HiLumi LHC

FP7 High Luminosity Large Hadron Collider Design Study

Scientific / Technical Note

Quench property of twisted-pair MgB2 superconducting cables in helium gas

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Quench property of twisted-pair MgB_2 superconducting cables in helium gas

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CERN's twisted-pair superconducting cable is a novel design which offers filament transposition, low cable inductance, and is particularly suited for tape conductors such as 2G YBCO coated conductors, Ag-sheathed Bi2223 tapes and Ni/Monel sheathed MgB_2 tapes. Typical design of such twisted-pair cables consists of multiple superconducting tapes intercalated with thin copper tapes as additional stabilisers. The copper tapes are typically not soldered to the superconducting tapes so that sufficient flexibility is retained for the twisting of the tape assembly. The electrical and thermal contacts between the copper and superconducting tapes are an important parameter for current sharing, cryogenic stability and quench propagation. Using an MgB_2 twisted-pair cable assembly manufactured at CERN, we have carried out minimum quench energy (MQE) and propagation velocity v_p measurements with point-like heat deposition localised within a tape. Furthermore, different contacts between the copper and superconductor around the hot spot have also been studied, including the co-twisted assembly in Kapton wrapping and locally soldered/separated tapes. The measurements have been performed in helium cooling gas at temperatures between 20K and 35K and with different current fractions with respect to the thermal runaway current. The results suggest a potential optimisation strategy by compromising between: a higher stabilisation with better contact between the copper and superconducting layers; and a faster propagation velocity and easier quench detection with a higher contact resistance.

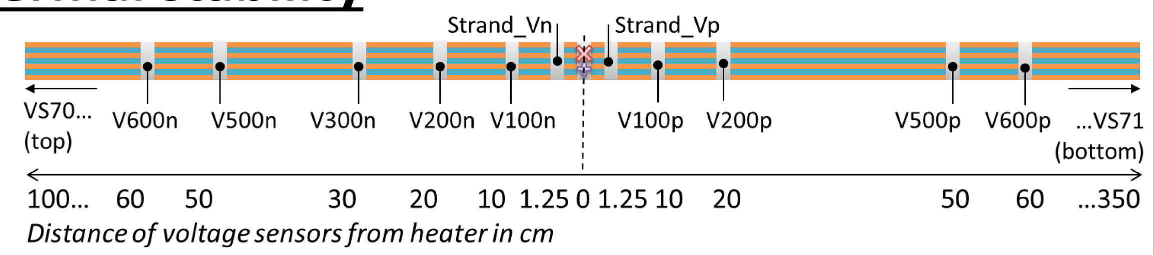
Quench Detection

Voltage measurement of stabilised and non-stabilised strands

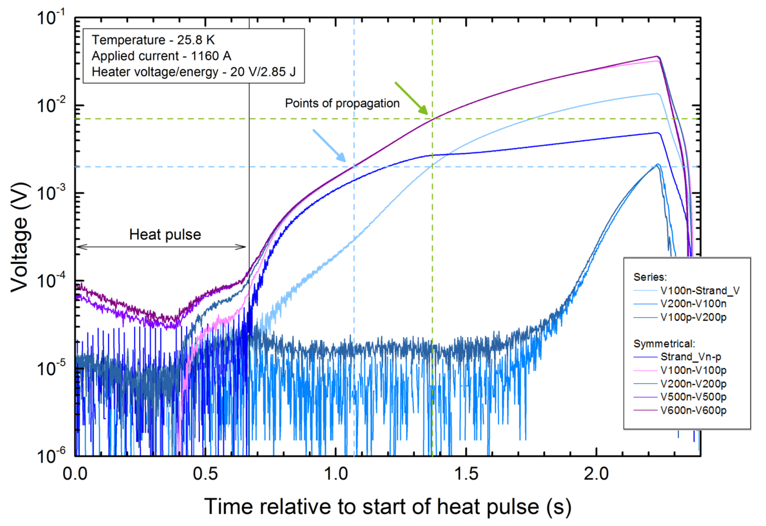
- Simultaneous recording of voltages on all/selected strands and intra/inter-pair joints; voltage profile measurement of two locally-heated strands.

Effect of increased thermal stability

- Strand #37/VS70-71: stabilised, v-taps soldered across top of all tapes.



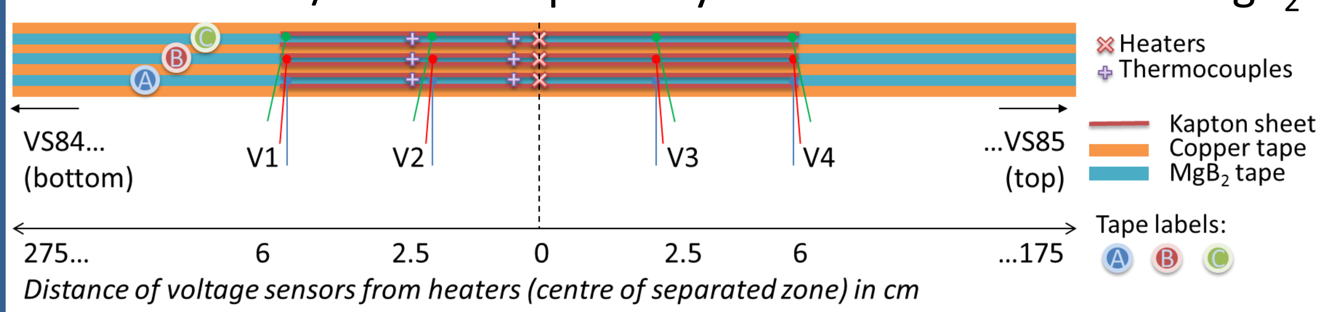
- Large scale/long length applications require high voltages in order to register quench occurrence above high noise levels.
- Increased thermal stability of 'sandwich' design leads to and maintains greater homogenisation of temperature along cable length.
- Longer time constant for strand to reach high enough temperatures to produce detectable voltages.

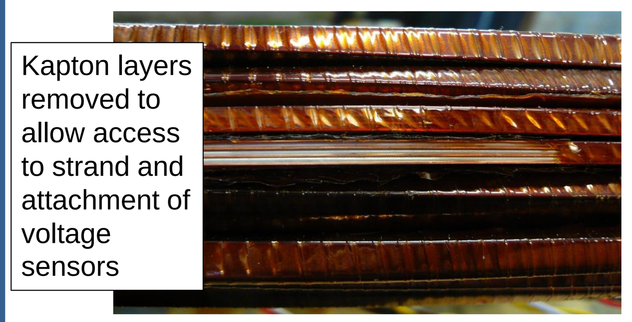


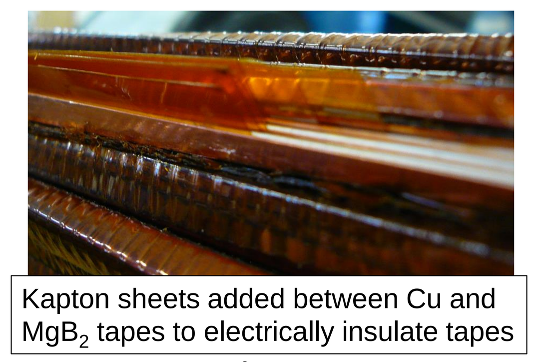
- At point at which quench propagates outside initial normal zone (potentially at blue dashed line, definitely on/before green dashed line), strand voltage measured = 7mV (although potentially only 2 mV).

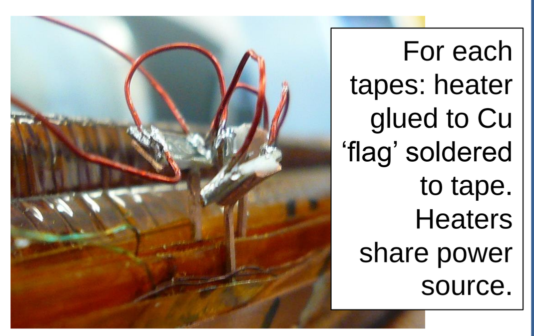
Effect of increasing contact resistance between superconducting and stabilising tapes

- Strand #44/VS84-85 – partially non-stabilised: Cu and MgB_2 tapes separated by Kapton sheets over 12 cm-long section.

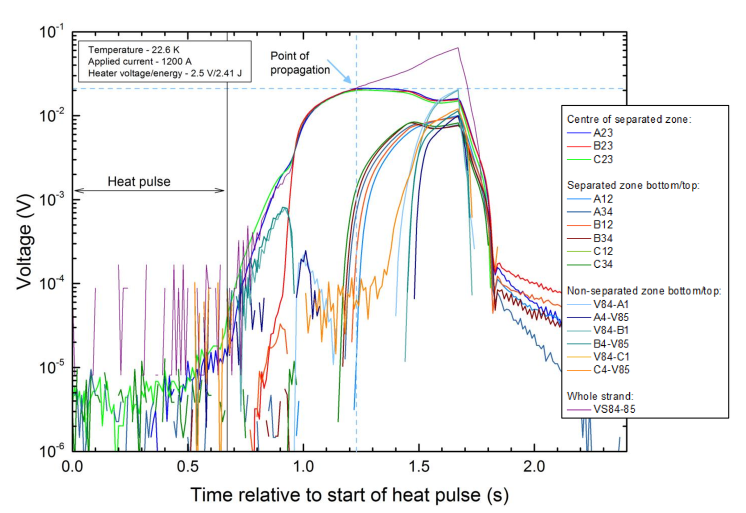








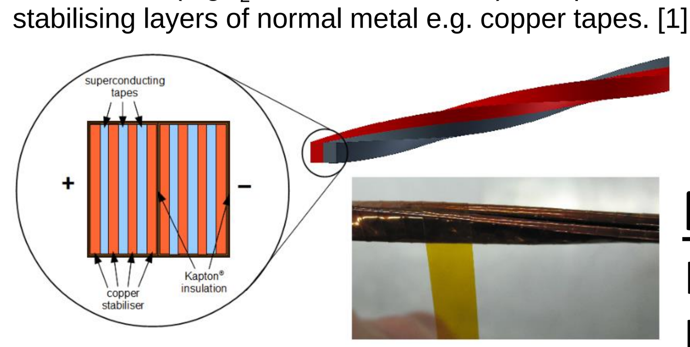
- By separating MgB_2 and copper tapes i.e. increasing to infinite contact resistance, strand voltage at point of quench propagation outside normal zone (blue dashed line) = 21 mV.
- Increase by at least factor three, potentially factor of ten.
- Cable as stable/recoverable as in fully stabilised case.



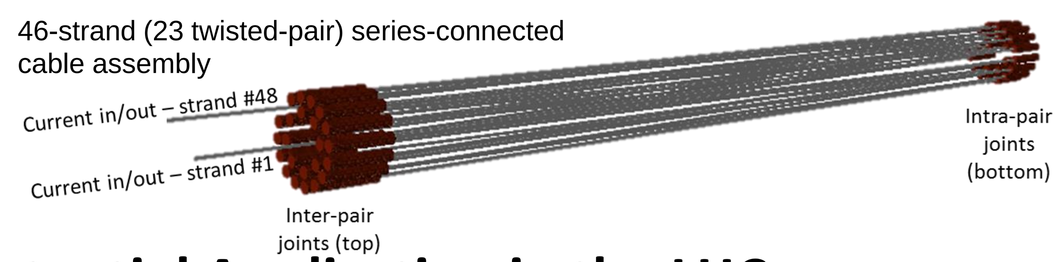
Introduction

Concept of twisted-pair cable for HTS tapes and cable assembly

Novel *twisted-pair* cable concept optimized for **tape conductors** (MgB_2, Y-123 and Bi-2223) incorporates stabilising layers of normal metal e.g. copper tapes. [1]



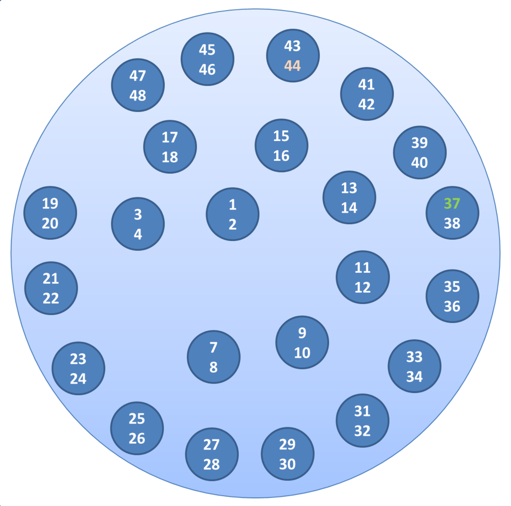
46-strand (23 twisted-pair) series-connected cable assembly



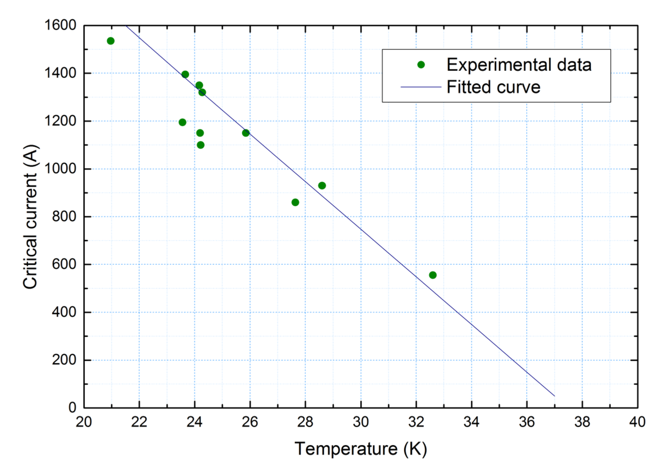
Potential Application in the LHC

Helium gas cooled superconducting bus-bar for High luminosity upgrade of Large Hadron Collider (LHC).

Cable Properties



Right: Thermal runaway current differs between strands creating I_c distribution band. Curve approximates upper limit of band.
Left: Distribution/relative positions of twisted-pairs.



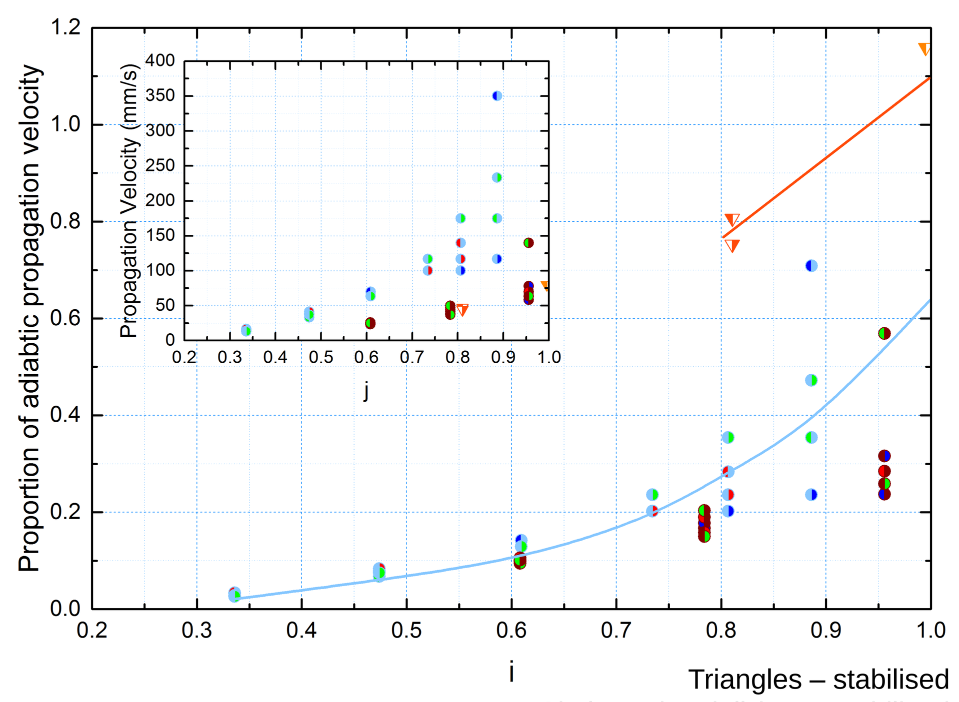
Propagation of Normal Zone

Agreement with theoretical models

- Adiabatic propagation velocity, $v_p = \frac{J}{C}\left\{\frac{\rho k}{T_{av}-T_0}\right\}^{\frac{1}{2}} = j \cdot \frac{J_C}{c_p \gamma}\left\{\frac{\rho k}{T_{av}-T_0}\right\}^{\frac{1}{2}}$ where $j = \frac{J}{J_C}$, γ is the density of the sample and $T_{av} = \frac{T_0+T_C}{2}$ when operating at the generation temperature, T_g [9].
- Reasonable agreement with this is shown on plotting $v_p / \frac{J_C}{c_p\gamma}\left\{\frac{\rho k}{T_{av}-T_0}\right\}^{\frac{1}{2}}$ as a function of j as shown below.

Fully stabilised vs (partially) non-stabilised cases

- Early indications suggest that absolute propagation velocity, shown in inset, is greater in the non-stabilised case.
- Correlates with trend: v_p generally increases as MQE decreases.
- Further values of v_p in the fully stabilised case can be generated with improved measurement method.



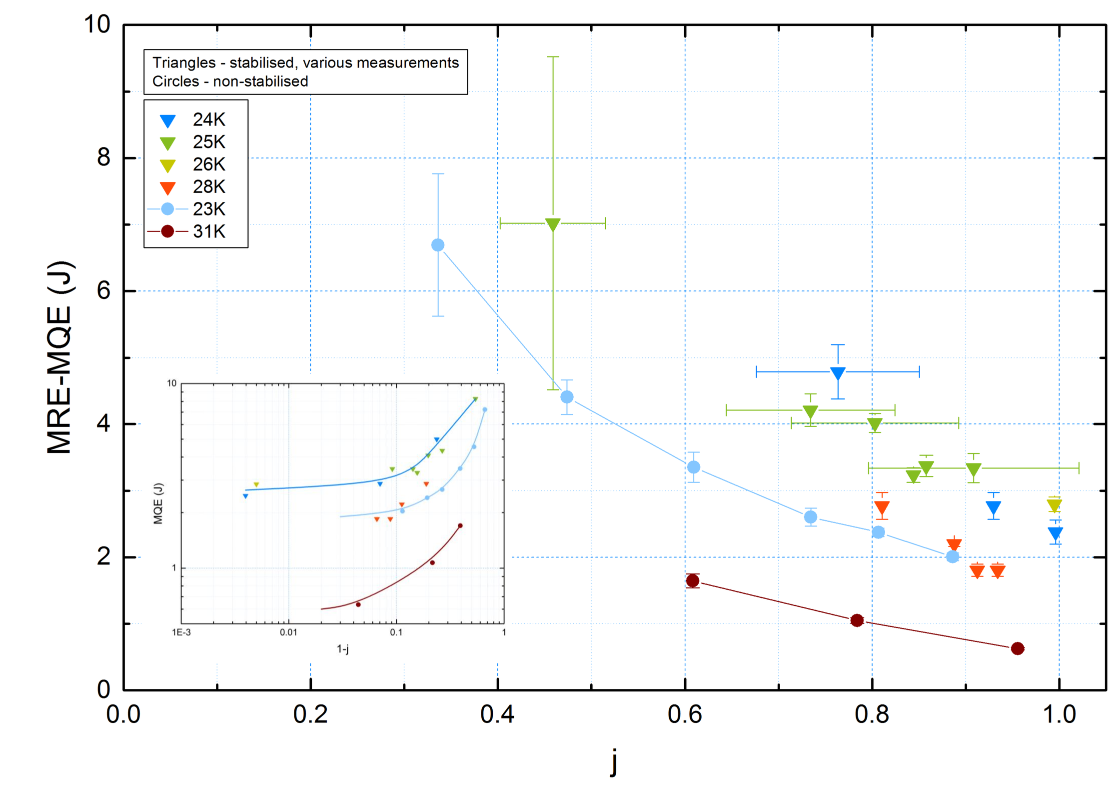
Triangles – stabilised
Circles – (partially) non-stabilised
Colour scale, blue to red – temperature, low to high
Symbol fill colour – MgB_2 tape A, B, C (non-stabilised case only)

Overall stability effect

Although it is often inversely proportional to MQE, a low v_p leads to very high temperature increase near the initial disturbance and damage to sample.

Increased Thermal Stability

- Measured minimum quench energies (MQEs) for similar MgB_2 tapes without stabilisation reported less than 2.5 J [2-3] and, more often, less than 1 J [4-8].
- Fully stabilised case MQE measured as 1.8 – 9.8 J.
- Partially non-stabilised case MQE measured as 0.2 – 7.9 J i.e. reduced compared to fully stabilised (trade-off with detectability) but still higher than previously reported values.
- MQE range (maximum recovery energy, MRE, to minimum applied energy that caused a quench) presented below.



Critical state and power law models

As shown in the graph inset, as critical current is approached, the MQE does not disappear, as predicted by the critical state model, but appears to approach a constant value, as predicted by the power law model.

Conclusions

- Further stability tests were carried out on a 23 twisted-pair cable assembly and increased thermal stability, demonstrated by higher MQE, was shown.
- However, reduced detectability in the event of thermal runaway or quench was also shown.
- By increasing the electrical and thermal resistance between the copper stabilisation and superconducting tapes a higher, and therefore more easily detected, voltage at the point of thermal runaway propagation was shown with acceptable decrease in MQE and an increase in v_p.
- It is possible that the quench voltage could be further increased within acceptable compromise of thermal stability.
- By controlling the contact resistance between the superconducting and stabilising layers of a twisted-pair cable along its length, a solution optimising for both detectability and stability may be possible.

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