

Workshop on Advanced Superconducting Materials and Magnets
January 21 - 23, 2019@KEK

Recent progress of DI-BSCCO wires and their magnet applications

Kazuhiko Hayashi

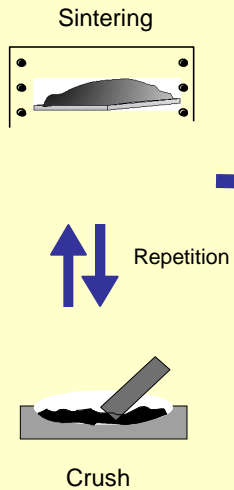
Superconductivity Technology Division
Sumitomo Electric Industries, Ltd.

- ✓ SEI Superconductivity Technology Division got
“Certificate of Approval” by LRQA to ISO 9001 2015
- ✓ 22 March 2018 --- 21 March 2021
- ✓ Scope of this approval
**Design and manufacture of superconducting wire
and its application except power cable**

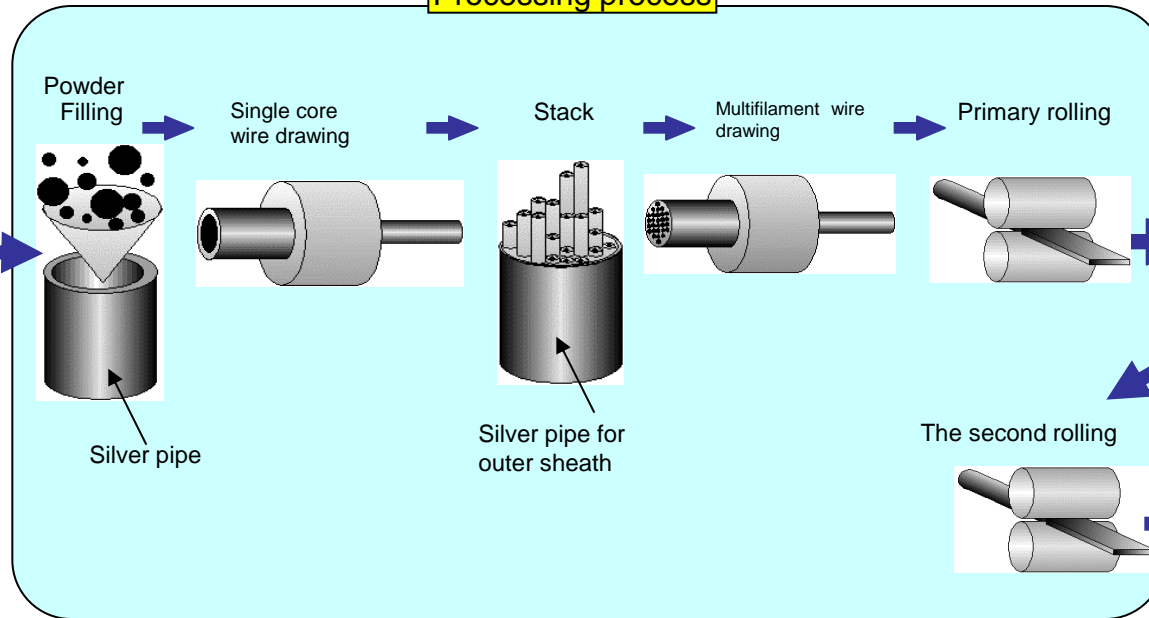
DI-BSCCO wire production process **DI-BSCCO**

$(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$

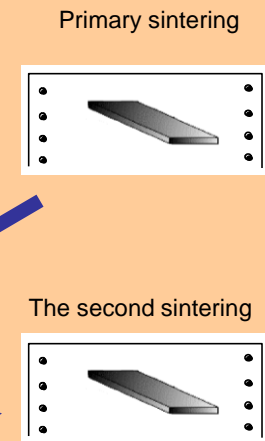
Powdery process



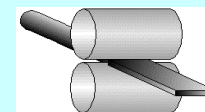
Processing process



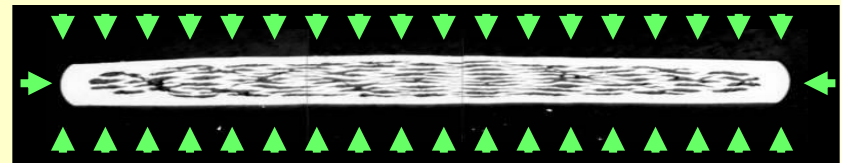
Sintering process



The second rolling



Pressurization sintering:
Total control of temperature,
pressure, the atmosphere



ConTrolled OverPressure Sintering

Bare wire

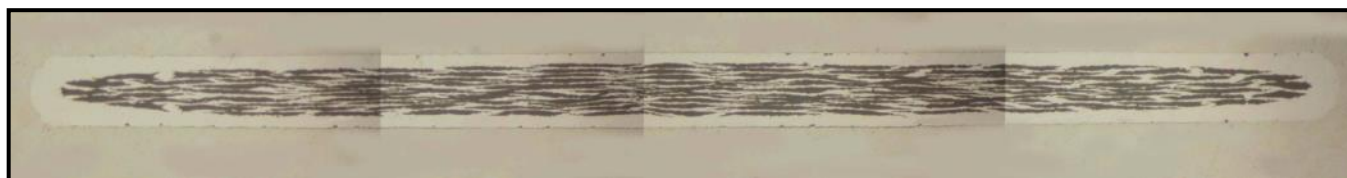
<http://www.sei.co.jp/super/>

	Type H Basic wire	Type G Au-Ag alloy (Ag-5.4wt%Au)
Average Width	4.3±0.2 mm	4.3±0.2 mm
Average Thickness	0.23±0.01 mm	0.23±0.01 mm
I_c (77K, Self Field)	170 A ~ 200 A	180 A ~ 200A



Current lead application
Ex. ITER by ASIPP

Type H



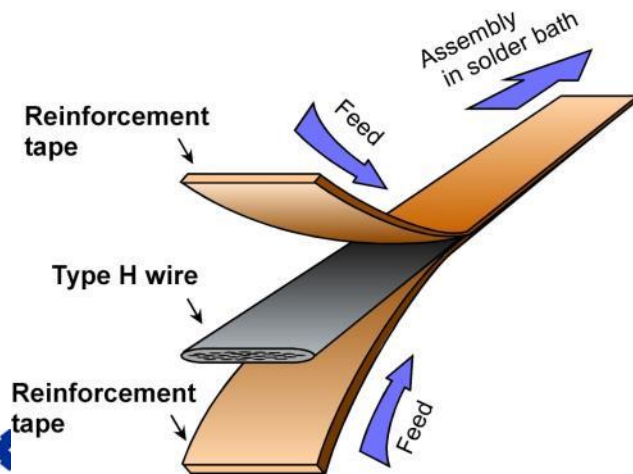
Specifications of DI-BSCCO

DI-BSCCO

(DI: Dynamically innovative)

	Type H	Type HT-SS	Type HT-CA	Type HT-NX
Average Width	4.3+/-0.2mm	4.5+/-0.1mm	4.5+/-0.1mm	4.5+/-0.2mm
Average Thickness	0.23+/-0.01mm	0.29+/-0.02mm	0.34+/-0.02mm	0.31+/-0.03mm
Reinforcement tape	—	Stainless steel (0.02mm ^t)	Copper alloy (0.05mm ^t)	Nickel alloy (0.03mm ^t)
I_c (77K, Self Field)	170A, 180A, 190A, 200A			
Critical Wire Tension * (RT)	80N **	230N **	280N **	410N **
Critical Tensile Strength * (77K)	130 MPa **	270 MPa **	250 MPa **	400 MPa **
Critical Tensile Strain * (77K)	0.2% **	0.4% **	0.3% **	0.5% **
Critical Double Bending Diameter * (RT)	80mm **	60mm **	60mm **	40mm **

* 95% I_c retention, ** Typical value

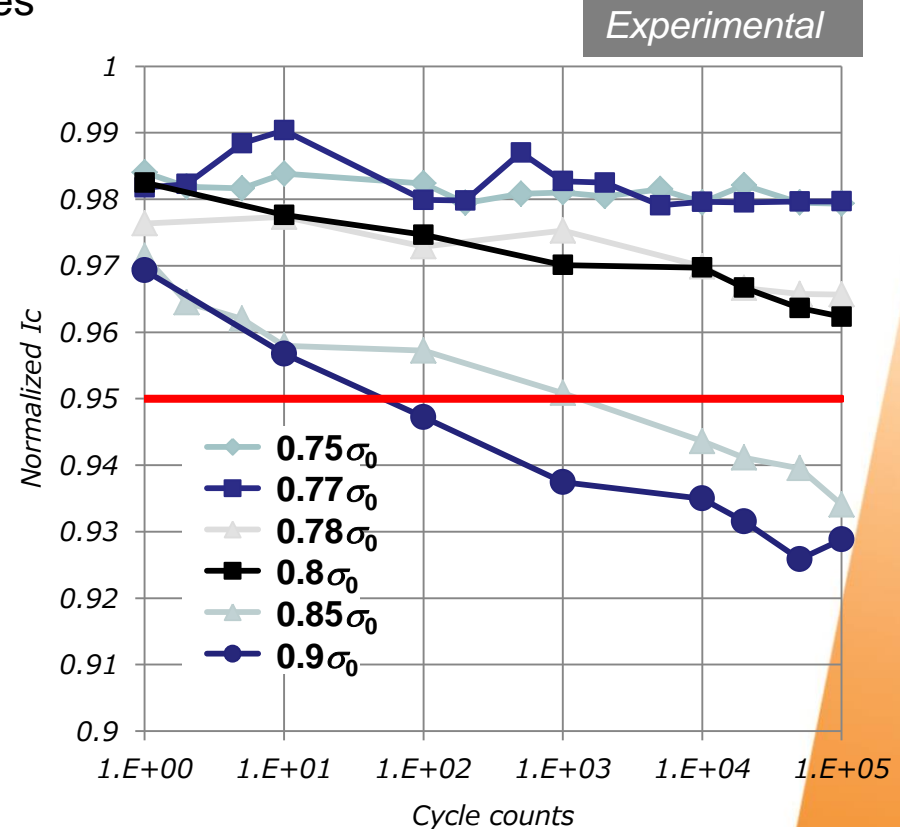
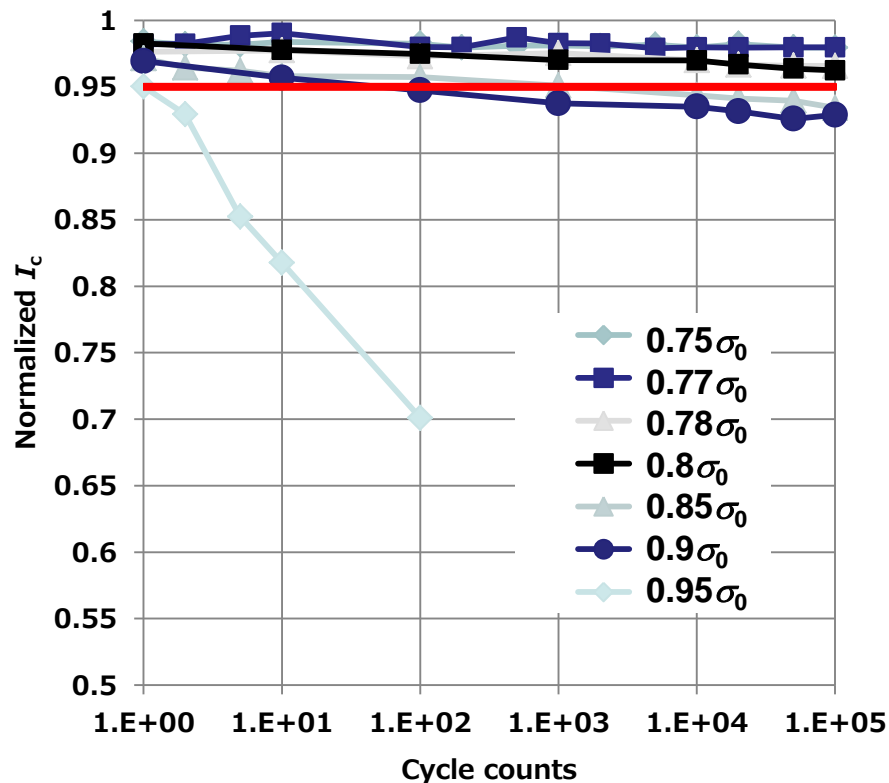


Type HT-NX



Type HT-NX endurance under tensile stress

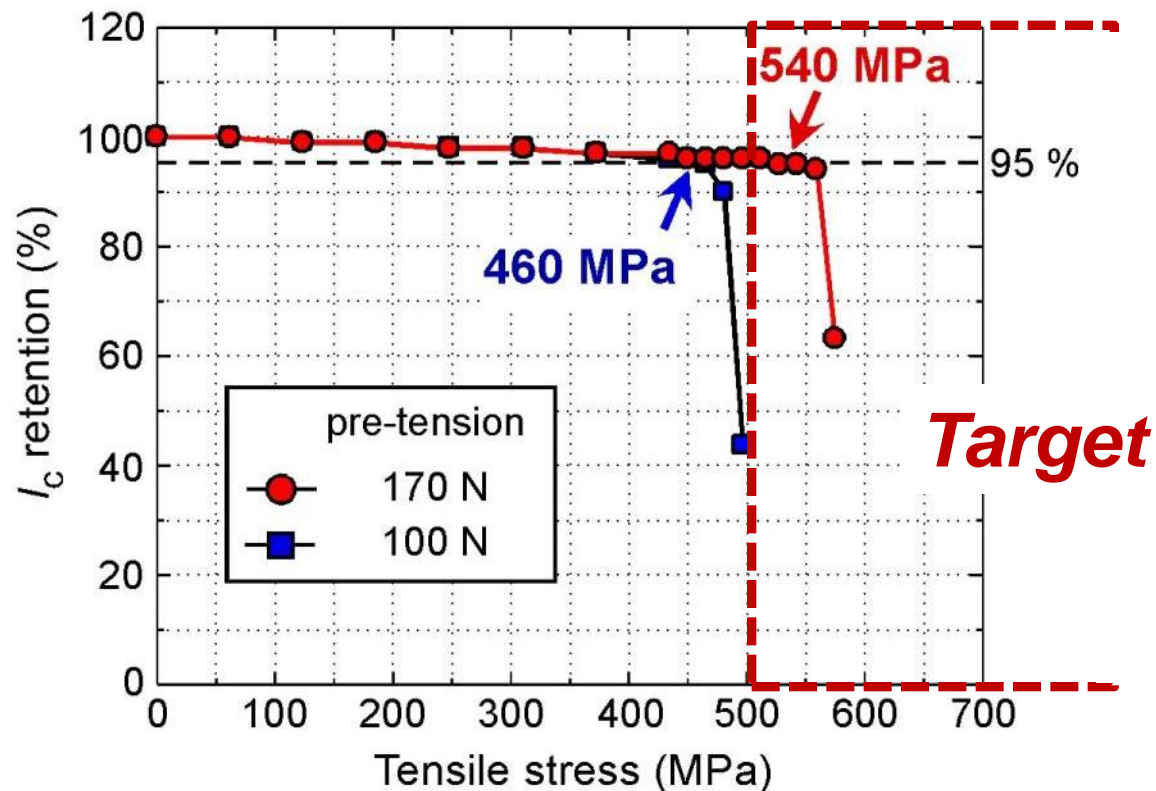
Test condition Sampled from typical HT-NX product (Bare 4.3mm^w/0.23mm^t)
Temperature: 77K (Strength of the Type HT sample σ_0 : ~400 MPa)
Number of Cycles: up to 10^5 cycles



Up to 0.8σ , I_c keeps more than 95% after 10^5 cycles tensile load

Strength of trial Type HT-NX

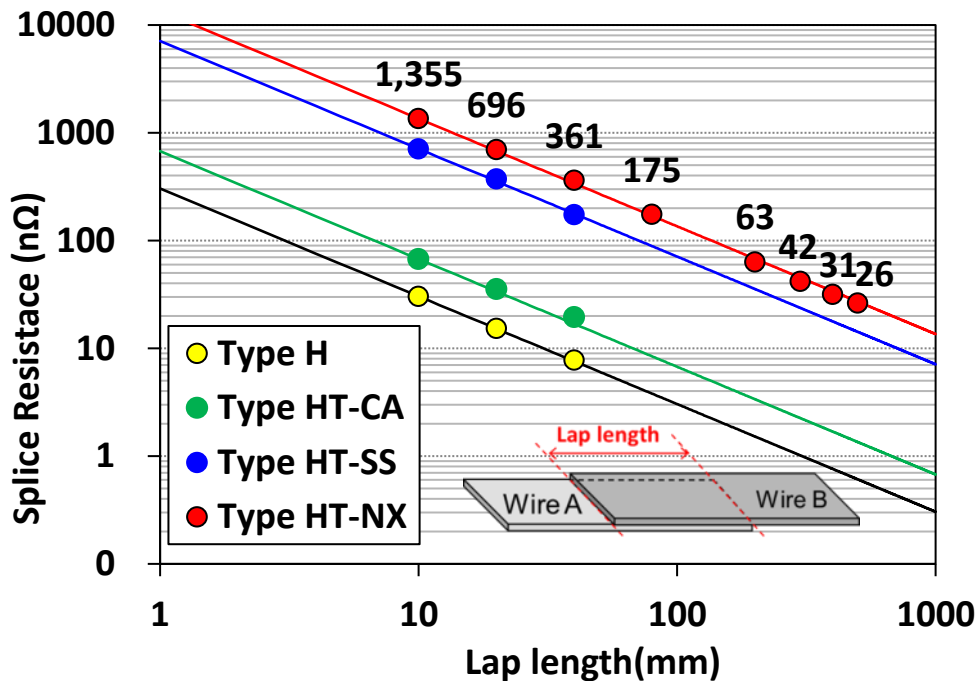
The first trial Type HT-NX with **0.050 mm-thick NX** tape was produced and evaluated.



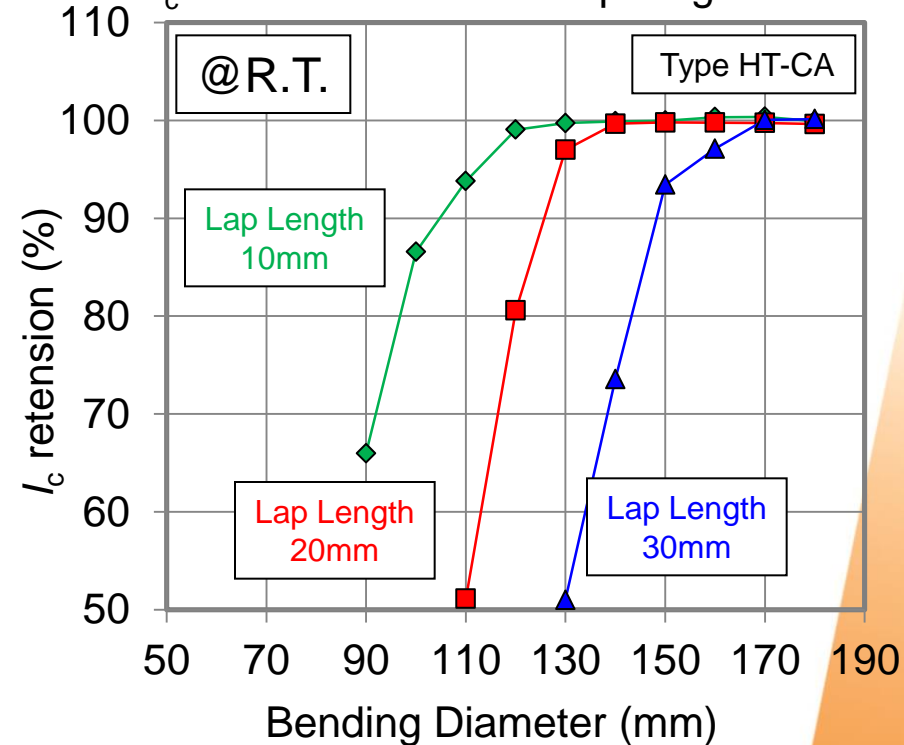
The trial Type HT-NX with pre-tension of 170 N exhibited the critical tensile stress of **540 MPa !!**

Splice resistance

Relation between lap length and splice resistance



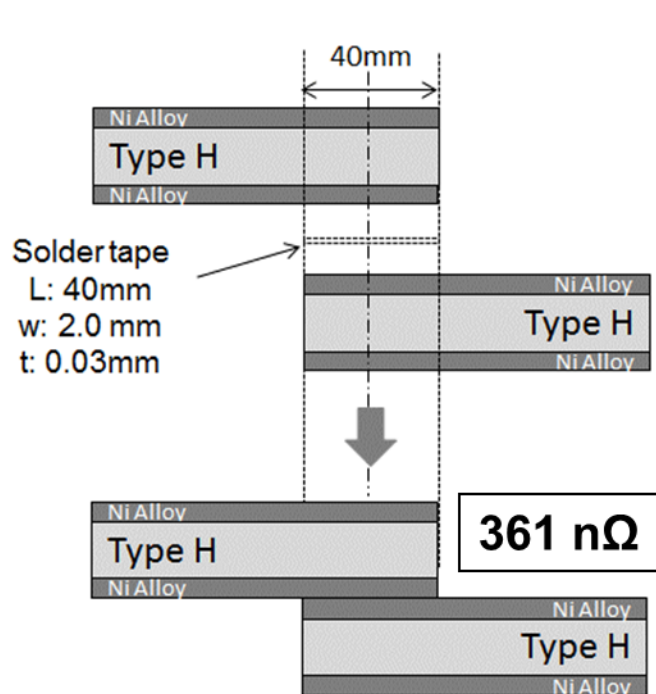
Bending diameter's dependences on I_c retention of various lap length wire.



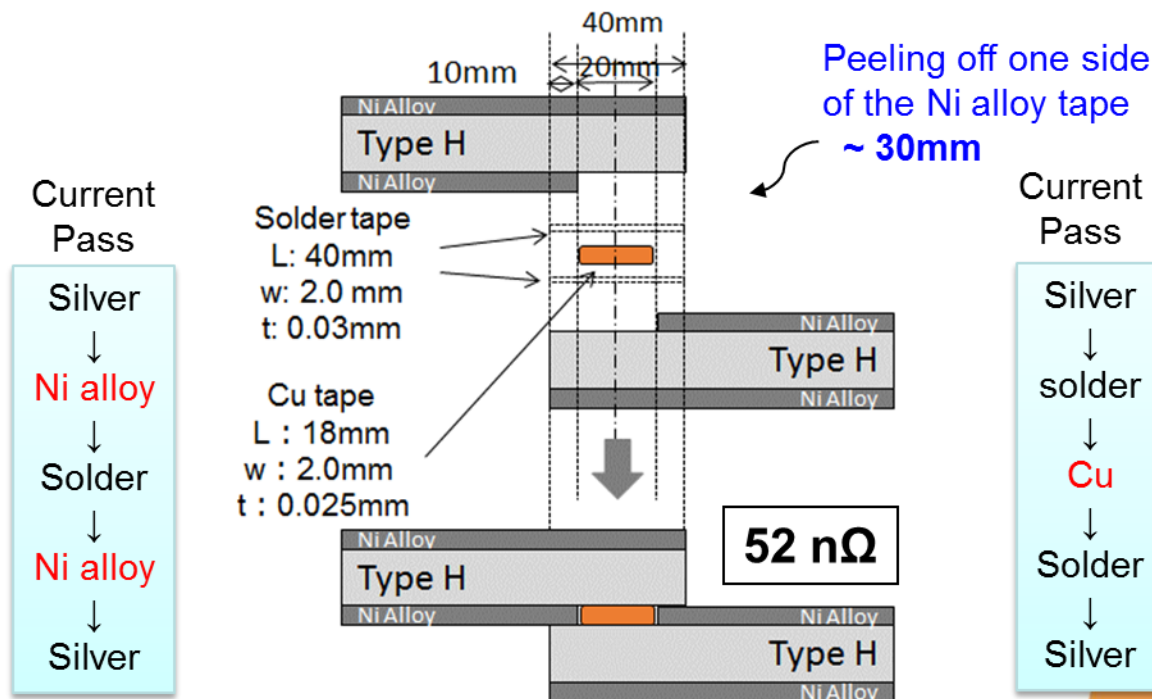
Splice resistance of the Type HT-NX is higher than other Type HT because resistivity of Ni-alloy reinforcement material is high. Longer lap length reduces the splice resistance but bending property becomes worse because of rigidity.

Peeling splice (with a Cu tape)

**Peeling Nickel alloy, splice resistance is much decreased.
Mechanical property keeps ~90% by sandwiching a Cu tape.**



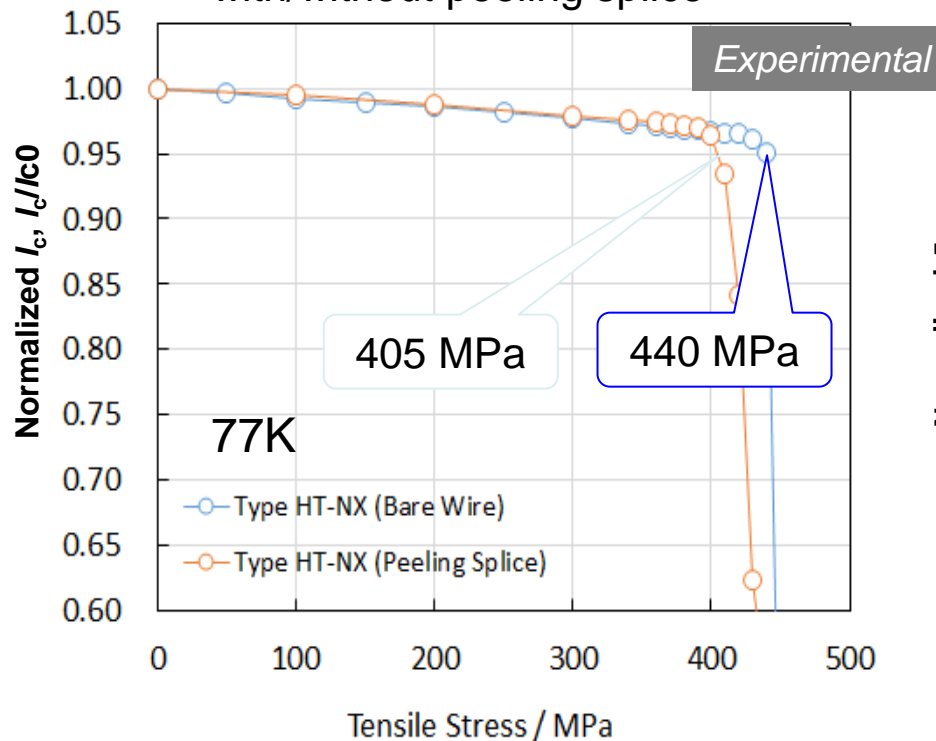
Conventional Splice
(High resistance)



Peeling splice with copper
(Low resistance)

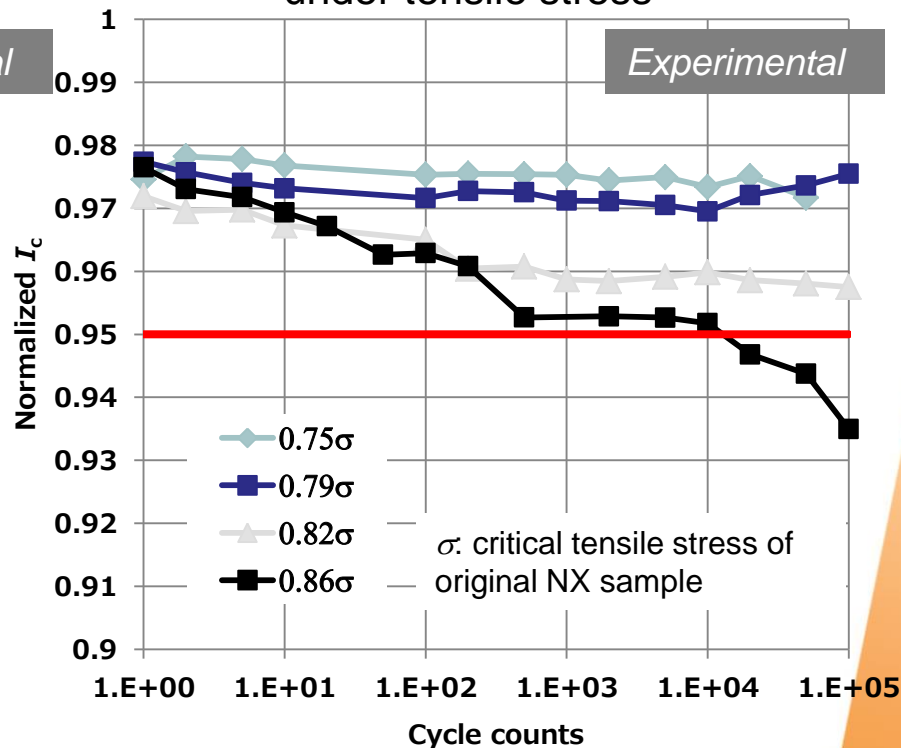
Strength of Type HT-NX with peeling splice

Tensile stress tolerance test of Type HT-NX with/without peeling splice



Critical tensile stress of peeling splice shows strength more than 90% as original one.

Type HT-NX (with peeling splice) endurance under tensile stress



Up to 0.82σ , I_c of Type HT-NX with peeling splice keeps more than 95% as that of original NX sample. Deterioration point is almost same as Type HT endurance.

Fatigue properties of peeling splice structure's wire

Test condition

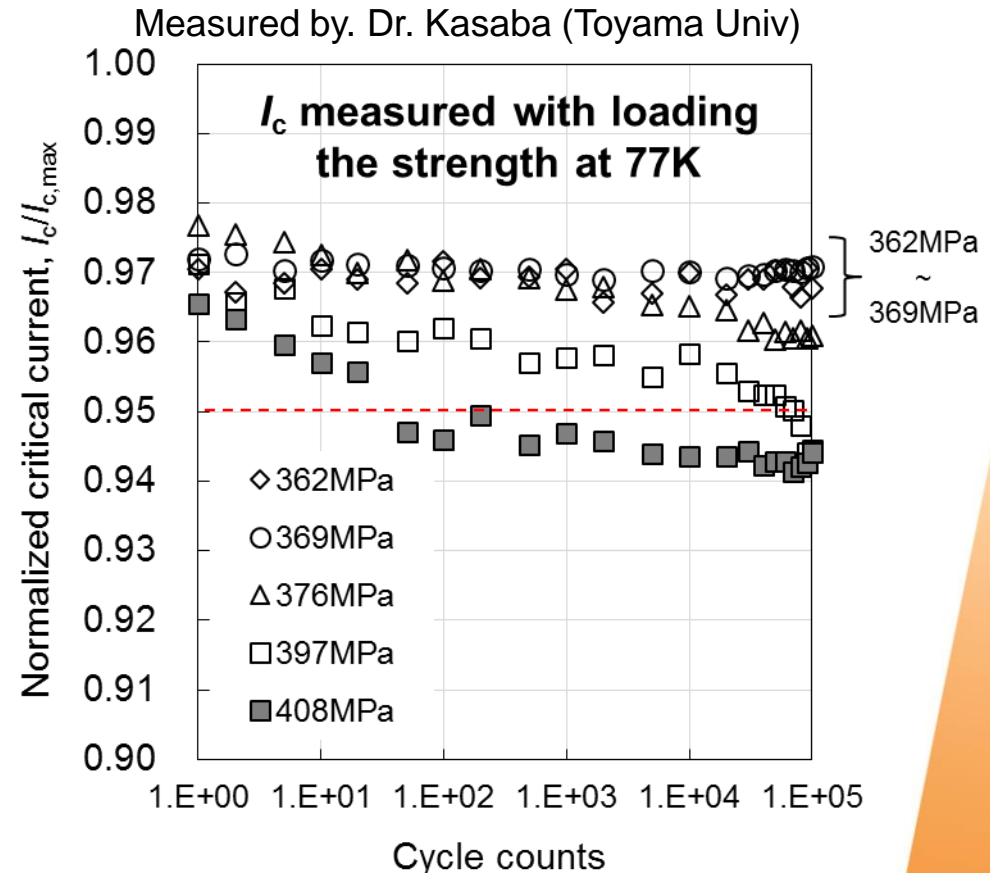
Wire: HT-NX

(0.03mm^t, Mass-produced product)

Temperature: 77K

Tensile loading: 362 MPa~419MPa
(Spec. 400MPa@77K)

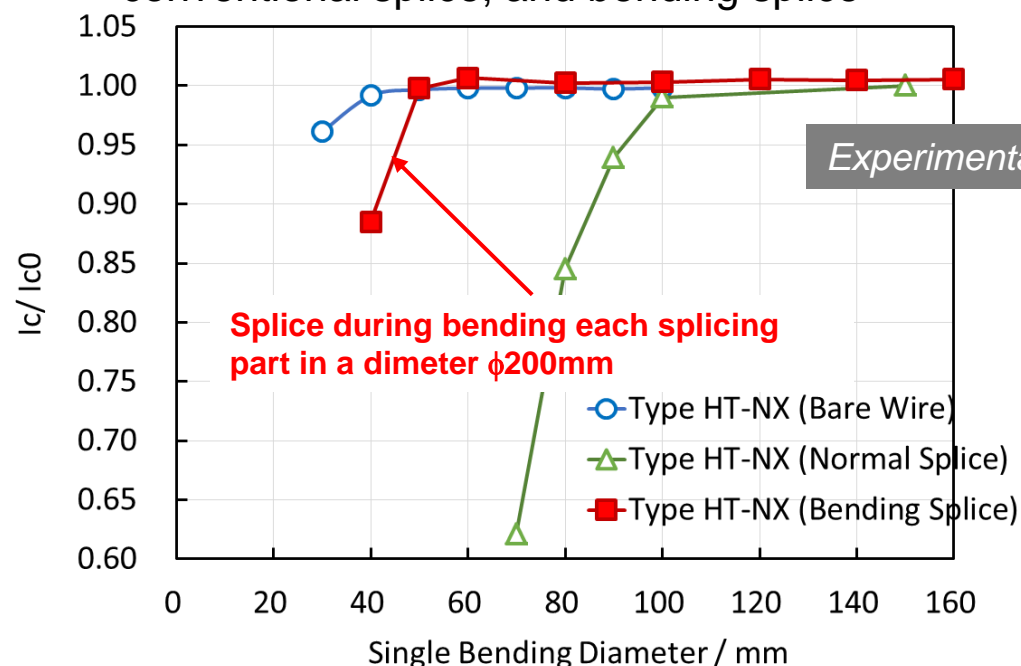
Number of Cycles: up to 10⁵ cycles



✓ I_c was maintained up to 370MPa

Bending property of bending splice

Single bending tolerance test of Type HT-NX, conventional splice, and bending splice



Critical single bend diameter

Conventional splice : 85 mm

Bending splice : 50 mm

Portable Splicing Machine
New Design



- ◆ Lap length: $\phi 130$: 105mm, $\phi 200$: 145mm
- ◆ Applicable Wire width: $\sim 5.0\text{mm}$
- ◆ Adjustable Pressure: 100~400N
- ◆ Adjustable Temperature: 50~ 280°C
- ◆ Size: W250 x D650 x H700 mm
- ◆ Weight: 53 kg
- ◆ Power supply: 200~220V

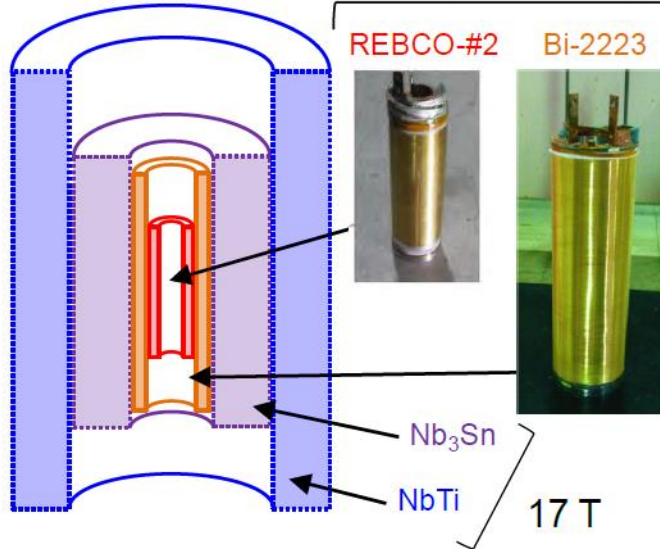
Recent Achievements of Type HT-NX (High Field Magnets)

RIKEN 27.6 T
superconducting magnets



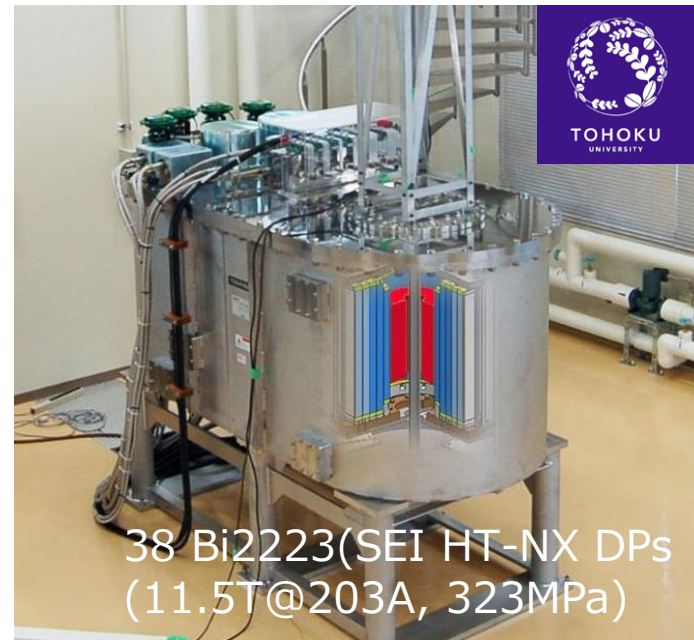
Series connected
11T (6.5 T + 4.5 T)

REBCO-#2 Bi-2223



Y. Yanagisawa et.al., IEEE/CSC & ESAS
SUPERCONDUCTIVITY NEWS FORUM (2016)

TOHOKU UNIV
25 T cryogen-free
superconducting magnet



38 Bi2223(SEI HT-NX DPs
(11.5T@203A, 323MPa)

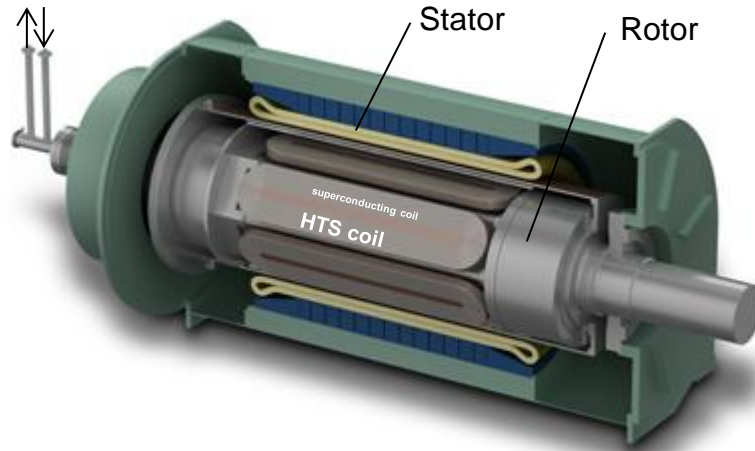
S. Awaji et.al., Supercond. Sci. Technol. 30 (2017)
065001

- ☑ These magnets showed that Type HT-NX could be used in magnets generating over 24T. We achieved the purpose of beginning.

3 MW HTS ship propulsion motor

DI-BSCCO

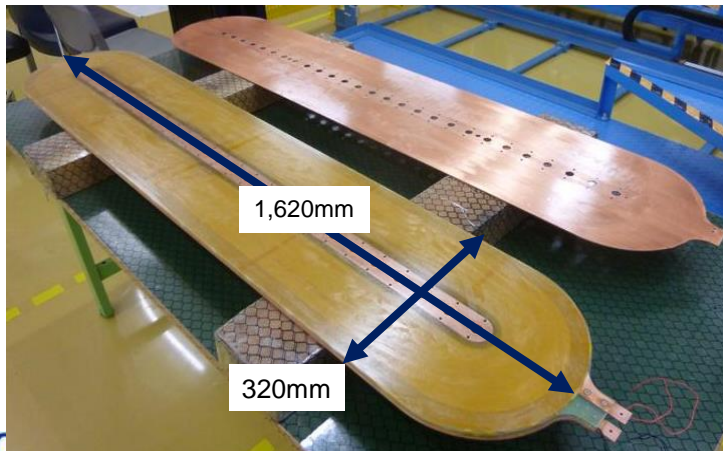
He Gas



Manufactured by Kawasaki Heavy Industries



- Rated output 3 MW
- Rotating speed 160 rpm
- Efficiency 98%
- Fuel saving 18%
- Torque density 40 kNm/m³



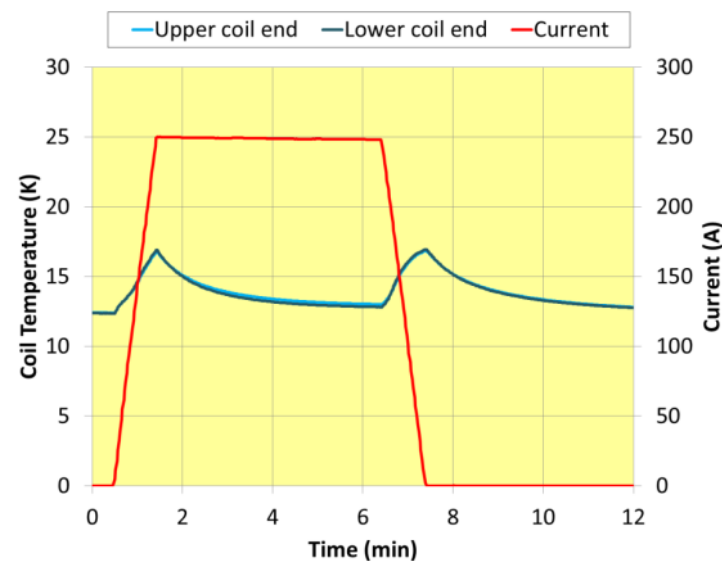
This study was supported by New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Refrigerator cooled magnet

DI-BSCCO

+/-5 Tesla / ϕ 100 mm

+/-5.7 Tesla / ϕ 150 mm



	A	B	C	D
Center field	+/-5 T	+/-10 T	+/-5.7 T	+/-5 T
R.T. bore	100 mm	100 mm	150 mm	300 mm
Iop	175A	250A	250A	250A
Inductance	4 H	11 H	5H	20 H
Storage Energy	61 kJ	344 kJ	156 kJ	625 kJ
Sweep rate	5 T / 30s	10 T / 10 min.	5 T / 50s	5 T / 180s
Wire type	Type H	Type HT-SS, Type H	Type HT-SS, Type H	Type HT-SS, Type H

DI-BSCCO[®] Compact magnet system

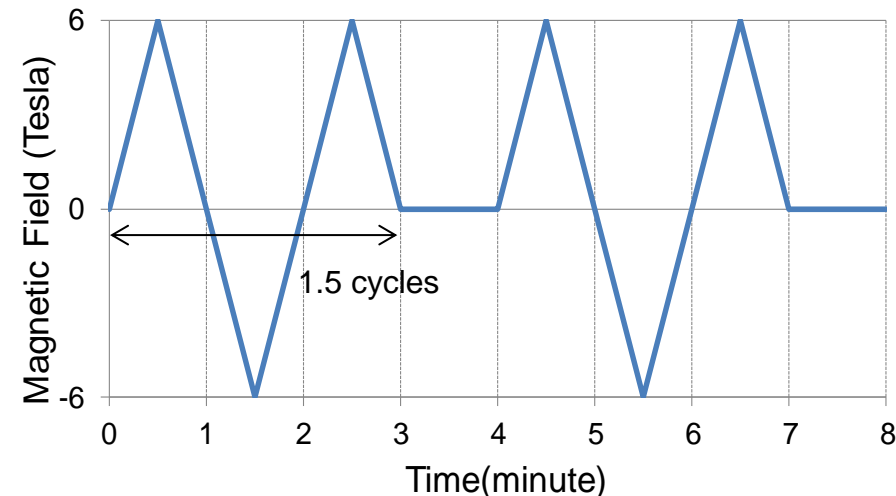
- ✓ Fast sweep rate (1T / 5 sec.)
- ✓ A wide variety of operating methods and patterns
- ✓ No refrigerant
- ✓ Compact, light, and low residual field

< Use application >

BH curve tracer, VSM, Field annealing, Test, Experiment



Model name	DI-BSCCO-MS 6T-70
Field strength	$\pm 6\text{T}$
R.T. bore	$\Phi 70\text{mm}$
Sweep rate	6T/30sec.
Operating current	250A
Inductance	about 1H
Field homogeneity	0.3%/10mmDSV
Size	0.8mX0.3mX0.3m
Weight	About 100kg



[VSM-5HSC] High Temperature Superconducting Type of Vibrating Sample Magnetometer

The world's first* of one-twentieth of measurement speed is realized compared to this company's existing product by adopting high temperature superconductivity magnet to VSM.

Br, HcJ high accuracy measurement of 0.5 mm cube magnet becomes possible.

*Investigated as of July, 2014 by Toei Industry Co., Ltd.

Features

Realization of High Speed Measurement

High speed measurement is realized by adopting high temperature superconductivity magnet.

Hmax = 5Tesla, Full I Loop measurement becomes possible in 20 minutes.

(This company's existing machine: Full Loop measurement needs 40 minutes.)

High Accuracy Measurement of Small Sample

High accuracy measurement of Br, HcJ of 0.5 mm cube magnet, etc. of Br, HcJ and comparative measurement of micro surface area become possible.

Also, comparative measurement of finishing degradation becomes possible.

Sample Temperature Variable Measurement

-50°C - +200°C temperature variable UNIT(Optional)

Miniaturization of Magnetic Field Generation

Size of magnet system part: 0.8 x 0.3 x 0.3 m

High
speed

High
accuracy

Compact



Refer to

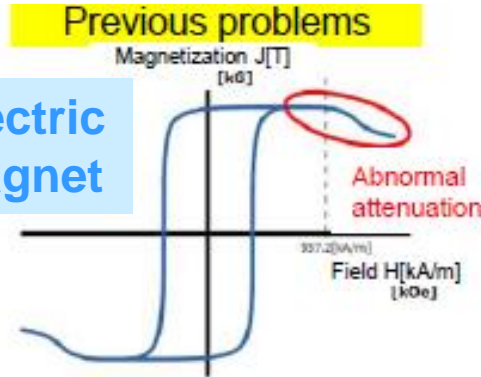
<http://www.toeikogyo.co.jp/english/products/sei-01/vsm-5hsc.html>

VSM is a device measuring the magnetization characteristic of the sample by vibrating the sample in the uniform magnetic field at a constant frequency and an amplitude, and by detecting electromotive force evoked by the detection coil which is located in the neighborhood of the sample using PSD (Phase Sensitive Detector phase sensitive detection).

Measurement Methods of High Field Properties

Field H max
25~30(kOe)

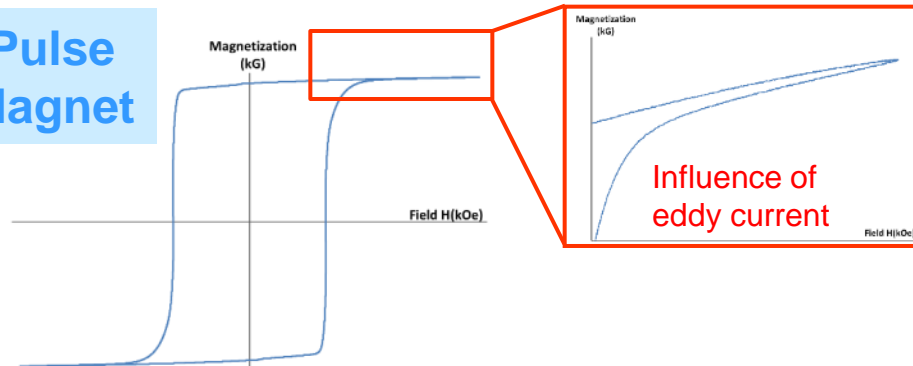
**Electric
Magnet**



Closed Loop Measurement
Cu electric magnet
Limit of highest field
(magnetic saturation)

Field H max
80~150(kOe)

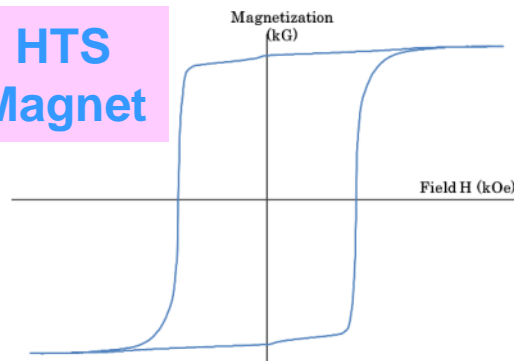
**Pulse
Magnet**



Open Loop Measurement
Cu pulse magnet
Too fast sweep speed
(Eddy current effect)

Field H max
50~100(kOe)

**HTS
Magnet**



Open Loop Measurement
Superconducting magnet
+ VSM
Statistic measurement
No Eddy current effect
Best method

Magneto-Optical Effect Measurement System

Micro region B-H Curve Measurement by Kerr Effect in High Field

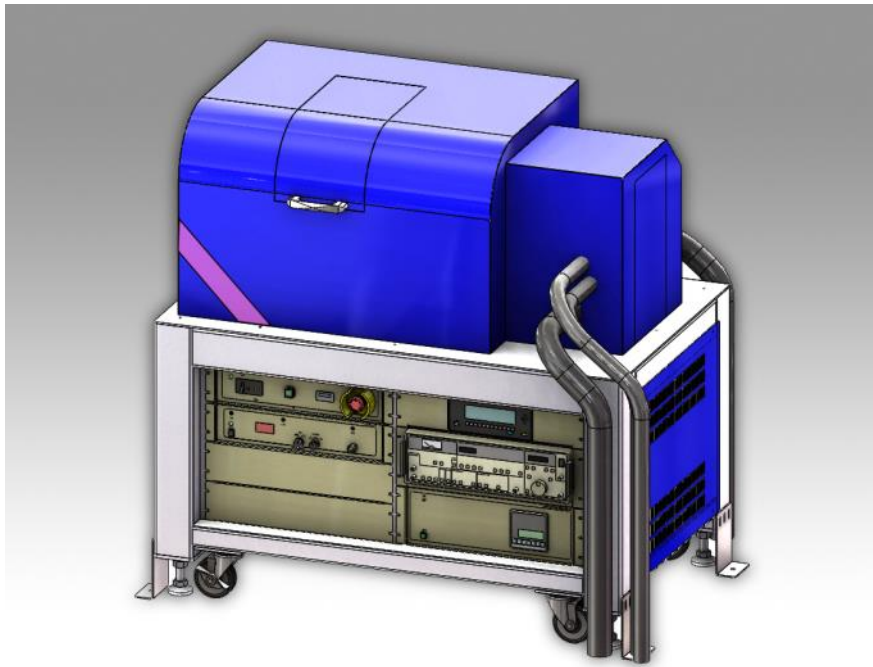
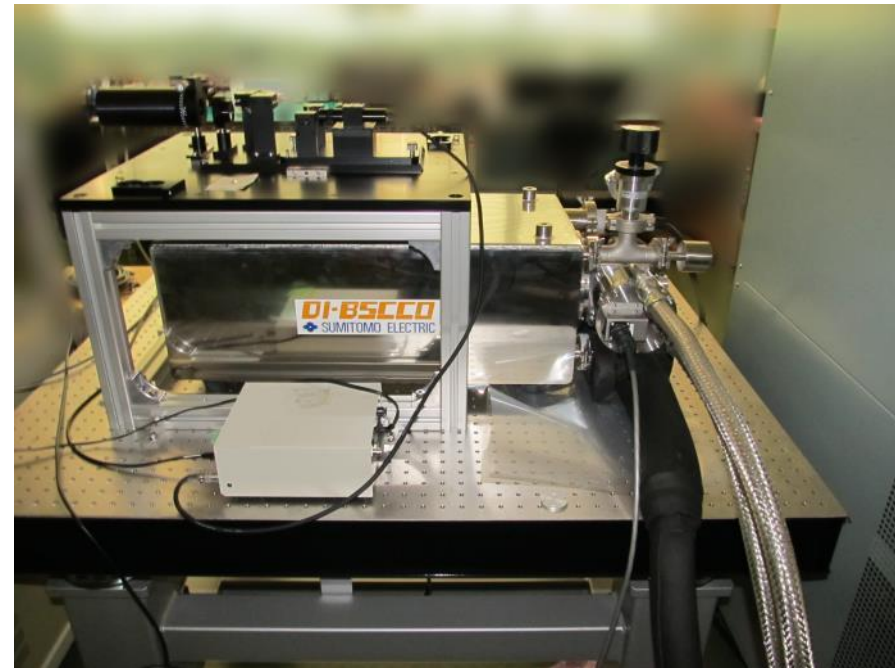


Image of Product



Prototype

Courtesy of NEOARK

Cryogen-free Compact 3T-MRI for

DI-BSCCO

Human Brain Research

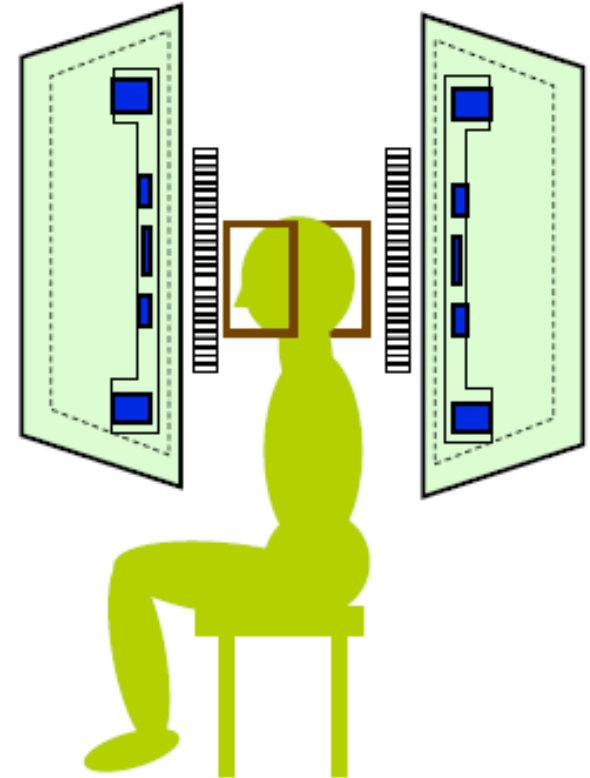
(Supported by JST-Sentan ,2008-2012)

✓ Purposes

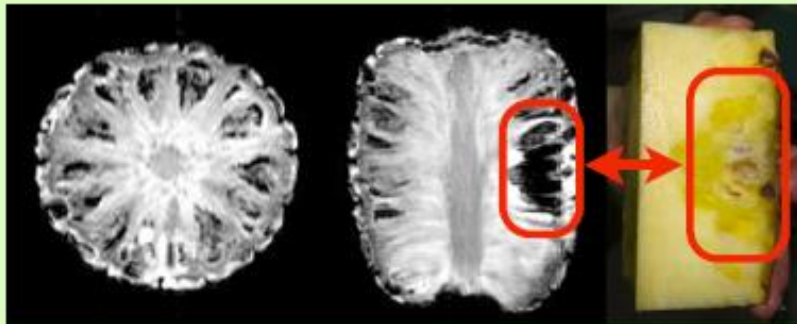
- Helium-free MRI using BSCCO tapes.
- For human brain research (vertical bore).

✓ Specifications of the magnet

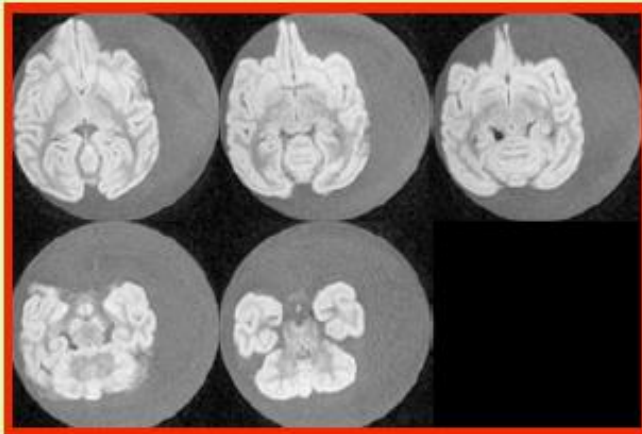
- Field strength : 3T
- Operating temperature : 20K
- RT bore size : 500 mm (almost half of that of the whole body scanner)
- Power supply driven (because persistent current operation is impossible)
→ this can be a cause of field instability.



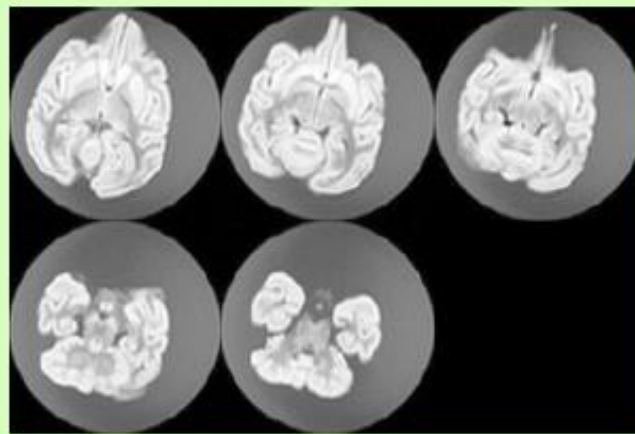
Kyoto Univ, NIMS
Kobe Steel (Coil)
Sumitomo Electric(Wire)
Takashima Manufacturing(RF coil etc.)



Cross-sectional images of a pineapple. **Rotten flesh** (right) is well depicted on the longitudinal image (middle).



T1 weighted SE images of an extracted Macaca brain (right) scanned with our HTS-MRI (left) and Siemens 1.5T Sonata (middle).

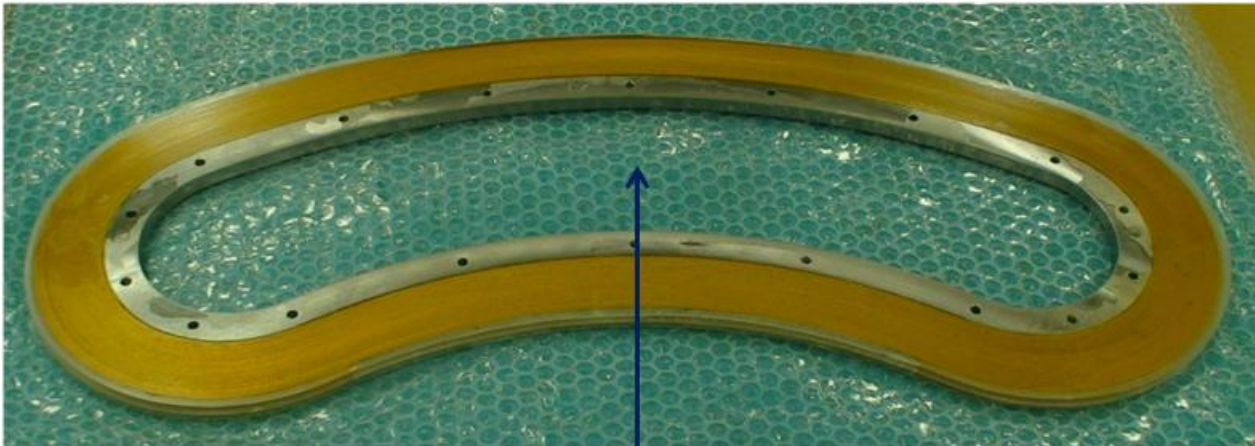
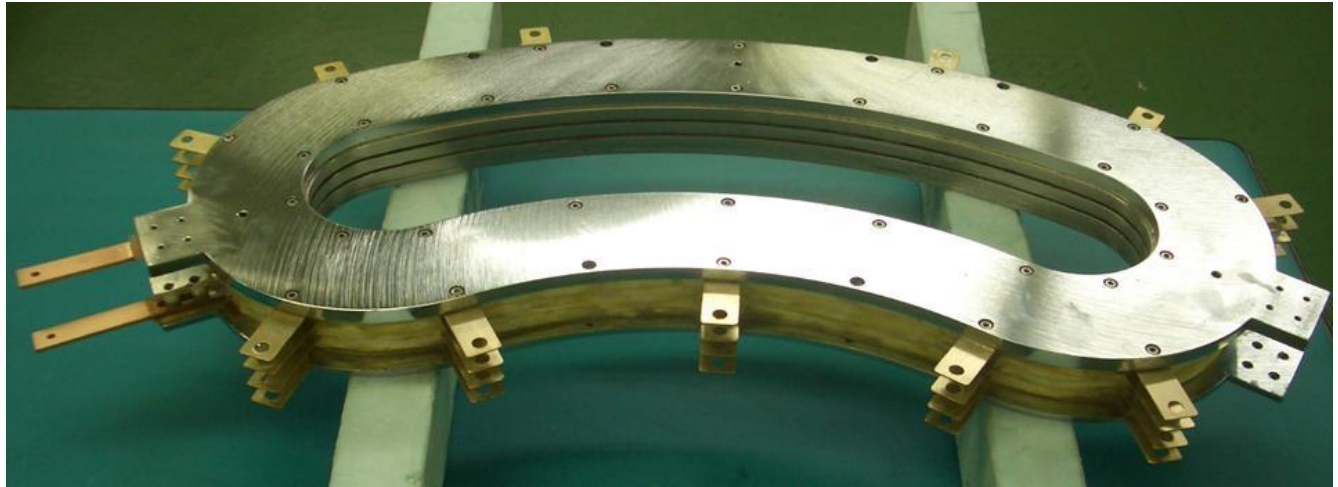


Anatomical structure is well depicted with HTS-MRI although SNR is low and Gibbs artifact is observed.




Deflection magnet

DI-BSCCO



$R=400\text{mm}$


Coil for Osaka university




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HTS Wire




DI-BSCCO(Bi2223) wire

[HTS Wire](#)

[DI-BSCCO' Type H](#)


[DI-BSCCO' Type HT](#)

HTS Magnet/Coil




Various HTS magnets
HTS motor cooled by LN₂

[HTS Magnet/Coil](#)




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HTS Cable



3-in-One HTS cable

[HTS Cable](#)

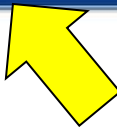
Movie



What's New

- October 29, 2013
[High Tc Superconducting Cable Project celebrates its first anniversary.](#)
- October 29, 2012
[High Tc Superconducting Cable Project](#)
- October 22, 2012
[We supplies Type HT-CA wire to HTS Cable project in Germany & Russia](#)
- May 15, 2012
[200A DI-BSCCO \(Type H, Type HT and Type G\) released.](#)


Click here for product catalog request



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Please utilize our WEB site.

www.sei.co.jp/super/



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