Production of 2G HTS Conductor at SuperPower: Recent Progress and Ongoing Improvements

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Topics

• Evolution of SuperPower’s approach to the market
• Listening to the *Voice of the Customer*
• Technology and manufacturing program
• Current status and continuous improvement activities
• Summary
SuperPower’s evolution from years of experience

• 2000-2006: The Intermagnetics Years
  – 2G HTS technology development
  – Production scale-up
  – Demonstration projects – energy focus

• 2006-2012: The Philips Years
  – Transition from scale-up to commercialization
  – Exploration of wide range of commercial markets
  – Buildup of broad customer base

• From 2012 onward: The Furukawa Years
  – Continuous manufacturing improvements over established baseline capabilities … to address market needs
  – Steady expansion of production to meet market requirements
  – Focus on long-term sustainability in a slowly evolving market
SuperPower benefits from Furukawa’s strengths

Three core materials across five business segments

Metals
Photonics
Telecommunications
Light Metals
Energy/Industrial Products

CORPORATE PHILOSOPHY
Drawing on more than a century of expertise in the development and fabrication of advanced materials, we will contribute to the realization of a sustainable society through continuous technological innovation.
Market expectation: at 20-30% of device cost, significant growth expected for HTS wire market by 2017

<table>
<thead>
<tr>
<th>Global Market for S/C Materials ($M)</th>
<th>2012</th>
<th>2017</th>
<th>CAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTS Materials</td>
<td>$353.70</td>
<td>$441.80</td>
<td>4.50%</td>
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<tr>
<td>HTS* Materials</td>
<td>$12.30</td>
<td>$370.00</td>
<td>97.50%</td>
</tr>
<tr>
<td>Total</td>
<td>$366.00</td>
<td>$811.80</td>
<td>17.30%</td>
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<table>
<thead>
<tr>
<th>Superconducting Magnet Market ($M)</th>
<th>2012-2017 Growth: HTS* vs. LTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Wire</td>
<td>2012</td>
</tr>
<tr>
<td>LTS</td>
<td>353.6</td>
</tr>
<tr>
<td>HTS*</td>
<td>6.6</td>
</tr>
<tr>
<td>Total</td>
<td>360.2</td>
</tr>
</tbody>
</table>

* HTS = MgB$_2$, BSCCO and YBCO

The Voice of the Customer provides our roadmap

Application-specific requirements:

- **Performance**: critical current, in-field performance, engineering current density, low ac losses, piece length
- **Mechanical properties**: wire strength, joint options
- **Finishing options**: insulation, stabilization, multiple geometries
- **Quality**: uniformity, delivery time, price optimization, reliability
SuperPower® 2G HTS wire: Thin film deposition on robust, flexible substrate

- Routine, high quality production established – fast, high throughput, automated, reel-to-reel
We are meeting today’s needs

- **High Ic**: 100A standard; 110-140+ A premium (4 mm width)
- **Uniform Ic** over long lengths
  - Good, repeatable bandwidth
  - Good 2D uniformity (across width)
- **High engineering current density** (very thin substrate and stabilizers): 250-350A/mm²
- **Chemistry**: two formulations
  - AP (Advanced Pinning) (enhanced performance for in-magnetic field applications)
  - CF (Cable Formulation) (77K, low fields)
- **Flexible, robust architecture**
  - Multiple widths and thicknesses (substrate, stabilizers)
- **Superior mechanical properties**
  - Yield strength up to 700 MPa with superalloy-based coated conductors
  - Excellent joints and solderability
- **Long piece lengths**: routine 100-300 m lengths
And working on further advancements with Continuous Improvement Programs …

- **Higher** critical current
  - Increase in standard $I_c$
  - Increase in in-field performance
- **Longer** piece lengths
  - Increase in single piece lengths
  - Improvement in splicing techniques
- **Tighter** uniformity bandwidth
- **Stronger** mechanical wire properties
- **Faster** delivery time
  - Reducing production cycle time
  - Larger in-stock inventory (Quick Ship)
- **Better** price-performance ratio
Engineering new wire innovations to address customer requests and meet application requirements

• Additional wire insulation methods
  – Today: Kapton®/Polyimide wrapped
  – Other options under development: thinner profile, better coverage

• Additional wire architectures under development
  – Higher current carrying capability
    • Multi-layer combinations, i.e. EuCARD
    • Cable on Round Core (CORC)
    • Plus others …
  – Custom attributes
    • FCL – normal state resistance feature
Quality drives success: major focus on product quality and performance certification

• Additional Quality Assurance initiatives introduced to ensure product quality and production improvements:
  – Kaizen, Six Sigma (continuous improvement plans)
  – Lean manufacturing (5S program)
  – SOP, TPM, SPC, Documentation/Measurement

• Performance certification at device operating conditions
  – Expansion of in-field performance testing
    • In-house testing systems in place (up to 9T, 4.2K)
    • Additional system under development to allow for production qualification (77-30K, 0-2T, angular dependence)
  – Working with partners to expand testing in multiple field and temperature ranges
  – Long-term reliability, consistency and uniformity of product
Coil programs support customer activities and build expertise

- New coil winding approaches examined and under implementation
  - Coil modeling
  - 2G winding process development
  - Various coil types: solenoid, racetrack, pancake, and layer wound
  - Various coil testing techniques
  - Alternative insulation investigations
- Investigation of wire performance under stress
  - Tensile and compression strength testing
  - C-axis tensile/peel strength testing
  - Conductor characterization (Ic vs. stress)
Applications development programs support wire manufacturing activities

- **SFCL Transformer**: new wire architecture, FCL functionality, low ac loss configuration
- **ARPA-E SMES**: high current density for high field coil … also toward price improvement
- **Army SMES** for tactical micro-grid: adaptation of coil from utility medium voltage interface to lower voltage military performance requirement
- **ARPA-E REACT Wind turbine generator**: 4X improvement in current density under operating conditions … directly leading to price improvement
Technology development programs focused on next level of product improvements ... 

- Increase base Ic  
- Increase lift factor  
- Increase wire strength  
- Reduce ac losses

With structured, well-timed process to transfer advancements into production
Summary

- SuperPower’s wire production is stable and sufficient to meet today’s market
- Market requirements become more demanding
- Manufacturing initiatives directed toward improvements to meet application requirements and to speed adoption rate
- Further wire development efforts are focused on meeting demands of key applications

- For more information: www.superpower-inc.com
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