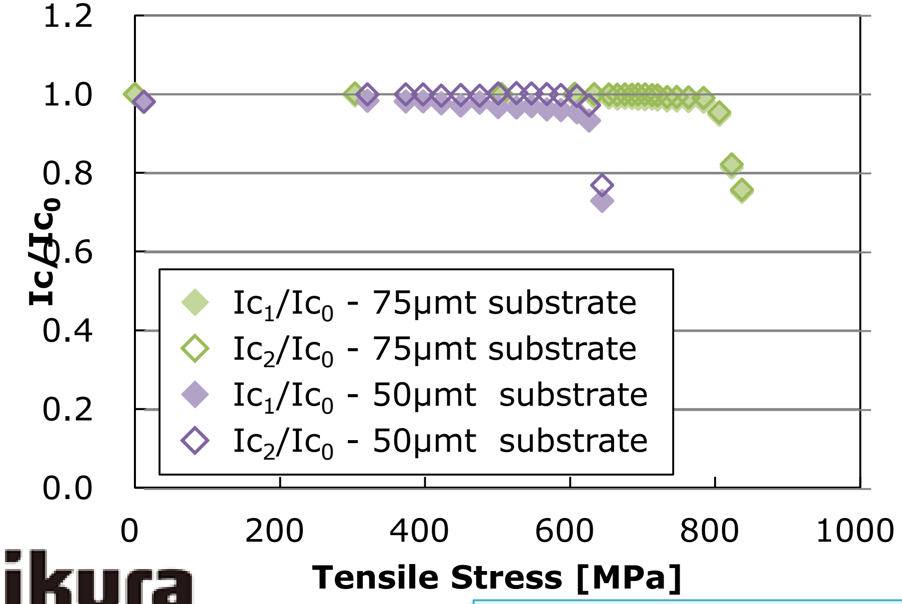
■ Tensile stress evaluation at LN_2 temperature (Reference)

- Sample : 4mm-wide, 75 µm-thick Hastelloy + 20 µm-thick Cu plating (FYSC-SCH04)
  4mm-wide, 50 µm-thick Hastelloy + 20 µm-thick Cu plating (FESC-SCH04)
- Measurement method :
  1. Ic measurement without load in LN_2 (Ic_0)
  2. Ic measurement with applying tensile strain in LN_2 (Ic_1)
  3. Ic measurement without load (Ic_2) after applying tensile strain in LN_2

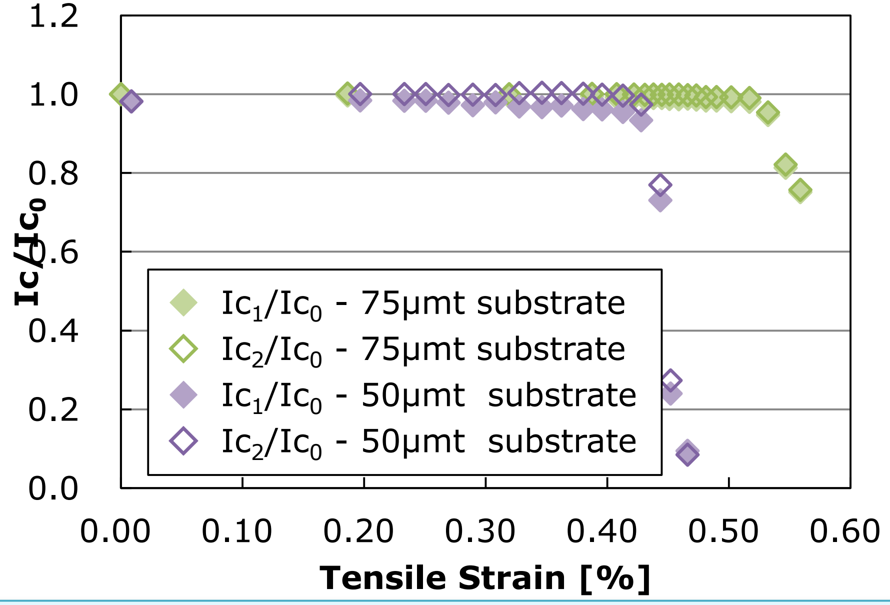


Schematic of tensile test

Ic/Ic_0 versus tensile stress



Ic/Ic_0 versus tensile strain



the difference is due to the difference of thickness of HTS layer → strain ≧ 0.4%

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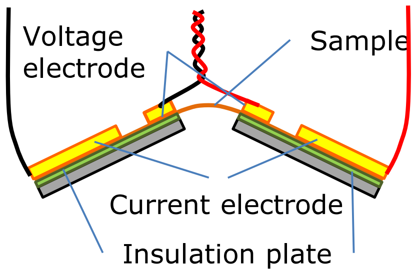
Bending Property

■ Bending property evaluation at LN_2 temperature (Reference)

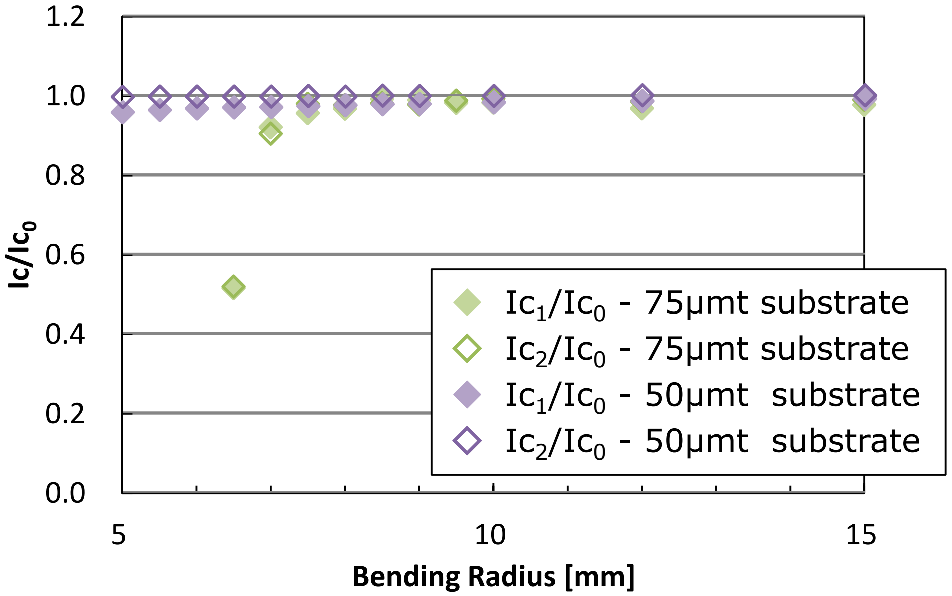
- Sample : 4mm-wide, 75 µm-thick Hastelloy + 20 µm-thick Cu plating (FYSC-SCH04)
  4mm-wide, 50 µm-thick Hastelloy + 20 µm-thick Cu plating (FESC-SCH04)
- Measurement method ("Goldacker" continuous bending method) :
  1. Ic measurement in straight in LN_2 (Ic_0)
  2. Ic measurement with applying bending strain at LN_2 (Ic_1)
     * Bending direction is tensile direction with superconducting layer outside.
  3. Ic measurement in straight (Ic_2) after applying bending strain in LN_2



Schematic of bending test

Ic/Ic_0 versus bending radius

No Ic degradation for 50µmt substrate below bending radius of 5mm of the measurement limit



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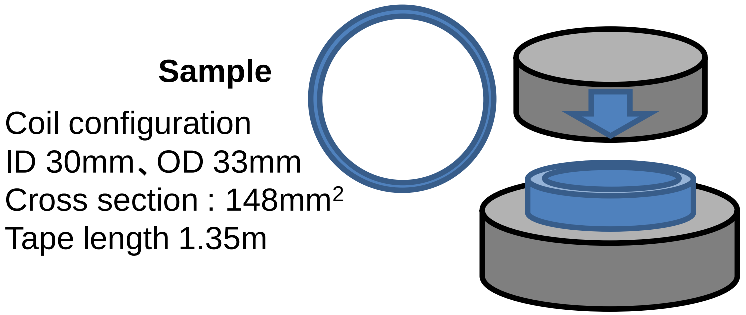
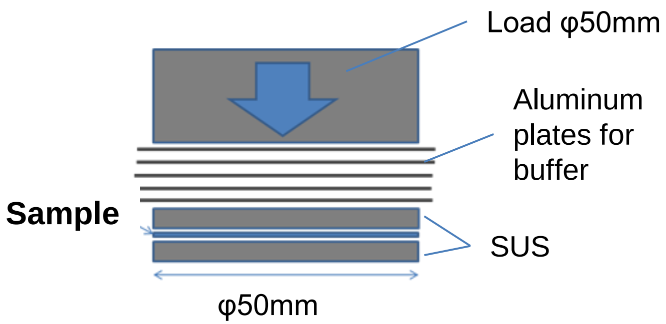
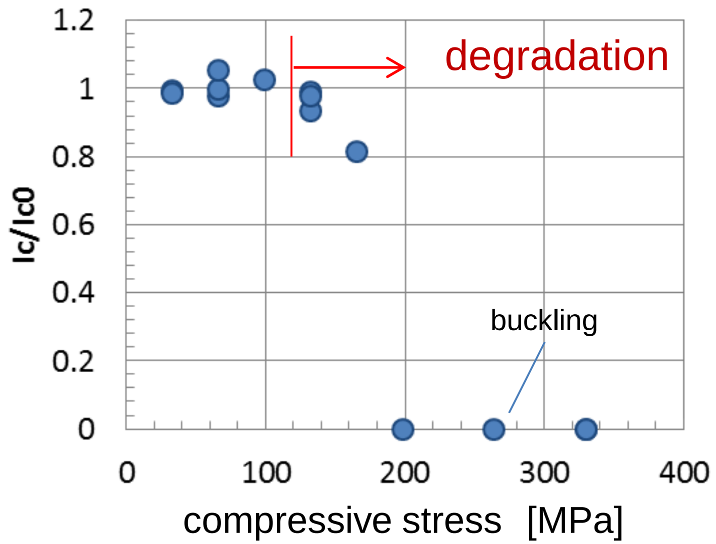
Example data of compressive test at room temperature

■ **Sample : FESC-SCH04 (4mm-wide, 50 µm-thick substrate + 20 µm-thick copper)**

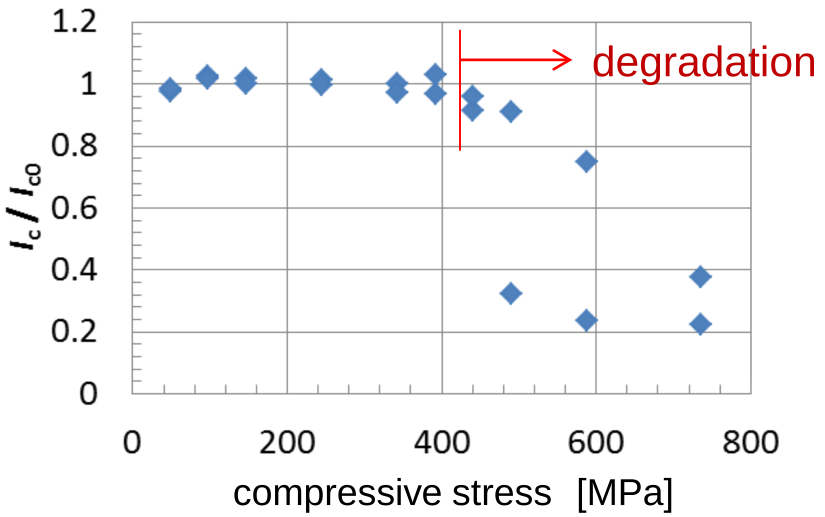




compressive stress in width direction



compressive stress in thickness direction



No degradation ~ 100 MPa

No degradation ~ 400 MPa

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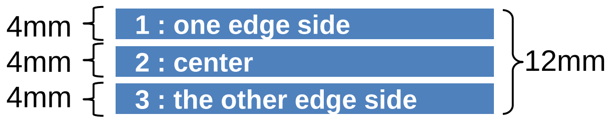
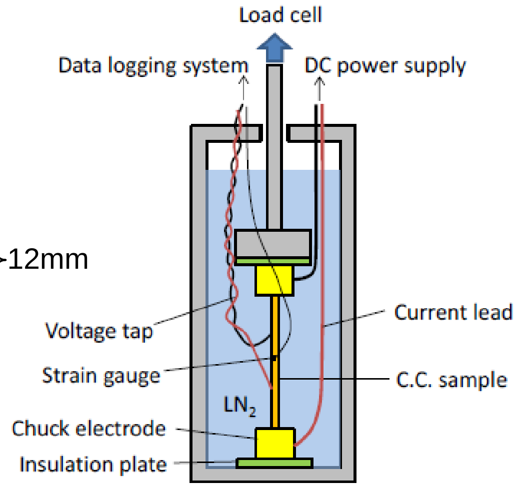
Evaluation of tensile properties of divided 4 mm-wide

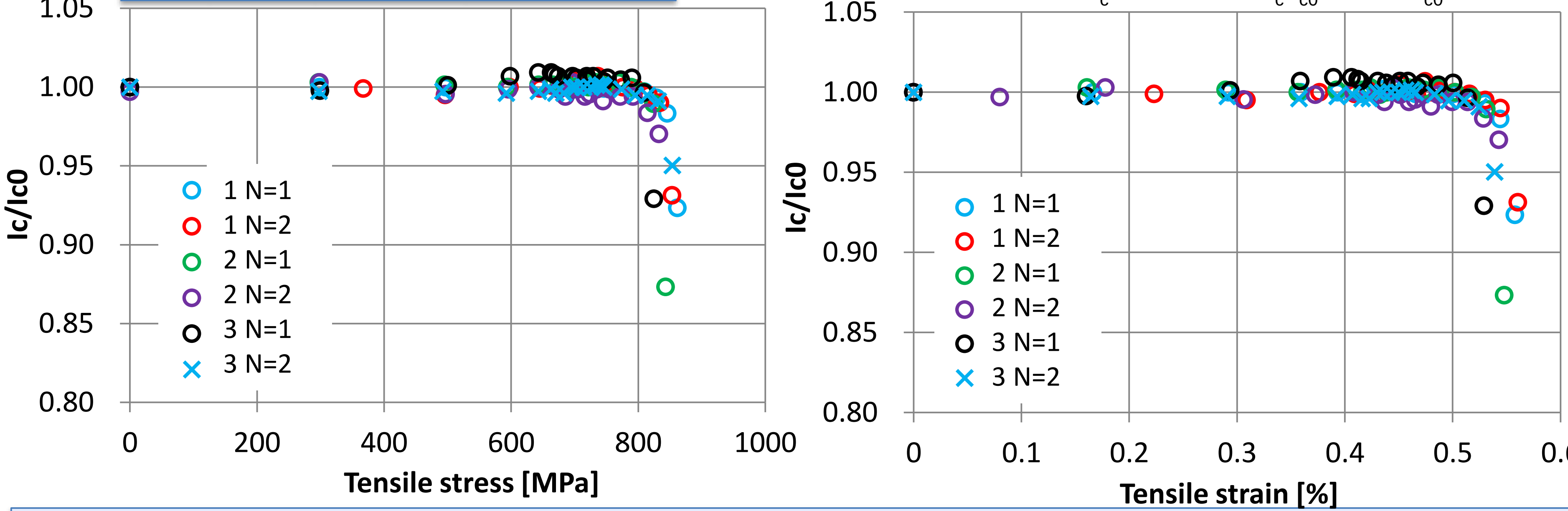
Tensile properties of 3 parts of 4 mm-wide tapes divided from 12 mm-wide coated conductor in LN2

Samples (FYSC)		reversible I_c Strain [%]	reversible I_c Stress[MPa]
1	N=1	0.523	820
	N=2	0.513	817
2	N=1	0.521	813
	N=2	0.497	768
3	N=1	0.514	810
	N=2	0.496	795





* Reversible I_c is defined at $I_c/I_{c0} > 0.99$ I_{c0} : Initial Ic



Each divided 4 mm-wide HTS tapes by laser slitting have shown equivalent tensile properties.

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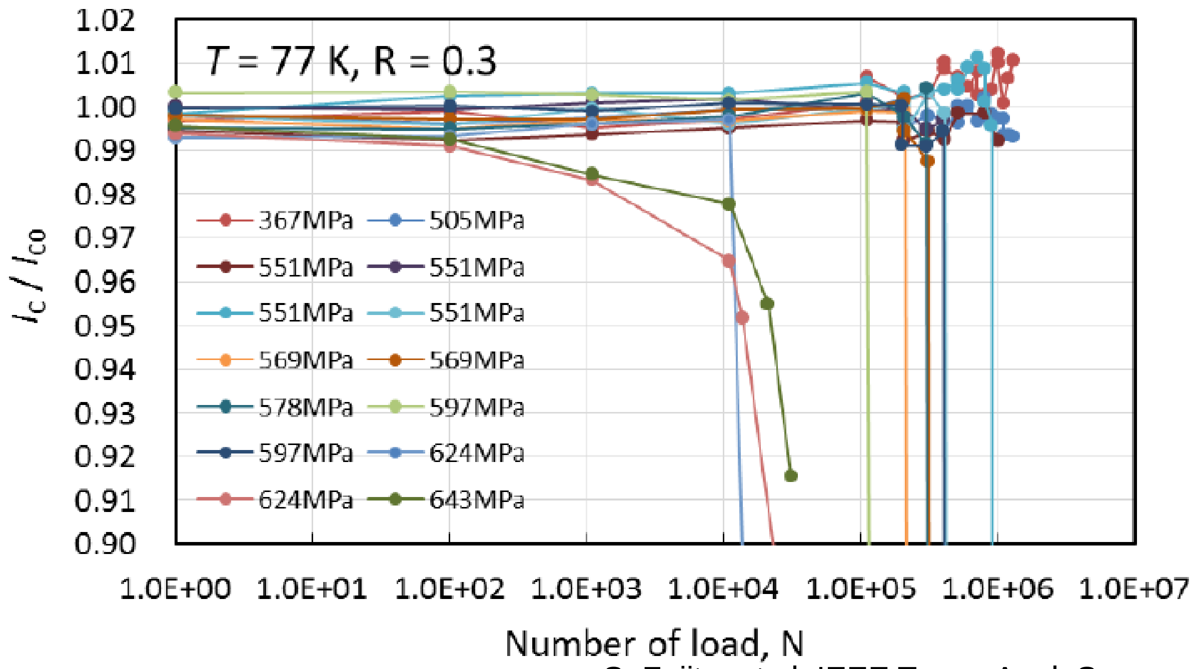
Mechanical Strength & Reliability Cyclic Fatigue Test

- Repetition frequency : 1 – 12 Hz (sine wave)
- Maximum stress : σ_{max} = 645 -365 MPa
- Stress ratio : R = $\sigma_{max}\sigma_{min}$ = 0.3 (constant)

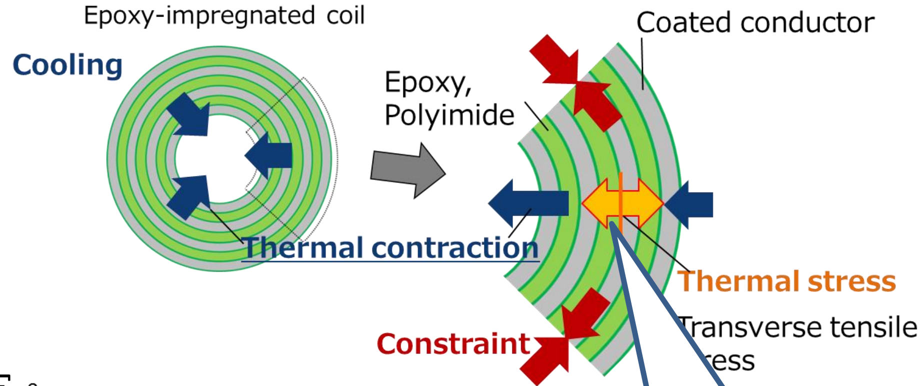
- Maintain initial strength up to ~ 10^5 cycles
- Above that, the tensile strength decreases due to fatigue of metal components of the tape.
- Origin of the crack is confirmed by the copper layer.

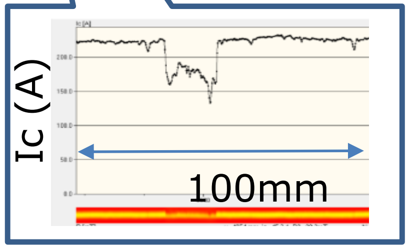


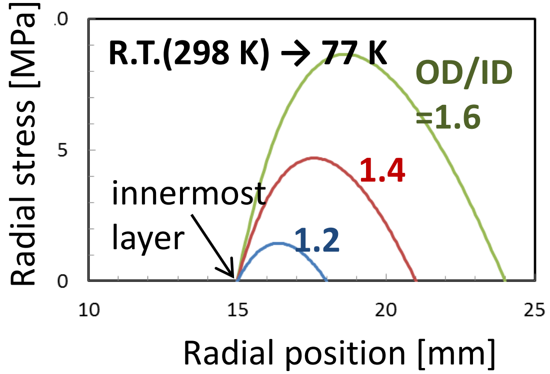
S. Fujita, et al.,IEEE Trans. Appl. Supercond. 30-4 (2020) 8400205

Improvement of delamination strength

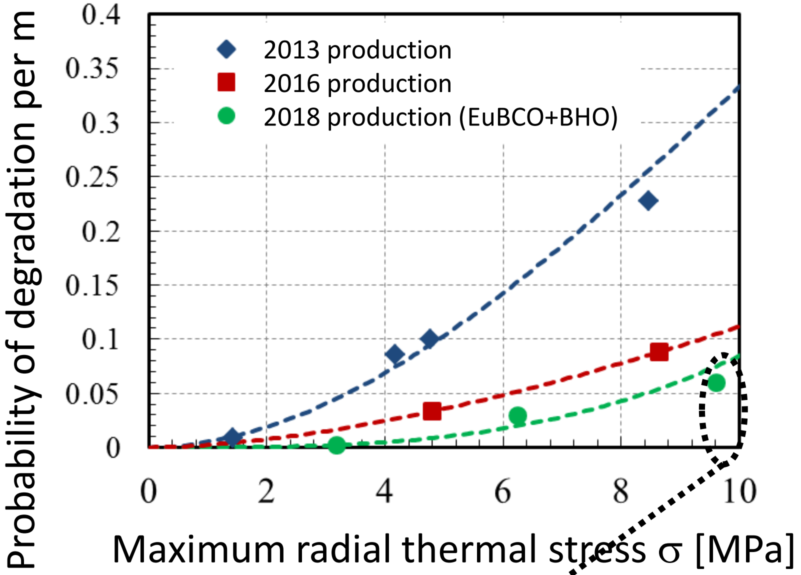
<Delamination stress test by thermal stress inside impregnated coil>





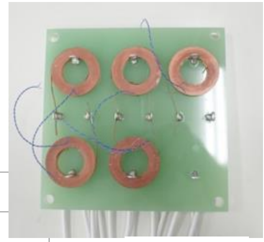


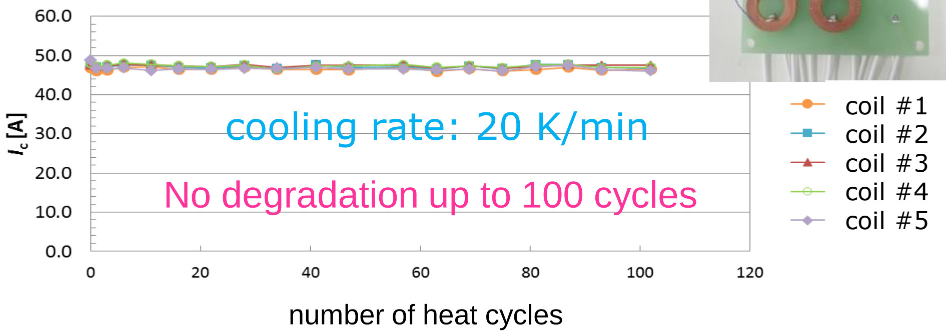
H. Miyazaki *et al*., IEEE TAS, **25** (2015) 6602305



Average delamination stress of 2G HTS tapes have improved by Weibull analysis

<Heat cycle test (R.T. ~ 77K)>





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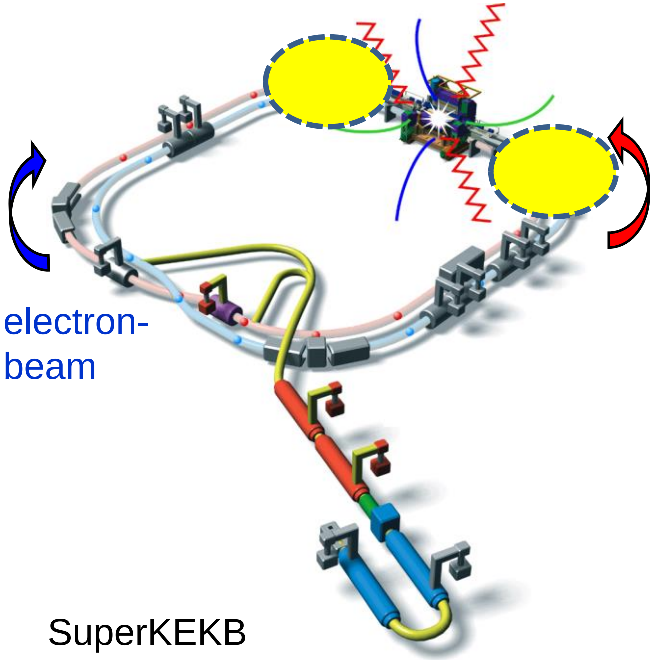
Feasibility Study of conduction-cooled sextupole HTS magnet

✓ **Development of quench detection and protection**
→ **Study of voltage detection**
→ **Optimization of copper stabilizer**

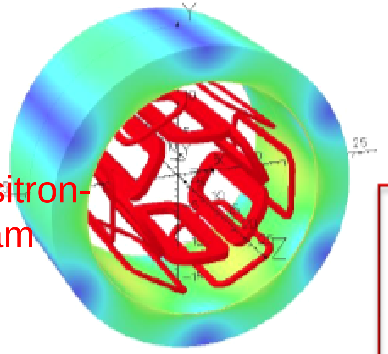
✓ Uniformity of magnetic field
→ Shield current
→ Windings

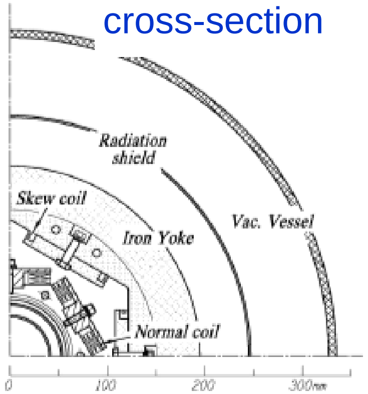
collaborate with KEK

K.Tsuchiya, et. al



SuperKEKB
KEK: High Energy Accelerator Research Organization





cross-section

Parameter	Value
Bore radius	40 mm
Coil length	200 mm
Yoke radius(inner, outer), length	150.5, 195, 200 mm
Normal sextupole	
Coil width (inner, outer), height	38.6, 83.6 mm, 9.0 mm
Number of turns	112 x 2 turns
Operating current	257.6 A
Max B// on the conductor	2.27 T
Max B⊥ on the conductor	1.30 T
Stored energy	2.1 kJ
Skew sextupole	
Coil width (inner, outer), height	76.6, 94.0 mm, 4.5 mm
Number of turns	43 turns
Operating current	259.5 A
Max B// on the conductor	0.79 T
Max B⊥ on the conductor	0.56 T
Stored energy	0.13 kJ

← **I'll show Today**

Recently fabricated

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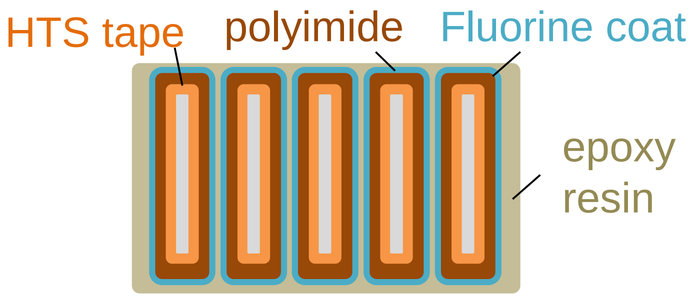
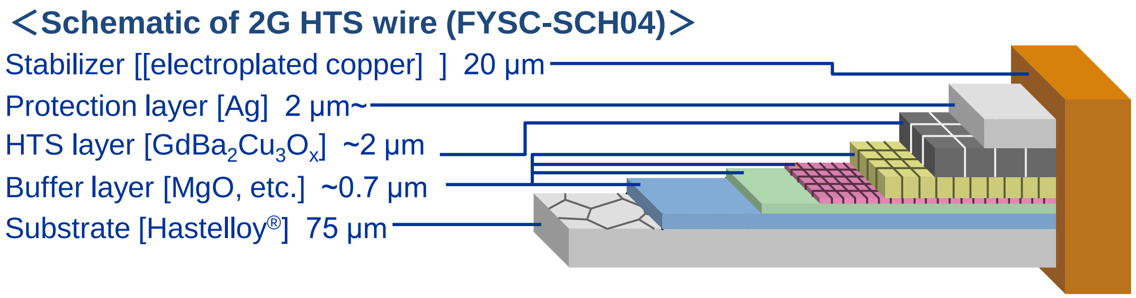
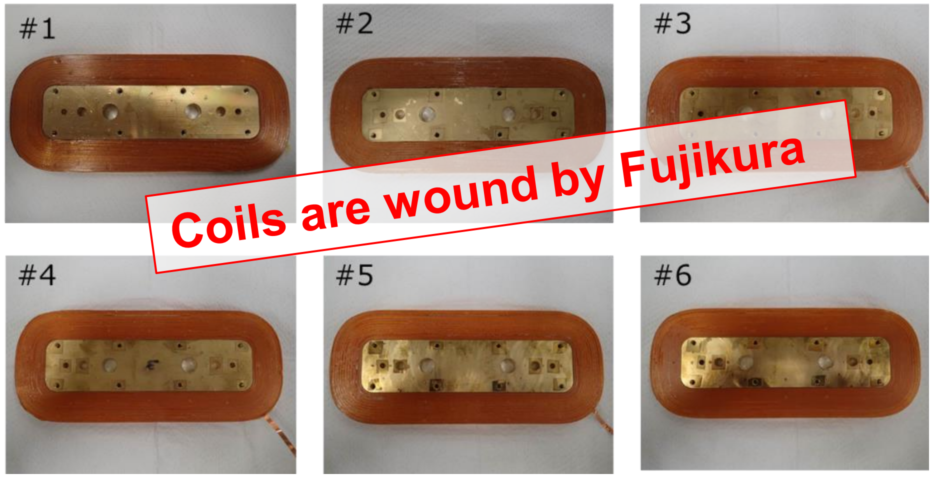
Fabrication and evaluation results of pancake coils

FYSC-SCH04-FPI : FYSC-SCH04 **with Fluorine coating polyimide tape** insulation

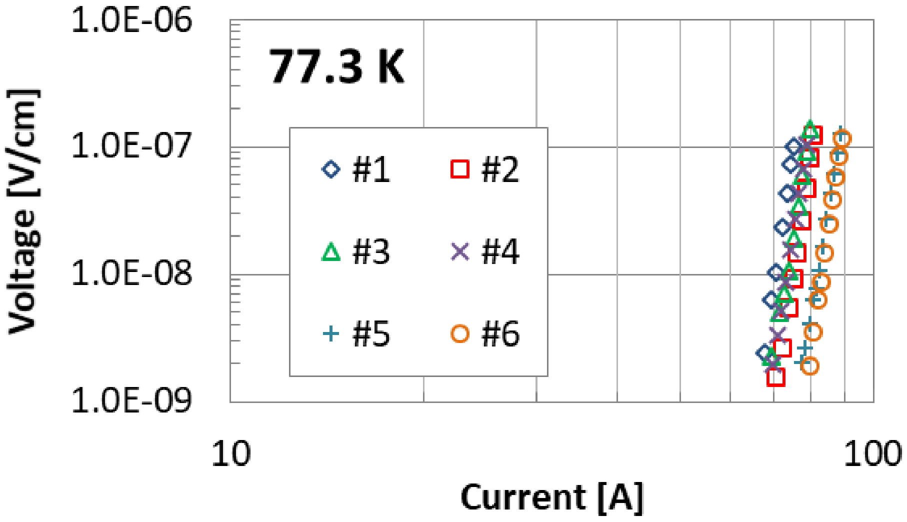


cross section of pancake coil





6 DPCC with Vacuum Pressure Impregnation



I-V characteristics of 6 DPCC at 77 K

n-values > 25 at 77 K of all 6 DPCC → Good performance

Fujikura

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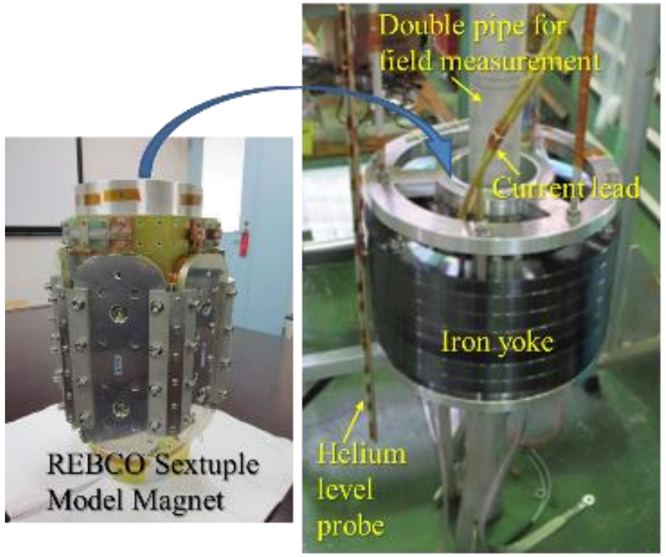
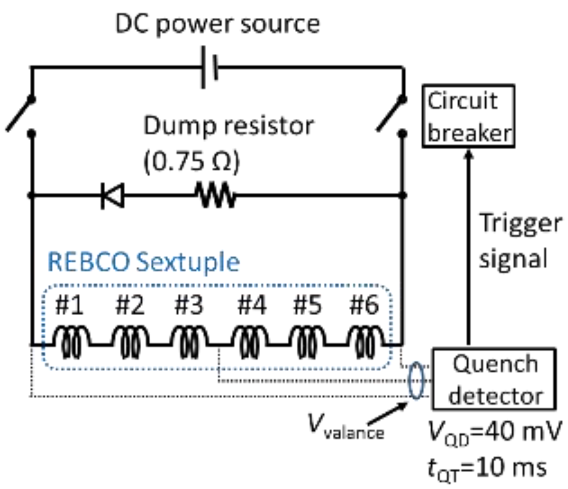
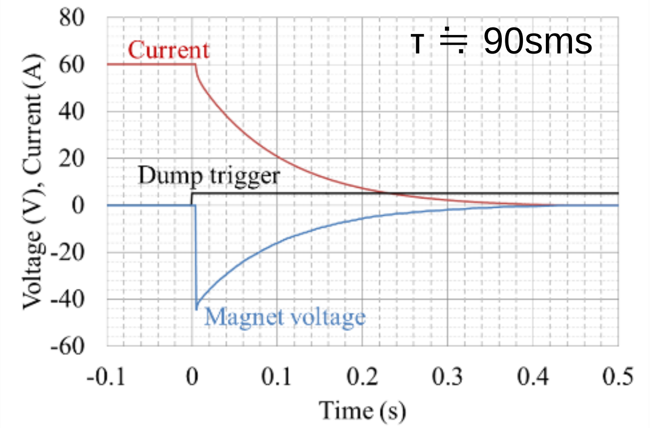
EFATS

Excitation test of sextuple HTS Magnet at 77 K, 4.2 K

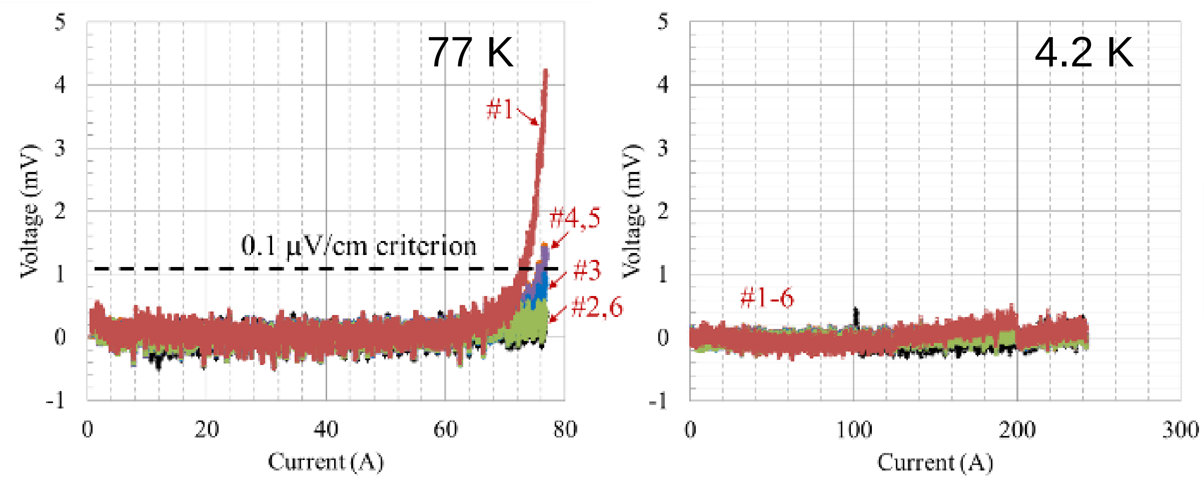




magnet and measurement setup, the electrical schematic of dump circuit.



Dump results of the sextupole magnet at 77 K



I-V curve of the sextupole magnet at 77 K and 4.2 K

The magnet excited up to 250 A at 4.2 K

Summary

■ Strengths of Fujikura's RE-based HTS wire is uniformity

- Fujikura has focused on manufacturing uniform RE-based HTS tapes
- We recently start to ship 2mm and 3mm-wide tapes
- We have investigated various mechanical properties of the RE-based HTS tapes for the applications.
- We try to understand our HTS tape through application of HTS magnets

■ Fujikura has studied for increasing current density at high field

Thank you for your attention !

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