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Title:

Performance Boundaries in Nb_3Sn Superconductors

Abstract:

The non-copper critical current density at a temperature of 4.2 Kelvin and magnetic field of 12 Tesla in commercial Nb_3Sn superconducting wires has approximately doubled from 1.7 kA/mm^2 in 1993 to 3 kA/mm^2 in 2003. This achievement raised the question to what further extent the critical current density can be improved using existing fabrication technologies. An answer is provided through detailed investigations of the origins of the critical surface in Nb_3Sn wires. A literature review is presented on the relevant properties of Nb_3Sn. It is shown that the superconducting compound of interest (the so-called A15 phase) is stable from about 18 to 25 at.% Sn and that its upper critical field and critical temperature, which are the main parameters controlling the critical current density, are reduced with increasing Sn deficiency in the A15. The A15 formation process and the A15 compositional variation were investigated and it was found that existing wires exhibit Sn gradients ranging from about 0.3 to 5 at.% Sn/micrometer, depending on the fabrication technique. The influence of these inhomogeneities in limiting the achievable current density, mainly through a reduction of the effective field-temperature phase boundary, was explored with measurements of the upper critical field as function of temperature. Existing descriptions for the critical current as function of magnetic field, temperature and strain were re-evaluated in relation to the observed A15 inhomogeneities to determine the performance loss that occurs through Sn deficiency. A new relation is proposed and verified with critical current measurements as function of magnetic field, temperature and strain. The new relation provides significantly enhanced accuracy with respect to the temperature and strain dependence and provides a better connection to the microscopic theory. These measurements and the improved relation were used to determine the maximum achievable non-copper critical current density in existing wire layouts which is estimated at 5 kA/mm^2 at 4.2 K and 12 T. This result is important for the manufacture and applications using Nb_3Sn wires since it suggests a well founded upper design limit for the present generation Nb_3Sn wires.