Tampere University

27th International Conference on Magnet Technology (MT27)
Fukuoka, Japan / 2021

Choice of 2G HTS tape for magnet design according to quench protection requirements

Dmitry Sotnikov, Mika Lyly, Tiina Salmi
Tampere University (TAU)

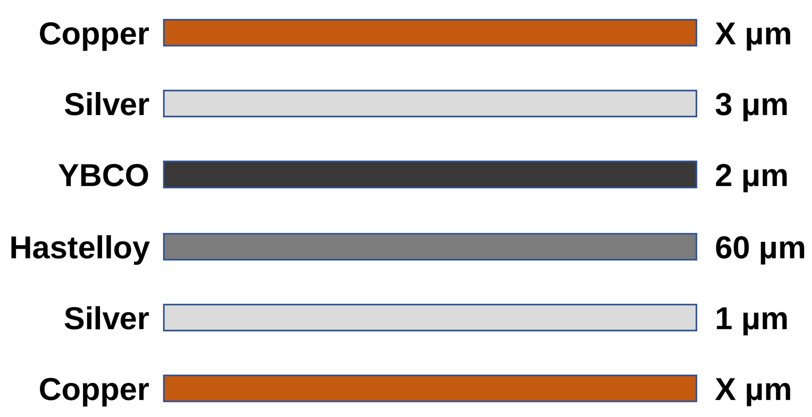
Abstract - This presentation describes a method for selecting the 2G HTS tape geometry for magnet design by analyzing quench using analytical methods. The analysis includes current sharing between layers of 2G HTS tapes in the external magnetic field and deviation of critical current values by length. Analysis of quench in 2G HTS tape with realistic critical current distribution by length allows predicting the temperature and voltage in each point of tape and provides specifications for an effective quench protection system.

Initial data

The goal of this work was to determine the 2G HTS tape parameters for a conduction cooled solenoid magnet. The operation conditions are limited by magnet power supply, cooling equipment, and quench detection capabilities of measurement devices. The initial parameters of adoptable equipment are shown in table.

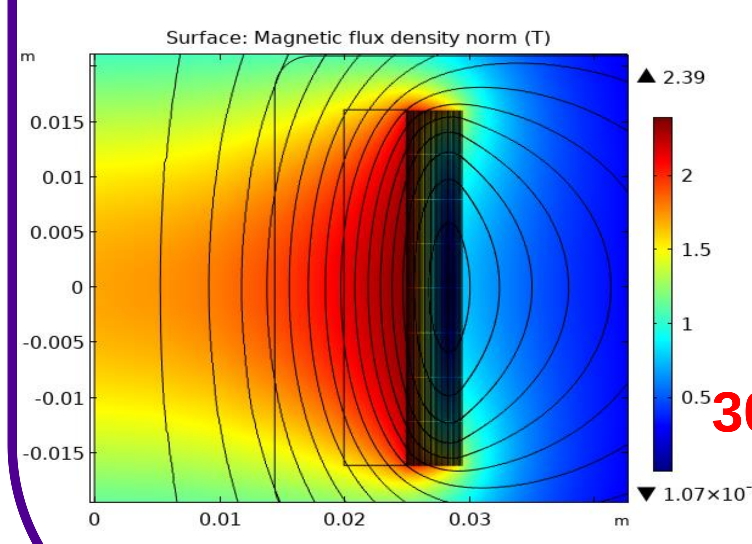
#	Parameter	Item	Value
1	DC maximal current	A	300
2	DC maximal voltage	V	5
3	Voltage detection level	mV	20
4	Protection system operation time	ms	30
5	Operation temperature range	K	12-50

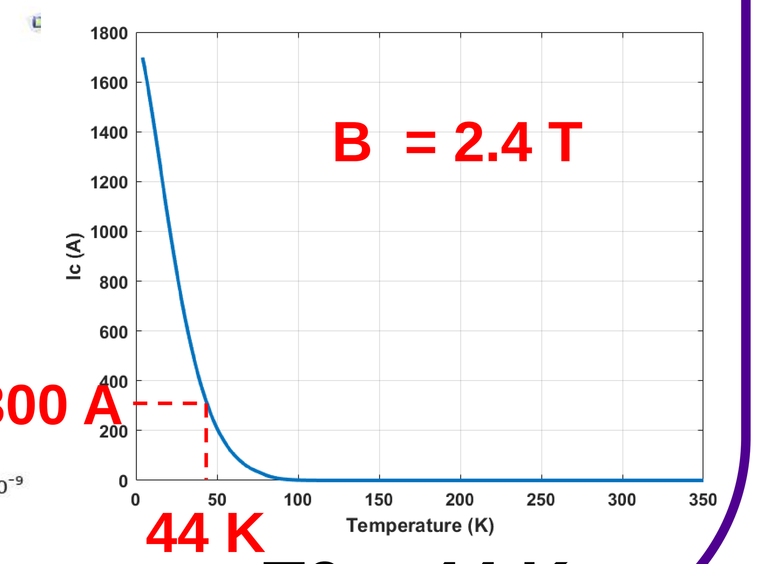
2G HTS tapes are multilayered materials with constant silver thickness and limited variation of substrate thickness depending on producer's choice. The easiest way for optimization of heating stabilization of 2G HTS tape is variation of copper layer thickness. Copper is a good conductor with good thermal conductivity properties.



Magnet properties

The magnet geometry was chosen according to available length 50 m of 2G HTS tape. It allows to create small solenoid with 2.5 cm main former radius and 8 winds with 36 turns in each. The operation temperature was determined by using FEM simulations with linear material parameters, and Ic(B,T) relation introduced in [1]. FEM model was used to search operation conditions in which the critical current of magnet corresponds to 300 A, and the temperature is within the cooling possibility.





Bmax = 2.4 T T0 = 44 K

2G HTS tape heating during quench protection

The quench protection system starts when quench was determined. Typical way to determine the quench is to measure voltage. When voltage is achieved some criteria then protection system launches. Heating process of 2G HTS tape could be divided on three stages:

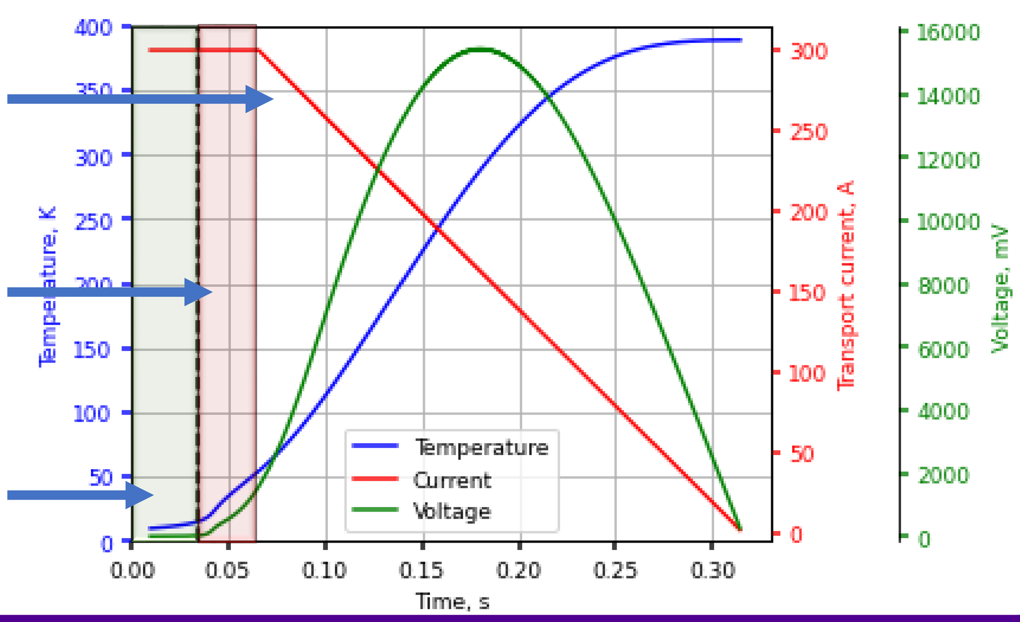
1. Quench occurs in hot-spot and voltage value of the tape is lower than criteria.
2. Protection system detected the quench and it turns the process of current reduce.
3. Heating is proceeding during current reducing.

The first stage is significant when detection voltage is high. Usually, 2G HTS tape is still in superconducting state and heating is too small. The second stage shows heating depending on protection system properties and should be taken into account. The third stage could be neglected by using of current sharp ramp down.
For this work we used mainly the second stage for analysis.

3. Reducing of current

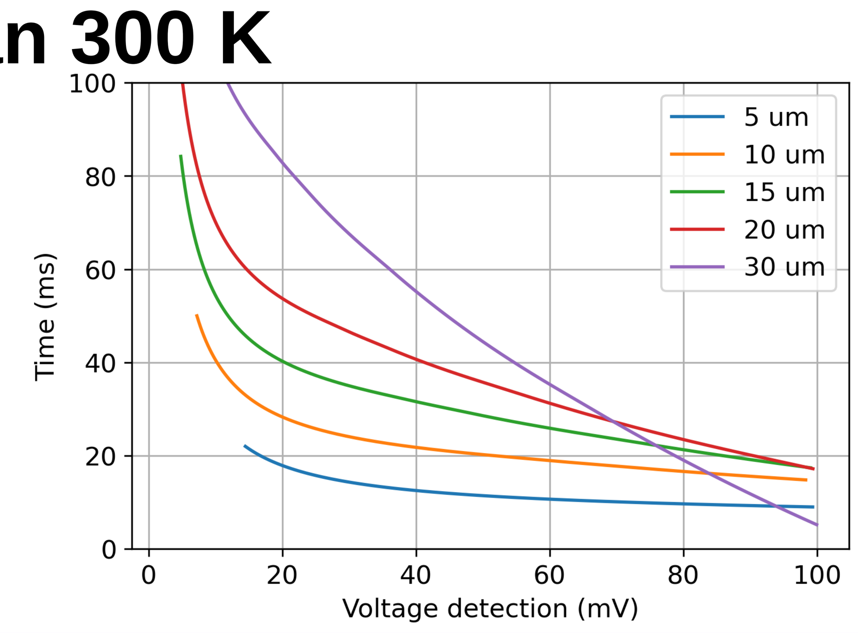
2. Heating during protection system operation

1. Quench occurs, but voltage is too low



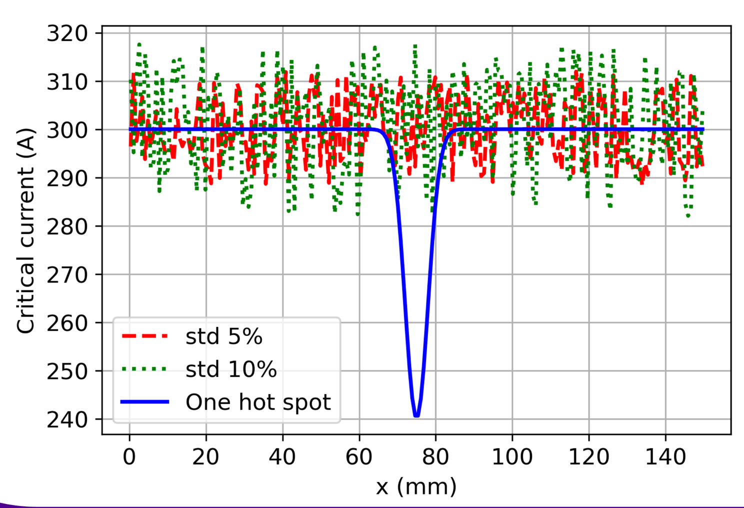
Voltage detection criteria for heating less than 300 K

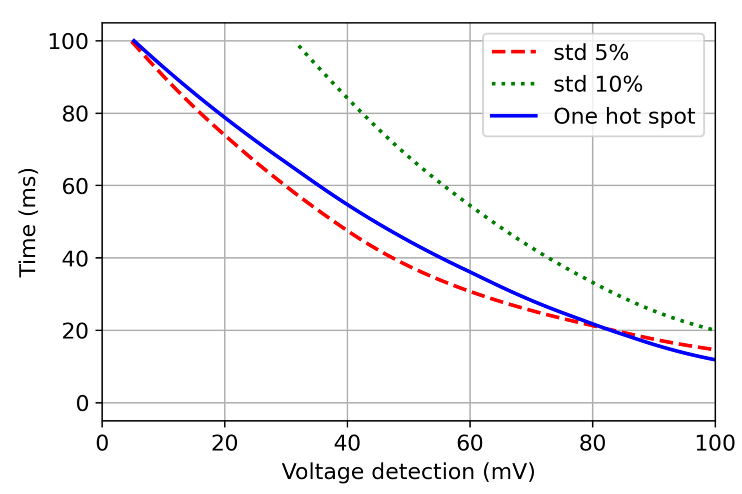
Typically, the voltage criteria for quench detection is calculated in adiabatic conditions for a short 2G HTS tape with a hot spot. It gives relevant results for estimation of 2G HTS tape behavior in the real magnet.
We took a piece 15 cm of length that is equal to one turn in the solenoid (the minimal critical current will be in the maximal magnetic field that typically corresponds to one or several turns) and hot spot of 1 cm length .
Value of Hastelloy and Silver thicknesses we took typical for 2G HTS tapes (60 um and 4 um) and changed thicknesses of the Copper layer from 5 um to 30 um of copper on each side of tape. The impact of Copper in stabilization is much more significant than Hastelloy due to physical properties.
As a criteria for selection of Copper thickness we took the time of heating the tape to 300 K after achieving of voltage detection level. Copper layer thickness should correspond to at least 20 mV of voltage detection and 30 ms of protection system operation.



Non-uniform Ic distribution

In practice, 2G HTS tape has non-uniform current distribution with some deviation along the tape. We calculated time for heating from detection of voltage to 300 K for three cases: 1) std 5%; 2) std 10%; 3) one high hot spot. As we can see from the picture, the low deviation is more dangerous for quench detection and magnet safety than even large drop.
The left figure indicates that the low deviation in critical current makes quench detection more challenging. For small detection voltages, there is less time to react before 300 K is achieved.





Conclusion

The selection of 2G HTS tape parameters was realized in the following order:

1. We determined the temperature of the magnet that allows to (use maximal parameters of equipment) apply maximal current of power supply. This temperature is the starting point for analysis.
2. We analyzed the effect of thickness of copper layer on the temperature rise during quench in HTS tape. The selection of thickness was based on the capability of our quench protection system.
3. We demonstrated the effect of non-uniform Ic distribution (along the tape) on quench detection scheme.

In quench analysis of HTS tape, typically a uniform Ic distribution along the tape is assumed. In practice, Ic can vary several percents and this can have a significant effect on quench detection scheme. Here, we presented an approach which takes this variation into account. This approach can be a good instrument for selecting 2G HTS tape for magnets.

[1] "Parameterization of the critical surface of REBCO conductors from Bruker", M. Danial and J. van Nugteren, July 20, 2017
[2] "Development and large volume production of extremely high current density $YBa_2Cu_3O_7$ superconducting wires for fusion", A. Molodyk et al., Scientific Reports volume 11, Article number: 2084 (2021)