“Punch-and-Coat”: a novel approach to mechanically strong 2G HTS Roebel cables

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A. Kario, S. Otten, W. Goldacker

S. Fetisov, V. Vysotsky
• Brief overview of SuperOx
  • Company’s path and development plans
  • New equipment
  • 2G HTS wire basic properties
  • 2G HTS wire mechanical properties

• Roebel cables
  • Coat-and-Punch
  • Punch-and-Coat
  • Cables supplied
SuperOx: 2G HTS path

+ Structure: SuperOx (Russia), SuperOx Japan LLC (Tokyo)
+ Manufacture: 2G HTS wire on the market since 2012
+ Customise: the widest selection of finishing options available
+ Integrate: develop and market ready HTS solutions
2G HTS wire: layer architecture

**Dual-Chamber: PLD system**
- PLD-2 (1-3 microns)
- PLD-1 (100-200 nm)
- RF sputtering (30-50 nm)
- IBAD with RF sputtering (5-7 nm)
- RF sputtering (30-50 nm)
- RF sputtering (50 nm)
- Cold rolled & electro polished (60-100 microns)

**Single Chamber: RF sputter + IBAD**
- IBAD - MgO
- LaMnO₃
- Y₂O₃ or LaMnO₃
- Al₂O₃
- Hastelloy C276
- Customised finish tailored to application
- DC sputtering (custom thickness)
- RF sputtering (50 nm)
### Production status and development

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<th>Originally: 2011-2015</th>
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<td>Moscow</td>
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<td>Cu</td>
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<th>At present: 2016</th>
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Decisions to increase throughput are driven by demand.

21.03.2016
New equipment in Moscow

2015: new buffer layer deposition line installed in Moscow
PLD-HTS system to be commissioned by the end of 2016

21.03.2016
Moscow: buffer layer line commissioned

Good IBAD-MgO RHEED patterns

$\Delta \phi \ (110) \ LMO \ < \ 7^\circ$

$I_c$ over 500 A demonstrated with PLD-HTS

21.03.2016
2G HTS wire: 12 mm width

Long lengths with $I_c$ up to 500 A/12 mm available
2G HTS wire: 4 mm width

Long lengths with $I_c$ up to 150 A/4 mm available
2G HTS wire: performance in magnetic field

Low angular anisotropy

Reproducible lift factors
Consistent composition and microstructure of the PLD-GdBCO layer over years of production results in consistent wire performance.
Mechanical properties: tensile strength

High tensile strength ensured by Hastelloy substrate
High tensile strength ensured by Hastelloy substrate
Tight bending radii are possible
2G HTS wire: delamination strength

1. Delamination IS AN ISSUE in 2G HTS wire
2. Large variation of delamination strength among different wires and within one wire
# 2G HTS wire: specifications

<table>
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<tr>
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<tr>
<td>Production Length</td>
<td>up to 500 meters</td>
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<tr>
<td>Substrate Thickness</td>
<td>60–100 µm</td>
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<td>Tape width</td>
<td>4 mm</td>
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<td>Critical Current @ 77K, s.f.</td>
<td>100-150 A</td>
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<tr>
<td>$J_e$ at 4.2 K, 20 T</td>
<td>&gt; 400 A/mm²</td>
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<tr>
<td>Current Uniformity</td>
<td>±10%</td>
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**Customisation:**
- Variable silver thickness
- Variable copper thickness
- Lamination
- Insulation
- Artificial pinning centres
- Solder plating
- Low resistance splices
- ... just ask

21.03.2016
At CERN, 5 T HTS inserts into 16 T LTS dipoles are wound with Roebel cables. 20+ T dipoles will enable FCC 80 km circumference instead of 100 km.
Roebel cables: Coat-and-Punch

Coat-and-punch results

CCA-2014, 300 A-class wire
EUCAS-2015, 400 A-class wire

1.2 kA
1.8 kA
2.4 kA
2.8 kA

21.03.2016
Roebel cables: Coat-and-Punch

Standard way: coat-and-punch

Copper

Substrate

Smooth cross-section of the punched edge

Cu gets smeared over HTS layer

Well, most times …
Roebel cables: Coat-and-Punch

Standard way: coat-and-punch

… But sometimes delamination occurs

S. Otten et al., SUST 28 (2015) 065014
Roebel cables: Coat-and-Punch

Good section: no degradation in thermal cycling
Roebel cables: Coat-and-Punch

Poor section: significant degradation/delamination in thermal cycling
Roebel cables: Punch-and-Coat

Novel alternative: punch-and-coat

Cu-plating of a punched strand

HTS layer fully enclosed
Sharp punch burr smoothened

21.03.2016
Roebel cables: Punch-and-Coat
Roebel cables: PnC vs. CnP

PnC vs. CnP: superior degradation/delamination stability in thermal cycling

21.03.2016
PnC Roebel cables: accepting orders

SuperOx acquired own machinery for Roebel cable fabrication

Accepting orders on advanced PnC Roebel cable
Commercial PnC Roebel cables

Jul 2015: 2.5 m PnC cable provided to CERN for testing

Dec 2015: 35 m PnC cable supplied to CERN for Feather 2 coil

21.03.2016
Summary

• Punch-and-Coat Roebel cables provide superior degradation/delamination stability in thermal cycling

• For PnC fabrication, it is essential that all processes are combined within one company

• SuperOx is accepting orders on advanced Punch-and-Coat Roebel cables
THANK YOU FOR YOUR ATTENTION

www.superox.ru