Quench propagation in MgB_2 Rutherford cables

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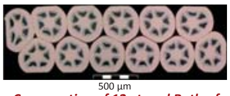
Introduction

Rutherford cables offer several advantages over single conductors for different foreseen applications, since they are more flexible and may achieve a reduction of the AC losses by using appropriate transposition length and inter-strand electrical resistance. Furthermore, the optimization of these cables should also achieve the required thermal stability.

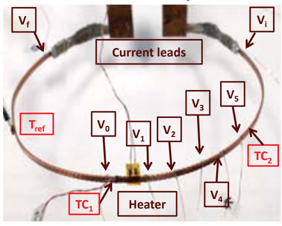
Two different configurations of 12-strand Rutherford cables have been analysed. The cables were assembled by IEE using a back-twist cabling machine with transposition length of 25 mm and have rectangular cross-section with final dimensions of 2.7 mm width and 0.7 mm thickness. The strands are 390µm-diameter wires from HyperTech Research, Inc, and have Cu or Cu10Ni sheath, and Nb barrier to minimise the chemical reaction between the precursor powders and the sheath during the *in situ* formation of the MgB_2 phase.

Quench propagation has been measured and analysed in self-field conditions. These experiments were performed in vacuum and cooled by thermal conduction using a cryocooler.

Case 1: Cu-sheathed wire



Cross-section of 12-strand Rutherford cable. Each strand has 6-filaments

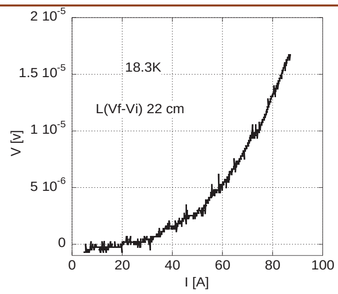


Heat pulses of variable duration were used to trigger the quench.

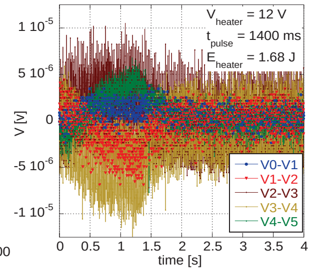
Heater: A strain gage of electric resistance, R=120 Ω, was glued to the sample. Maximum heat power without damaging the heater is about 1.5 W.

Sample prepared for quench analysis

- *L: 25 cm*
- *Distance between V_i and V_f is 22 cm*
- *The heater was placed between V_0 and V_1 (1 cm separation).*
- *Additional voltage taps: V_2 … V_5 (1.5 cm separation) to measure quench development and propagation.*
- *2 Thermocouples (TC_i) were soldered.*



I-V curve of the Cu-sheathed cable showing very low n-value (~ 2.5). Similar n-values were measured in the wires (before cable manufacturing).

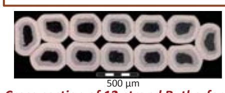


Voltages measured at I= 84 A for E_{heater}= 1.68 J

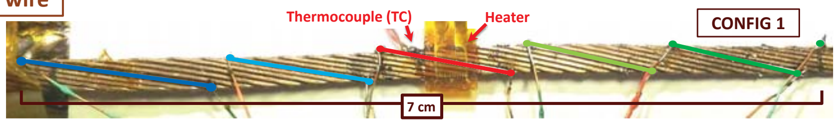
For this test, sample is initially at T_{ref} = 18.3 K.
Maximimum temperatures: TC_1 ~ 25.3 K and TC_2 ~ 21.4 K.

- Voltages lower than 10 µV were measured for all energy pulses: E_{pulse} < MQE.
- Some voltages are positive and other negative. This reflects small I-V differences among strands.
- Due to the very low *n*-values and the high thermal conductivity of the Cu-sheath, we were not able to induce a quench in this cable.
- In all cases, recovery after the heat pulse is observed.

Case 2: Cu10Ni-sheathed wire



Cross-section of 12-strand Rutherford cable . Each strand is monocore



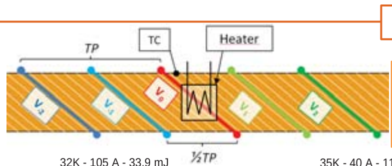
In **configuration 1** voltage taps were placed every half-***twist pitch*** (*TP/2*). Time delay between voltages V_{-1} and V_{-2} and V_1 and V_2 were used to estimate quench propagation velocities. In **configuration 2**, the separation between voltage taps was lower than *TP/2*.

I-V curve could not be measured for this cable. Instead, quench current, **Iq (T)**, was defined as the current that induces a quench without any external heat source (in self-field). It is always above local Ic.

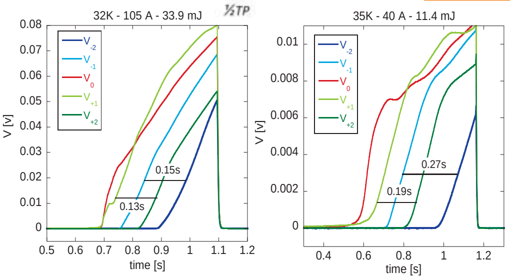
Measurements were done at 32 K and 35 K.

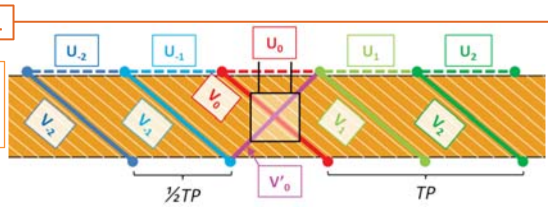
Different voltage taps configurations were used.

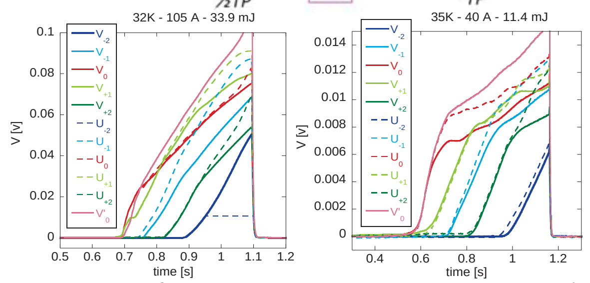
Configuration 1



Tests for *I*= 0.6 I_q(T)
T = 32 K, I_q=175 *A*
T = 35 K, I_q=69 A







<u>Quench development is not symmetric</u> around the heater.

In some conditions, V_1 signal starts at the same time than V_0 (which measures voltage of the strand placed under the heater).

This suggests that some parts of this cable (in the right part of the heater) would have lower I_c.

Estimated quench propagation velocities (v_p) in [cm/s]

	***T* = 32 K**	***T* = 35 K**
I = 0.6 Iq	10.0-10.1	5.6- 6.8
I = 0.7 Iq	10.1-12.7	6.4-7.4

Voltages measured for the same conditions, but here also voltages U_i (see scheme) are plotted.

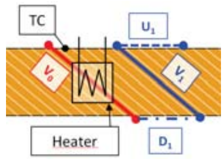
V'_0, which measures the voltage of the strand in the opposite face of the cable, beneath the heater, is similar to V_0, but slightly higher (longer length).

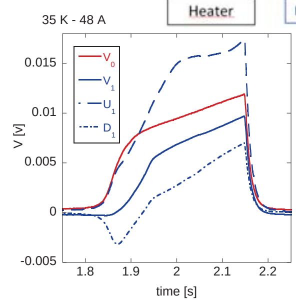
In this configuration, measured "*intra-strand*" voltages, V_i, and corresponding "*inter-strand*" voltages , U_i, are similar but not equal.

Under these conditions maximum temperatures registered by TC were: 64.8 K at 32K test and 47.7K at 35K. *Note:* U_{-2} signal at 32K test saturates at t>0.95s.

Configuration 2

Test at 35K
0.7 Iq(T) = 48 A





For this voltage-tap configuration, large differences were observed between measured voltages U_1, V_1 and D_1.

This is caused by inhomogeneous local I-V characteristics among strands in this area. Current sharing between strands is difficult due to the high electrical contact resistance between strands in this cable.

Conclusions

We have analysed experimentally the thermal and electrical behaviour of different MgB_2 Rutherford cables under hot-spot conditions. The quench behaviour strongly depends on the metal sheath.

Cable consisting of strands of multifilamentary Cu-sheathed wires has very low *n*-value, which is also measured for the individual wires. So, it is not caused by damage during cable assembling.
Low n-values together with high thermal conductivity of the Cu-sheath make this cable very stable against local thermal disturbances and it is difficult to trigger a quench.

Cable made with Cu10Ni-sheathed monocore wires presents some inhomogeneities in the local I-V of the different strands in some parts of the cable.
Different voltage-tap configurations have been analysed to understand the quench development and propagation in this cable. More experiments are currently underway.

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