
2G HTS Wire and Device Demonstration Programs at SuperPower: Recent Progress and Continuous Improvement Programs

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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 as 2G HTS industry leader

• 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.
The Voice of the Customer provides our roadmap

Each application has its own unique 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) (77K, 0T)
- **Uniform Ic** over long lengths: STDEV +/- 10%
  - 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) (cable, FCL, transformer)
- **Flexible, robust architecture**
  - Multiple widths and thicknesses (substrate, stabilizers)
- **Superior mechanical properties**
  - Yield strength 550 MPa and higher with superalloy-based coated conductors
  - Excellent joints and solderability
- **Long piece lengths**: routine 50-300 m lengths
  - Up to 1 km with high quality splices
And working on further advancements with Continuous Improvement Programs …

- **Higher** critical current
  - Increase in standard Ic
  - 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
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, verification
  - Long-term reliability, consistency and uniformity of product
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)
    • ROEBEL cable
    • Plus others …
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)
- Engineering services to assist customer efforts
In-field performance – the key to coil applications

$I_c(B,T)/I_c(\text{self field, } 77\,\text{K})$ defined as **Lift Factor**
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 aimed at 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
DOE Smart Grid SFCL transformer demonstration

• Funding: DOE Smart Grid Demo $10.7M (Total Program = $21.5M)
• Partners:
  – SuperPower (project lead)
  – SPX | Waukesha Electric
  – University of Houston
  – Southern California Edison (host utility)
• Project objective:
  – Design, develop, manufacture and test SmartGrid-compatible SFCL Transformer
    • 28 MVA 3-phase FCL Medium Power Utility Transformer (69 kV / 12.47 kV class)
    • Testing on So. California Edison Smart Grid site in Irvine, CA – plan min 1 year of grid operation
  – First transformer to use significant amounts of 2G HTS wire (14km/12mm)
• Relevance:
  – Smaller footprint than conventional transformers, enabling existing substations to increase distribution capability without expanding into limited or expensive real estate

• Benefits
  – Greater efficiency
  – Smaller, lighter, potentially quieter
  – Safety: no oil for cooling
  – Can run indefinitely above rated power without affecting device life
• Add FCL feature …
  – Compatibility with Smart Grid requirements
  – Incorporation of FCL feature to rapidly detect and limit surges at high power levels that can be handled by downstream equipment
    – 30-50% reduction of prospective fault current
    – Low ac loss conductor development at UH
ARPA-E SMES Development

- Funding: DOE ARPA-E $4.2 million (Total program = $5.25 million)
- Project timeline: 2011-2013
- Partners:
  - ABB, Inc.: project lead, power electronics
  - Brookhaven National Lab: SMES coil
  - SuperPower Inc.: 2G HTS wire, coil development
  - University of Houston, TcSUH: manufacturing improvements for wire cost reductions
- Objective: proof-of-concept of modular, scalable SMES system by integrating an advanced power conversion concept with superconducting magnet coil
  - 20 kW UHF SMES device with 2.5 MJ class capacity
  - Field over 20 T at 4.2K
  - 2G HTS wire with high critical currents (~ 800 A) to drive down price/performance
  - Capable of flexible connection to medium voltage distribution networks at 15-36 kV
- Relevance:
  - High power and high energy storage in a compact device with cost advantages in material and system
  - Modular units for both long (hours) and short term (seconds) storage requirements to help load leveling on the grid being fed by variable renewable sources
Army Research Lab – SMES for Micro-Grid

- **Funding:** US Army Research Laboratory
  $4.2M of $7M funded to date
- **Project timeline:** 3 yrs., Q4/2012 – Q3/2015
- **Partners:**
  - **SuperPower Inc:** project lead, 2G HTS wire, coil development
  - **Brookhaven National Lab:** SMES coil
  - **MTech Labs:** power electronics
  - **University of Houston, TcSUH:** low ac loss material development

- **Objective:** Build upon the developments achieved in the ARPA E-SMES project with HTS superconductors and adapt those developments to the Army’s tactical Microgrid application (lower voltage)
  - Model, design and fabricate a 2.5MJ tactical Microgrid SMES
  - Modify 2G HTS MJ ARPA E-SMES coil to meet the tactical Microgrid requirements
  - Develop robust quench protection and switching components
  - Investigate methods to reduce ac losses through superconductor tape design

- **Relevance:**
  - High power and high energy storage in a compact device enables a power solution for remote areas.
  - Build on ARPA E investment in SMES technology to provide a practical application in real world environments
**ARPA-E REACT Program**

(Rare Earth Alternatives for Critical Technologies)

- Develop high performance, low-cost superconducting wires and coils for **wind turbine generators** that are lighter, more powerful, and more efficient – and will provide an alternative to RE-based permanent magnets

- Partnering between university, institution, and companies
  - University of Houston – project lead, further improvement in in-field/low temperature wire performance
  - SuperPower – wire manufacturer
  - NREL (National Renewable Energy Laboratory) – impact evaluation of enhanced s/c wire on overall system performance
  - Tai Yang Research Company – coil fabrication and test
  - TECO Westinghouse Motor Company – device design

- **Goal:** four-fold improvement in lift factor (2.5T, 30K)

- **Project started in January 2012**

- **Program period:** 3 years

- **Budget:** $3.1 million
Technology development programs focused on next level of product improvements …

- Increase base $I_c$
- Increase lift factor
- Increase wire strength
- Reduce ac losses

Structured, well-timed process for transfer of these advancements into production

68% improvement in wire performance at wind generator operating condition of 30 K, 2.5 T
Summary

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

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