The way Nb$_3$Sn wire was developed and improved for ITER Project

Japan Superconductor Technology, Inc.
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• About JASTEC (Japan Superconductor Technology, Inc.)
• Contribution to ITER: Superconducting magnet
• Contribution to ITER: Superconducting wire
• Development for future
Originated from Research Laboratory in Kobe Steel LTD
Established in 2002
Products: Superconducting wire and magnet
Manufacturing and Sales of High field magnet and superconducting wire for the magnet
Products lineup in JASTEC

Superconducting wire
- NbTi ⇒ low magnetic field
- Nb₃Sn ⇒ high magnetic field

Superconducting magnet
- Biology/Chemical Analysis : NMR
- Medical Imaging : MRI
- Silicon Crystal Growth : MCZ
- Gyrotron: High power Microwave radiation
Contribution to ITER – Superconducting magnet -

Cryo-cooler cooled magnet

Magnet for superconducting wire evaluation
Max Field 15T (150000 Gauss)
Bore size 170mm
Delivery in May 2005 at QST, Four GM-cryocoolers installed
Generates 15 Tesla magnetic field without Liquid Helium

Magnet for Gyrotron
Installed in Microwave generation for plasma heating
Generates 6-7 Tesla
About Gyrotron  （How Superconducting magnet works）

What is Gyrotron?

- High power microwave generator by ultra high speed rotation of electron. For the rotational movement of electron, high magnetic field required.
- Electron heating and current controlling for fusion plasma is enabled by high power microwave.

How Superconducting magnet works

- Supply magnetic field for electron rotation
- Generates magnetic field distribution suitable for gyrotron
  e.g. Higher filed at cavity, lower field at collector
Development history of 7T240 for Gyrotron

- 2006 Prototyping
  Superconducting gun coil is installed.
  Fast field distribution change by sweep coil
  Presentation in MT-20 at Philadelphia

- 2011 Type II installed in KSTAR Korea
  Two compensation coils could change field distribution
  Presentation in MT-22 at Marseille

- 2011, 2013 Two Type II delivered for JT-60SA

- 2011, 2014 Two 6.5T260 magnets delivered to NIFS (Tsukuba Univ.)

- 2013 8T240 magnets delivered
  Development of higher field magnet. Enabling beyond ITER specification

- 2015～2017 Eight Type III magnets delivered
  Realized large cost down by reducing cryocooler, homemade power supply
  Updated design criteria could reduce training quench
7T240 magnet for ITER Gyrotron

Field distribution

Magnet cross section

Variable 0.24-0.34T

7T240 SCM installed in QST
- **TF Coil**: 420 Ton *(Japan supplies 105 Ton)*
  (For Tokamak plasma confinement)
  Wire procurement: 2009~2012
  #2,3: JASTEC #1,4,5: Hitachi

- **CS Coil**: 140 Ton *(Japan supplies all)*
  (For Tokamak plasma current induction)
  Cable procurement: 2012~2016
  #1,2,6: JASTEC #3,7: Furukawa #4,5: KAT (Korea)

The No.1 Nb$_3$Sn supplier for ITER in the world
Superconducting wire

Superconducting filaments are embedded in copper matrix.

Current flows only in the filaments, not in the matrix. “Multi fine filament structure” is inevitable for practical superconducting wire.

Very small current flows in the superconducting wire in early stage.
Structure of superconducting wire

**NbTi wire**
- Niobium-Titanium filaments are embedded in oxygen free copper matrix.
- Number of filament: 30 ~ 200
- Filament diameter: 20 ~ 40μm

**Nb₃Sn wire**
- Niobium filaments are embedded in Copper- Tin alloy
- Barrier (Niobium/Tantalum) raps the alloy and there is copper matrix most outer layer.
- Nb3Ti is synthesized from Niobium and Tin by heat reaction process
- Number of filament: 20000 ~ 40000
- Filament diameter: 2 ~ 6μm  →  1/10 size of human hair
Production process of Nb$_3$Sn superconducting wire

**First multi stack process**

- 原材料 BzT ベレット
- 多穴加工
- 原材料 Nb棒
- 洗浄 1st組立
- EB溶接 押出加工（熱間静水圧押出）
- 伸線加工
- 六角加工 3mm

**Second multi stack process**

- Cuパイプ
- Nb/Taシート
- 六角材
- 洗浄 2nd組立 17000本 =19p x 900p
- EB溶接 押出加工（熱間静水圧押出）
- 伸線加工
- 仕上伸線（タイト）Φ0.8mm 被覆（Crメッキ）検査
Landscape in Superconducting wire factory
Challenge: Wire breakage during production

Superconducting wire = Composite metal material of sophisticated structure

Challenge: Drawing the metals of different hardness as a composite

\[
\text{Diameter from } 150 \text{mm to } 0.8 \text{mm } \Rightarrow 1/200, \text{ Area } \Rightarrow 1/40000
\]

Soft metals are drawn easily, Hard metals are NOT.

⇒ Hardness should be averaged by “Integration”

If not, wire will be broken

Cross section model of CS wire

Drawing process simulation
In CS Nb$_3$Sn wire manufacturing, suffering from frequent wire breakage,

Yield rate before improve action

![Graph showing yield rate distribution before improvement]

There are good and bad
Large deviation is the problem
Had a big crisis by low yield, lack of products
Tackled to address the problem with a lot of help

Criteria
Bad $\rightarrow$ Good

Yield rate after improve action

![Graph showing yield rate distribution after improvement]

Yield rate improvement
Average 20% up
Deviation 1/20

Design: Cross section, Size
Material: Mechanical property
Process: Environment, Control
For future

- JASTEC has contributed to ITER project by supplying both superconducting wire and magnet.
- Especially for Niobium Tin superconducting wire, JASTEC supplied more than 100 Ton as the world No.1 supplier.
- JASTEC will continue to produce next generation superconducting products using the cutting edge technology which was developed in ITER project.

Fusion, Industrial application（Semiconductor process）
Science, HEP, MRI, NMR etc.
Thank you for your attention