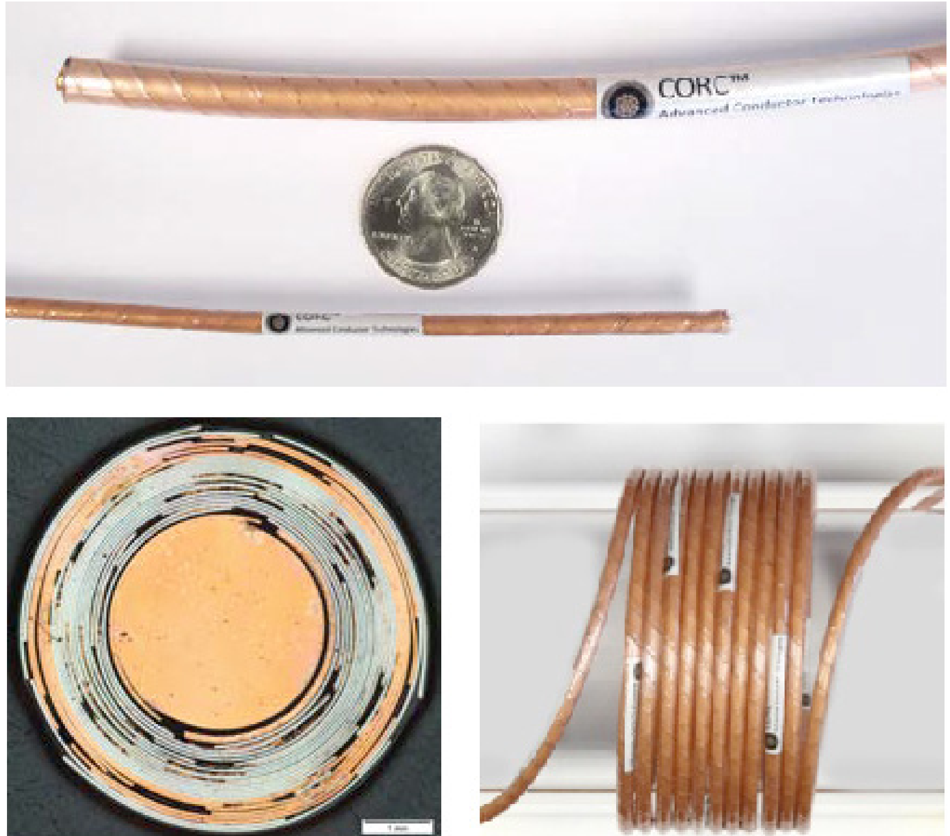
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Cost-effective Conductor, Cable, and Coils for Next-Generation Electric Machines



Multiple views of Conductor on Round Core (CORC®) cable at various magnifications. *Graphic image courtesy of Advanced Conductor Technologies*

Developing cost-effective, high-current-density products for industry

High current density permits motor and generator windings to achieve very high flux density, higher than what is possible with technologies based on copper, iron, or permanent magnets. This makes electric machines compact and lightweight. Superconductivity also removes resistive losses to increase efficiency.

Coated conductors made of rare-earth copper oxide superconductors can be used to produce high-current-density cables. Flexible Conductor on Round Core (CORC®) cables build-in protection of the individual conductors by allowing current to share mutually across the entire cable. This property confers significant reliability advantages to superconducting rotating electric machines and power transmission.

Each conductor is made of rare-earth copper oxide superconductor coatings that achieve very high current density. The simple coated-tape conductors, with superconductor composition $REBa_2Cu_3O_7$ (RE = Rare Earth) or REBCO, are helically wound around a central core to produce CORC® cables. A 5 mm diameter cable can have a rating in excess of 5,000 amperes.

This project will develop, produce, and test high temperature superconductor (HTS) tapes, cables, and coils for next generation electric machines as well as magnet applications. The project will involve production and testing of lengths of these products to improve performance. This will begin with the production and performance testing of HTS superconductor tape. This tape will then be wound into CORC® cables; starting with short lengths characterized by conductor used, and moving into the production of longer lengths where specific protocols are developed to characterize cable performance. The ultimate goal of the project is to wind the improved CORC® cable into coils of sufficient length and performance for industrial applications.

Benefits for Our Industry and Our Nation

Robust, highly reliable superconducting cables facilitate:

- Reduction of electricity consumed by large electric motors.
- New types of electric motors and generators, with higher power ratings.
- Power cables for low-loss electricity transmission.
- High-field magnet technology for medicine, science, transportation, and electric grid management.

Applications in Our Nation's Industry

Superconducting machines become cost-effective above 1 MW rating because operating costs, system mass, system footprint, and other factors become prohibitive for technologies based on copper-iron and permanent magnets. Motors consume over 50% of all electrical energy in the U.S., and more than 85% of electrical energy consumed by industry.

Superconducting machines are presently developed for ship propulsion and electricity stabilization, with potential expansion into very large industrial motors. For example, wind power has an economic return that favors very large turbines, which can be fulfilled by superconducting machines. Finally, demonstration of superconductors in rotating machines could facilitate development of medical imaging magnet technology based on coated conductors.

Project Description

This project will develop, produce, and test CORC® cables to evaluate them for rotating machines, power transmission, and high-field magnets. Reliability of coated conductors is confronted by occasional zones of reduced capacity, which can instigate failures. The project will evaluate how the built-in properties of the CORC® design circumvent failures and improve reliability. The project will also investigate how coated conductors of different quality affect the cable rating. By mitigating the negative effects of reduced-capacity zones, higher manufacturing yield should be attained.

The project will consume long production lengths of conductor and will characterize properties over the full conductor length. This will result in a library of defect types and their consequences. Feedback to the manufacturing process will facilitate the eventual manufacture of longer conductor and cables with better performance. The ultimate goal of the project is to enable use of highly reliable CORC® cables in coils for rotating electric machines.

Barriers

Coated conductors operate in cryogenic conditions, where superconductivity occurs. Under these conditions, manufacturing variations that result in performance loss are difficult to characterize, and quality control information has limited ability to anticipate reliability in electric machines.

Manufactured conductors can become damaged by the processes of cabling and winding. Also, the effects of magnetic field, mechanical strain, and response to operating conditions can degrade capacity and trigger instances of conductor burn-out.

Pathways

Intricate systems for characterizing the conductor point-by-point have been developed. These systems permit identification of locations connected with the negative effects above, which allows them to be mapped throughout the cabling and winding processes. The mapping also facilitates traceability back to precursors in manufacturing processes to improve them.

Project partners will adapt these characterization methods to manage long, 500 m, production lengths of coated conductor. Mapped conductors will be integrated with short-length CORC® cable designs to test ideas about sharing current, avoiding conductor burn-out, and optimizing current density and amperage. Cable designs with high fault tolerance and reliability are expected to mitigate risks when wound into coils, where significant energy can be stored and high stresses can accumulate. Optimized cables of long length, over 30 meters, should result in coils large enough to model electric machines. Manufacturing lessons and tolerance of manufacturing variations by effectively mapping conductors should also result in higher yield and lower cost.

Milestones

This 3 year project began in 2017.

- Modify the present YateStar characterization system to accept full production lengths of conductor and assess 2G HTS tape properties relevant to superconducting electric machines (2018).
- Produce 2G HTS tape in production lengths on the order of 500 m, up to 2 km each project year, and 6 km total (2019).
- Produce CORC® cables for testing, with production of 10 m cables by year 3 of the project (2019).
- Test CORC® cables to validate characterizations (2019).
- Wind and test coils produced from CORC® cables (2019).

Technology Transition

Manufacturing of coated conductor into CORC® cables will serve as a starting point for magnet technology. The outcome of the project will stimulate private industry, national laboratory, and other parties to wind coils because the built-in stability of the cables makes it possible to achieve robust schemes to protect coils from failure. Achieving this goal would enable manufacturing of electric machines and magnet technologies to advance.

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