Study of Quench Propagation Properties in Rutherford-type Cables

Doctoral Program in Engineering
University of Tsukuba

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Ken-ichi Sasaki

Abstract

Quench propagation velocity is one of the most important parameters for quench protection of superconducting magnets. A larger quench propagation velocity is preferable in order to prevent local temperature from being increased significantly.

In a multi-strand cable whose strands are individually insulated, it has been reported that the quench propagation velocity increases by a current redistribution between strands. However, influences of current redistribution on a quench velocity for a cable made of non-insulated strands have not been studied. We examined the relations between the current redistribution and the quench propagation velocity in a Rutherford cable made of non-insulated strands. Measurements were performed in the cables with three contact conditions between strands, and it was found that the quench propagation velocity and the current redistributions depended on the contact conditions between strands.

A measurement was also performed in the cable without polyimide tape for the cable insulation, and we found that the polyimide tape also influenced on the quench propagation velocity.

A numerical simulation of current redistribution using a simple model was performed. We made comparisons between the test and the numerical results, and there was good agreement each other. We analyzed the numerical results in detail, and we found that the current redistribution occurred around the quench front caused the increase of the quench propagation velocity.

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Contents

Nomenclature

I	Transport current of the magnet [A]
A	Area of conductor cross section [m^2]
T	Temperature [K]
T_{max}	Peak temperature of the magnet [K]
T_0	Base temperature [K]
C_p	Specific heat of the cable [J/m^3K]
ρ	Resistivity of the cable [Ωm]
L	Inductance of the magnet [H]
R_0	Resistance of the external dump resistor [Ω]
R_q	Resistance of the normal region of the magnet [Ω]
κ	Thermal conductivity of the cable [W/mK]
g	Joule heat generation in the cable [W/m^3]
P	Cooled perimeter [m]
q_h	Heat transfer to a coolant [W/m^2]
v_i	Induced voltages of pickup coil i [V]
m_ij	Mutual inductance between pickup coil i and strand j [H]
i_i	Current of strand i [A]
$\boldsymbol{V}$	Matrix of pickup coil voltages
$\boldsymbol{I}$	Matrix of strand currents
$\boldsymbol{M}$	Matrix of mutual inductance between pickup coils and strand
I_{strand}	Current of the strand in the cable [A]
B_{max}	Maximum magnetic field on the cable [T]
B_{min}	Minimum magnetic field on the cable [T]

t_{fcr}	Time when the first current redistribution occurs [sec]
J	Current density of the strand [A/m^2]
$R_{(1,i)}$	Resistance of section i of strand 1 [Ω]
$R_{(2,i)}$	Resistance of section i of strand 2 [Ω]
R_c	Contact resistance [Ω]
$I_{(1,i)}$	Current of section i of strand 1 [A]
$I_{(2,i)}$	Current of section i of strand 2 [A]
I_{total}	Total current of the cable [A]
$I_{c(i)}$	Current through the contact resistance at section i [A]
$M_{(1,i)(j,k)}$	Mutual inductance between section i of strand 1 and section j of strand k [H]
$M_{(2,i)(j,k)}$	Mutual inductance between section i of strand 2 and section j of strand k [H]
Δl	Length of section [m]
σ_c	Contact conductance [S/m]
T_c	Critical temperature [K]
T_{c0}	Critical temperature at 0 T [K]
B	External magnetic field [T]
B_{c0}	Critical magnetic field at 0 K and 0 A/m^2 [T]
J_{NbTi}	Current density in NbTi [A/m^3]
$J_{c,NbTi}$	Critical current density of NbTi [A/m^3]
$I_{c,strand}$	Critical current of the strand [A]
α	Cu/Sc ratio
$C_{p,Cu}$	Specific heat of copper [J/m^{3}K]
$C_{p,NbTi}$	Specific heat of NbTi [J/m^{3}K]
ρ_{cu}	Resistivity of copper [Ωm]
ρ_{NbTi}	Resistivity of NbTi [Ωm]
ρ_0	Resistivity to define the critical current density [Ωm]

n	n-value of NbTi
κ_{Cu}	Thermal conductivity of copper [W/mK]
L_0	Lorentz number (= 2.44×10^{-8}) [WΩ/K^2)]
r	Radius of wire [m]
l	Length of wire [m]
h	Distance between two wire elements in the axial direction [m]
d	Distance between two wire elements in the horizontal direction [m]
ω	Angular frequency [rad/sec]
$I_{sw}(x)$	Complex current in sinusoidal wave circuit [A]
Z_c	External impedance of sinusoidal wave circuit [Ω]
Z	Distributed series impedance [Ω/m]
Y	Distributed parallel impedance [S/m]
A_{sw}	Arbitrary constant
R_{sw}	Series resistance per unit length [Ω/m]
L_{sw}	Distributed series inductance per unit length [H/m]
G_{sw}	Parallel conductance per unit length [S/m]
C_{sw}	Distributed parallel capacitance per unit length [F/m]
α_{sw}	Attenuation constant
β_{sw}	Phase constant
p_{cn}	Heat conduction between strands [W/m]
h_{const}	Constant thermal conductivity between strands [W/mK]