High Temperature Superconductive SECtor ASsembled cable for improved energy transmission

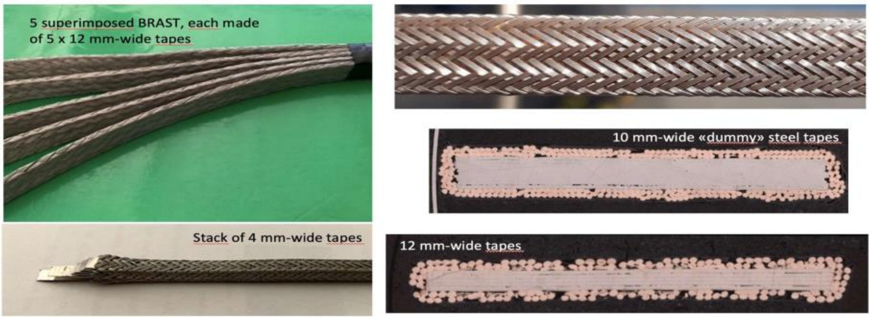
HTS group of ENEA - Centro Ricerche Frascati developed a new HTS sector-cable design, *to integrate HTS in the coil system of the fusion reactor. HTS materials increase the working range of coils compared to Low Temperature Superconducting (LTS) technologies, either at higher temperatures or at higher magnetic field levels, and in any case with greater operating margins. This technology is composed by two main elements the BRAided Stack of Tapes (BRAST) and the SECtor Assembled (SECAS) cable. The technology is available for further development and transfer in non-fusion markets, including power generation (motors, engines, generators, converters), power transmission (cables, coils) and energy storage.*

Description of the technology

The HTS sector cable concept developed by the ENEA HTS group is a SECtor ASsembled cable (SECAS) based on BRAided Stacks of Tapes (BRAST).

The basic sub-unit we propose to use in the conductor design is a BRAST. Using an industry-standard method, a stack of any number of tapes is built within a braid of thin, tin-coated Cu wires with widths ranging from 0.1 to 0.3 mm. This is a highly effective way to establish a stack of tapes and safeguard it during subsequent handling steps. The image below displays prototypes of an optimization method to determine the best braid pattern for different tape configurations based on wire diameter, number of wires in the bundle, and number of bundles composing the braid. The BRAST is a versatile and easy-to-use cable sub-unit that may be utilized in a variety of cable designs and layouts with any type of tape.

The cable concept developed featuring BRAST as the initial sub-unit, aimed at reducing the number of required tapes. It includes the use of 12 mm-wide tapes over 4 mm-wide ones, impacting both cable strain and AC losses. The manufacturing process involves constructing sub-cables around an extruded sector-shaped profile, with one or more BRASTs inserted and closed with filler and outer wrapping with open mesh, made of a Cu
or steel tape, depending on the specific AC loss requirements.
Despite acknowledging that the tape stacks are left unsoldered inside the slots, and knowing the potential for tape slipping, the technology provider anticipate that through careful consideration of geometries, tolerances, and manufacturing processes, the superconducting tapes can establish improved electrical and thermal contact with the stabilizing core.



Examples of BRAST prototypes and experiments produced thus far.

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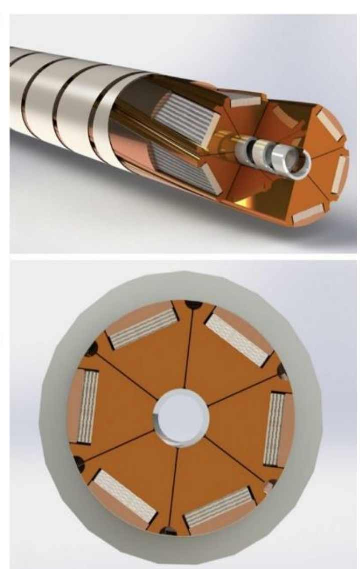
Description of the technology

The stabilizer cross-section is mostly driven by manufacturing requirements. Sub-cables are assembled around a central cooling spiral to maintain flexibility, with an outer steel jacket applied in the final step. The design can be adapted to different requirements but with 6 BRASTs, each consisting of ten 12 mm-wide tapes, and a cable outer diameter (inside the jacket) of about 40 mm, can achieve a target performance of 60 kA - 18 T. The central spiral acts as a pressure relief channel for circulating supercritical helium. Service channels left at the corners of sectors can be used as local helium reservoirs, signal cable routing, or quench detection sensors.
Mechanical considerations aim to minimize voids and gaps to support tape stacks against electromagnetic loads. Cable segmentation and twisted sector structure reduce AC coupling losses between HTS tape stacks. The filamentary structure of the braid in the BRAST contributes to reducing AC losses and allows coolant contact with the stacks. Copper or steel "dummy" tapes could be added to reduce stress concentration and mitigate the risk of damage.

Prototype sub-cables have been characterized at 77 K and self-field, as a crucial step towards the final goal of a Cable-in-Conduit-Conductor (CICC) functioning stably with 60 kA at 4.2 K and 18 T, and able to sustain bending over a 1.5 m radius, which is now of interest to the EU-DEMO Central Solenoid Coil.



The image above shows a schematic illustration of the sub-cable, which consists of an extruded sector-shaped core into which one or more BRASTs are put and sealed with a filler and an outer wrapping.

On the right, a constructed SECAS with BRASTs, sector-shaped core, fillers, outside steel wrap, and center spiral. Also shown is a cross-section of the final conductor with the external steel jacket.

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Innovation and advantages of the offer

HTS-based technologies are largely being examined for application in hybrid systems, with the possibility to incorporate Low-Temperature Superconducting (LTS) systems. One of the new elements is that they can widen the LTS performance range.

In the case of the central solenoid (CS), increasing the operational magnetic field above the values achievable by LTS may result in increased magnetic flux at a fixed coil outer radius or reduced coil dimensions at the same magnetic flux.

The HTS Cable-in-Conduit Conductor (CICC) is expected to demonstrate effective and stable operation at 60 kA, 18 T, 4.5 K, operating in pulsed conditions, to represent the typical CS coil operation, and sustain without degradation the bending over a radius of about 1.5 m.

Non-fusion Applications

The described technologies and methodologies have been developed primarily for applications in fusion. Nevertheless, their applications can also be transferred in a series of non fusion markets, in particular targeting sectors in which the minimization of energy losses is of strategic importance, such as power generation and conversion (e.g. motors, engines, generators, converters), power transmission (e.g. cables, wires, tapes, coils) and energy storage (e.g. battery systems).

EUROfusion Heritage

HTS are being examined in feasibility studies for the EU-DEMO coil system, the future European nuclear fusion reactor funded by EUROfusion. In this respect, HTS-based technologies are primarily evaluated for use in hybrid systems, with the potential to combine LTS systems and broaden their performance range. In the case of the central solenoid (CS), increasing the operational magnetic field above the levels achievable by LTS may result in either bigger magnetic flux at fixed coil outer radius or smaller coil dimensions at a fixed magnetic flux.

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