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Advanced second generation high temperature superconductor wire for fusion

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The use of high temperature superconductors (HTS) in magnetic systems of fusion devices enables magnetic fields over 16 T, unachievable with low temperature superconductors (LTS), and promises significant reduction in cryogenic and energy budget [1-4]. HTS materials are considered by some researcher groups as the enabling material to make magnetic confinement systems more compact and more affordable. Until recently, some unresolved obstacles for using HTS materials in fusion applications existed, including little knowledge available on critical current in field and mechanical properties at cryogenic temperature, unknown behaviour in alternating magnetic field, limited availability, short piece length, lack of proven cable technology, and high price. Recent technology advances resolved many of these tasks bringing HTS materials to greater maturity for use in fusion devices.

Recently, S-Innovations company successfully developed and marketed a new product, particularly suitable for creating high magnetic fields for fusion devices: SuperOx second generation (2G) HTS wire with modified ReBa2Cu3O7 (ReBCO, Re—rare earth element) composition [5]. The new SuperOx wire demonstrates exceptionally high critical current and engineering current density in high magnetic field; for instance, engineering current density over 1000 A/mm2 at 20 K, 20 T and over 2000 A/mm2 at 4.2 K, 20 T has been repeatedly achieved in commercially produced wire (Fig. 1). The in-field performance of the new SuperOx wire in the 4.2-65 K temperature range is 1.5-2.5 times better than that of the previous product based on the GdBCO superconductor (Fig. 2).

This impressive result has been achieved by S-Innovations in hundreds of 300-600 m long pieces of routinely manufactured wire. The unique feature of the new wire is that the ReBCO layer in it does not contain c-axis correlated nano-columns, in contrast to the common opinion that only with nano-columnar defects is it possible to achieve enhanced in-filed performance in 2G HTS wire.

The mechanical properties of this HTS wire largely depend on the mechanical properties of the strong Hastelloy C276 substrate. In particular, the wire exhibits tensile strength of over 600 MPa and is fully stable at least up to 0.4% elongation. The mechanical properties examined at various temperatures are available for SuperOx 2G HTS wire and compare favourably well to that of other manufacturers.

An important issue of the technology is an understanding of losses appearing in superconductor in alternating magnetic fields. A large set of data was recently collected for AC loss behaviour of SuperOx 2G HTS wire in liquid nitrogen at wide range of current and frequency up to 800 Hz. The results confirm earlier observations that AC losses of 2G HTS wires are low as compared to the most other practical superconductors. The available experimental data can be scaled and AC losses at the operational conditions of large fusion magnets can be calculated.

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Studies of SuperOx and other groups demonstrate that viable high current cables for fusion can be manufactured from these wires (see, e.g. [6]). More research is underway to perfect engineering approaches in this direction.

The new SuperOx wire has been routinely manufactured with reproducible quality and high yields at unprecedented volumes for 2G HTS wire industry. The manufacturing processes are highly automated and integrated into an intelligent production management system. A comprehensive quality management system comprises numerous in-line and off-line QC procedures. The production capacity was doubled during the past year, and 5-10-fold capacity increase scenarios are in place awaiting order commitments. The pending 5-10-fold expansion will result in a production volume of multiple tonnes per year, the level at which 2G HTS wire price will allow the construction of economical fusion power plants for future green energy [3,4].

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