8th Workshop on Mechanical and Electromagnetic Properties of Composite Superconductors

Electro-mechanical characterization of MgB_2 wires for the Superconducting Link Project at CERN

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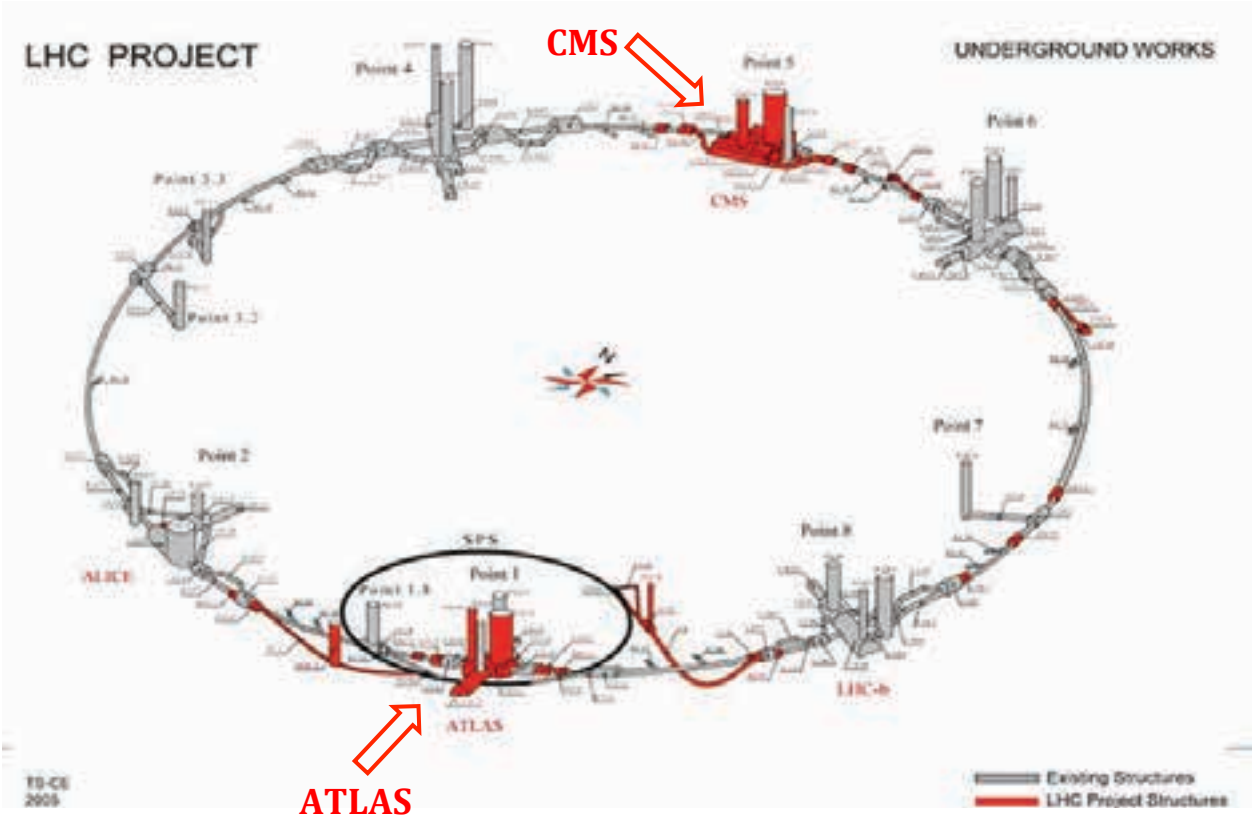
Outline

- Introduction
- MgB_2 superconducting wire
  - Microstructure
  - Mechanical characterization
  - Electro-mechanical characterization
- MgB_2 superconducting cable
  - Cable design parameters
- Conclusions

Introduction

HL-LHC (High Luminosity LHC project)

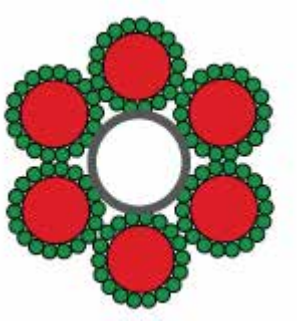
The necessity to upgrade the LHC has given rise to the HL-LHC project. HL-LHC relies on a number of key innovative technologies, representing exceptional technological challenges, such as cutting-edge 13 Tesla superconducting magnets, very compact and ultra-precise superconducting cavities for beam rotation, and between 100 and 150 m long high-power superconducting links with zero energy dissipation.



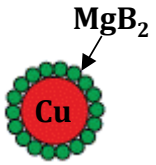
Ballarino A. (2014) Supercond. Sci. Technol. 27 044024
Rossi L. (2011) LHC upgrade plans: options and strategy Proc.

Introduction

Superconducting links for the LHC machine

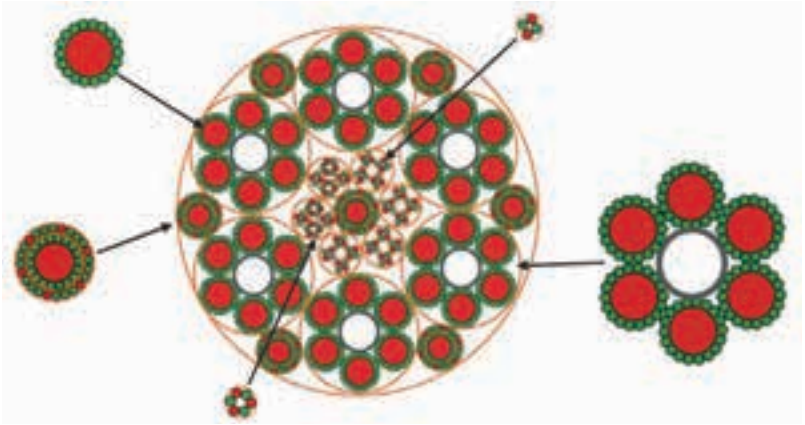


Cable of 20 kA



Sub-unit of 20 kA cable (Φ ~ 6 mm)

Cable assembly of 165 kA



Ballarino A. (2014) Supercond. Sci. Technol. 27 044024

Mechanical and electro-mechanical characterization (Why?)

Mechanical stresses due to:

- Handling during winding process
- Tension and bending
- Different thermal expansion coefficients
- Electromagnetic forces
- Mechanical stresses during installation

Degradation of the wire's superconducting behavior. The study of the mechanical properties is crucial for the proper operation of the cables.

Objective

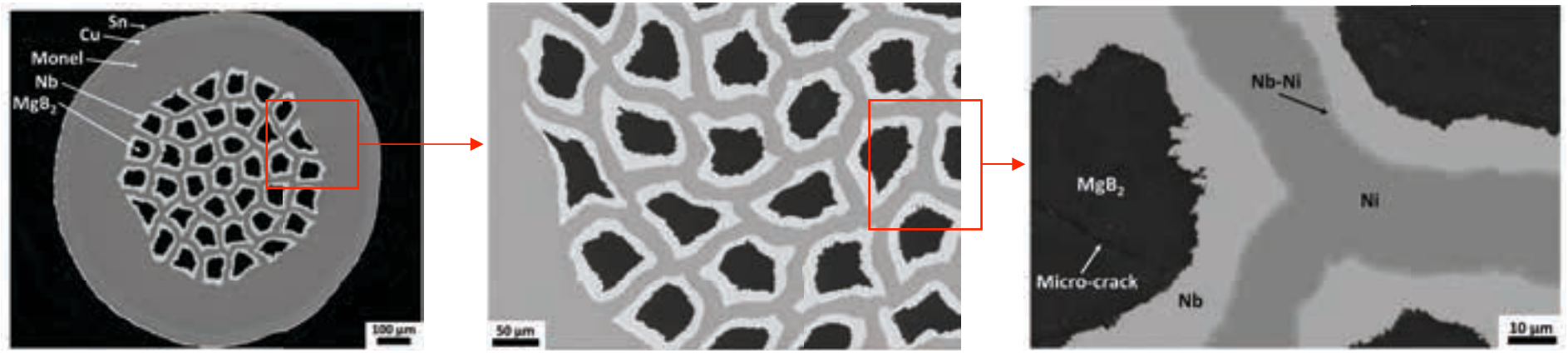
Electromechanical characterization of *ex-situ* composite MgB_2 wires at 4.2 K and in 3 T by means of a purpose built bespoke device. Calculation of the R_b and T_p for the preparation of the sub-units of 20 kA cable and study of the I_C degradation of extracted MgB_2 strands from the cable.

MgB_2 superconducting wire

Microstructure

Diameter	Filaments	Filament size	MgB_2	Nb	Ni	Nb-Ni	Monel	Cu
1.0 mm	37	55 µm	10%	8%	14%	4%	48%	16%

Alknes P. et al. to be submitted.



- Concentric distribution of the MgB_2 filaments
- Nb-Ni reaction layer of ~ 2µm
- No connection between the MgB_2 filaments
- Microcracks in the MgB_2 filaments

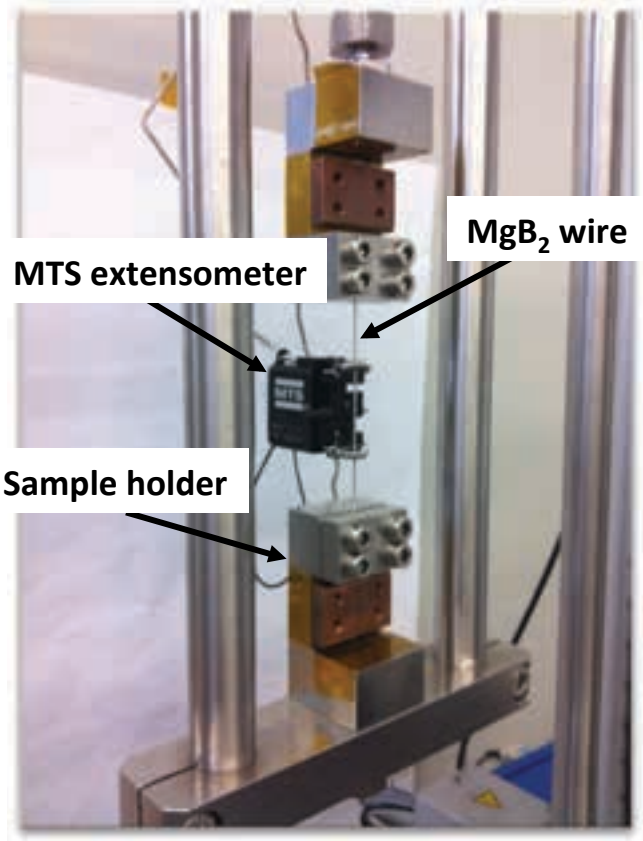
MgB_2 superconducting wire

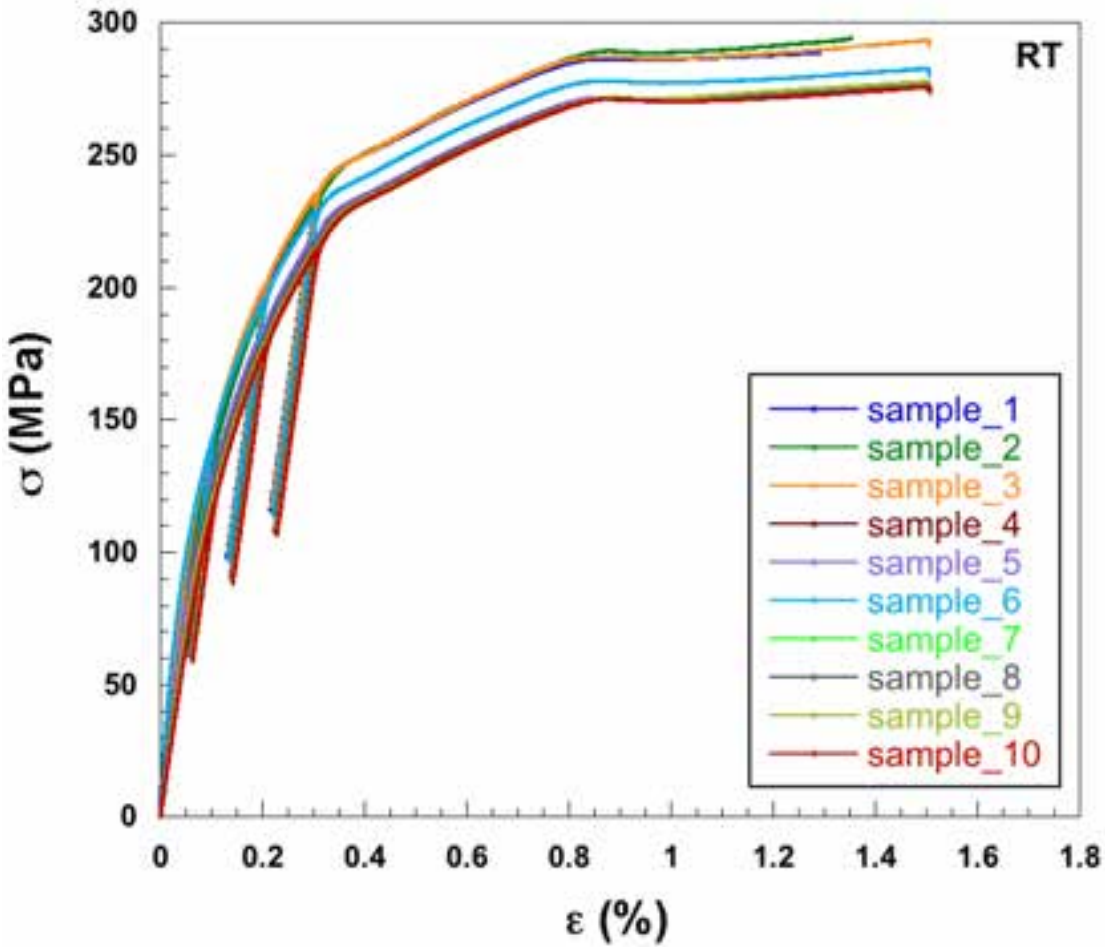
Mechanical characterization

Tensile tests at RT

E (GPa)	$\sigma_{y,\,0.2\%}$ (MPa)
151 ± 2	244 ± 3

Experimental set-up at RT





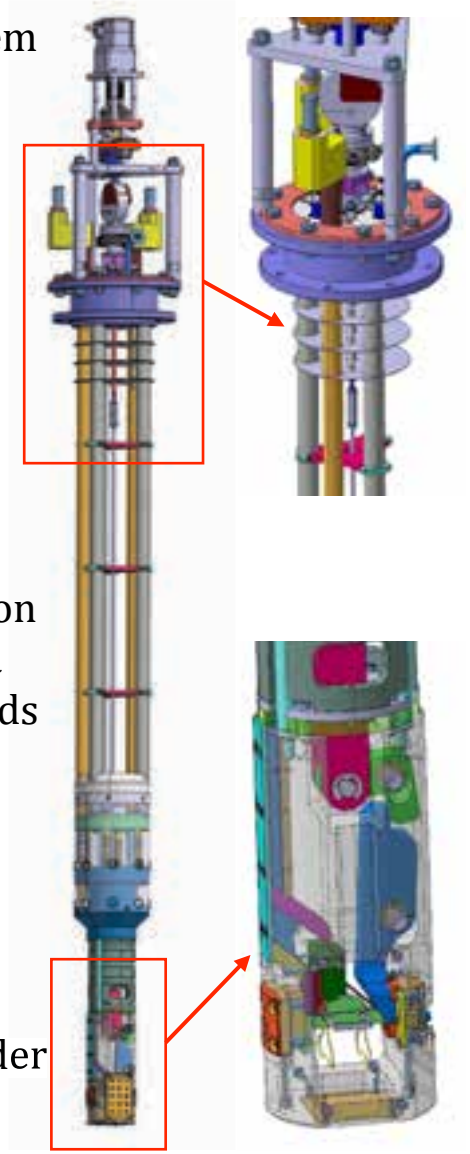
MgB_2 superconducting wire

Electromechanical characterization

Motor system
Load cell
5 kN

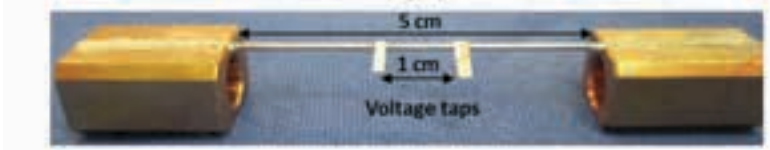
Force transmission system & current leads

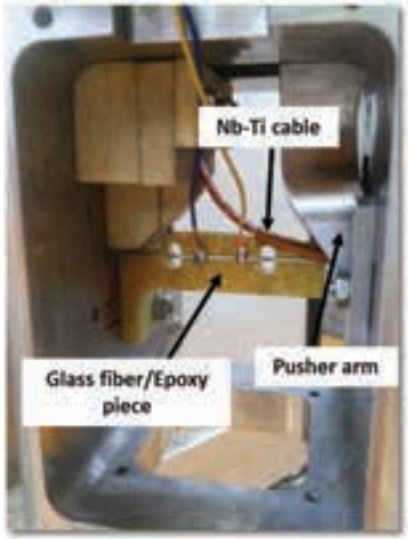
Sample holder



Custom made device for the study of the I_C-ε dependence LTS wires at 4.2 K in perpendicular external field up to 13 T

- I_C measurement
- Strain measurement
- Imax = 2 kA
- B range = 1-13 T
- Sample's length = 90 mm
- Total length of the device = 2.15 m





Experimental set-up

MgB_2 superconducting wire

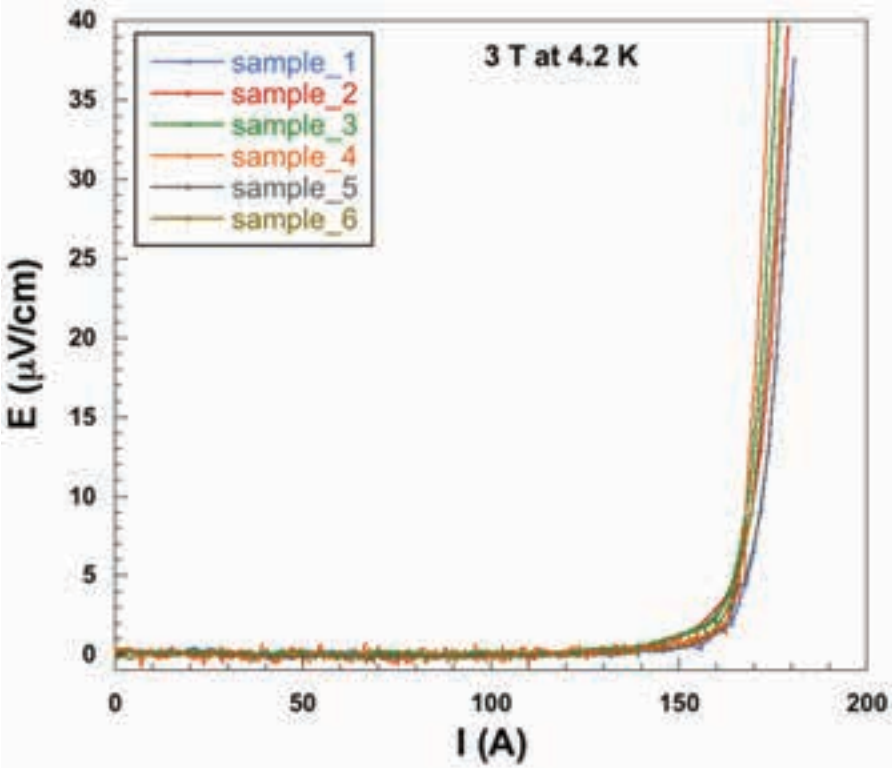
I_C measurement at 4.2 K

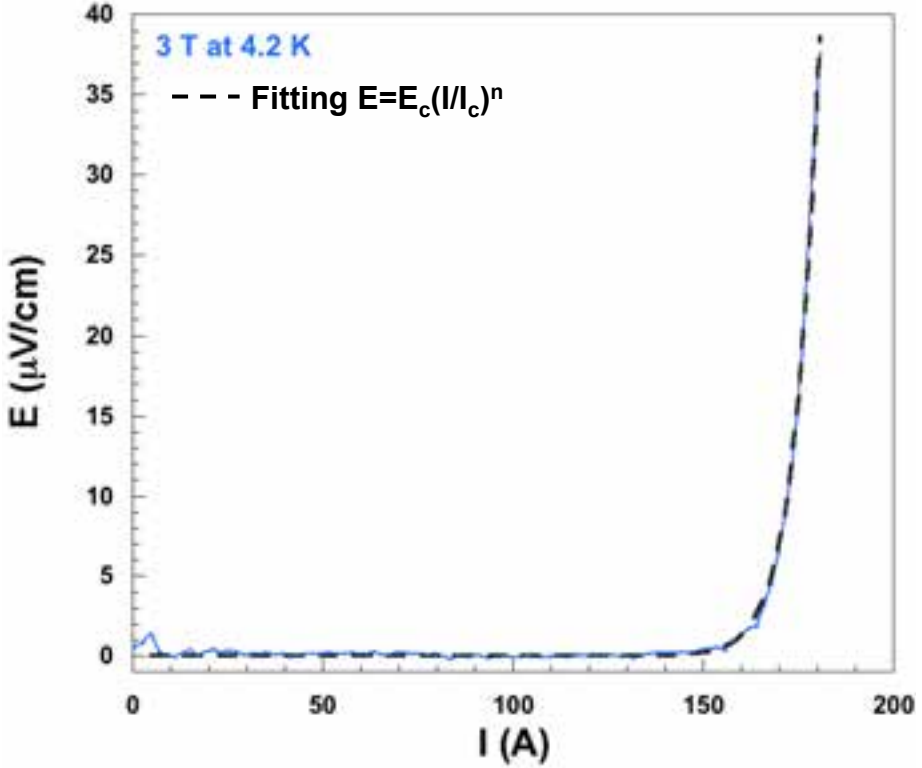
Electromechanical characterization

- I_C at 1 μV/cm
- *n*-value in the range of 5-10 μV/cm

I_C (A)	n-value
158 ± 1	29 ± 1

External field of 3 T perpendicular to the longitudinal axis of the wire



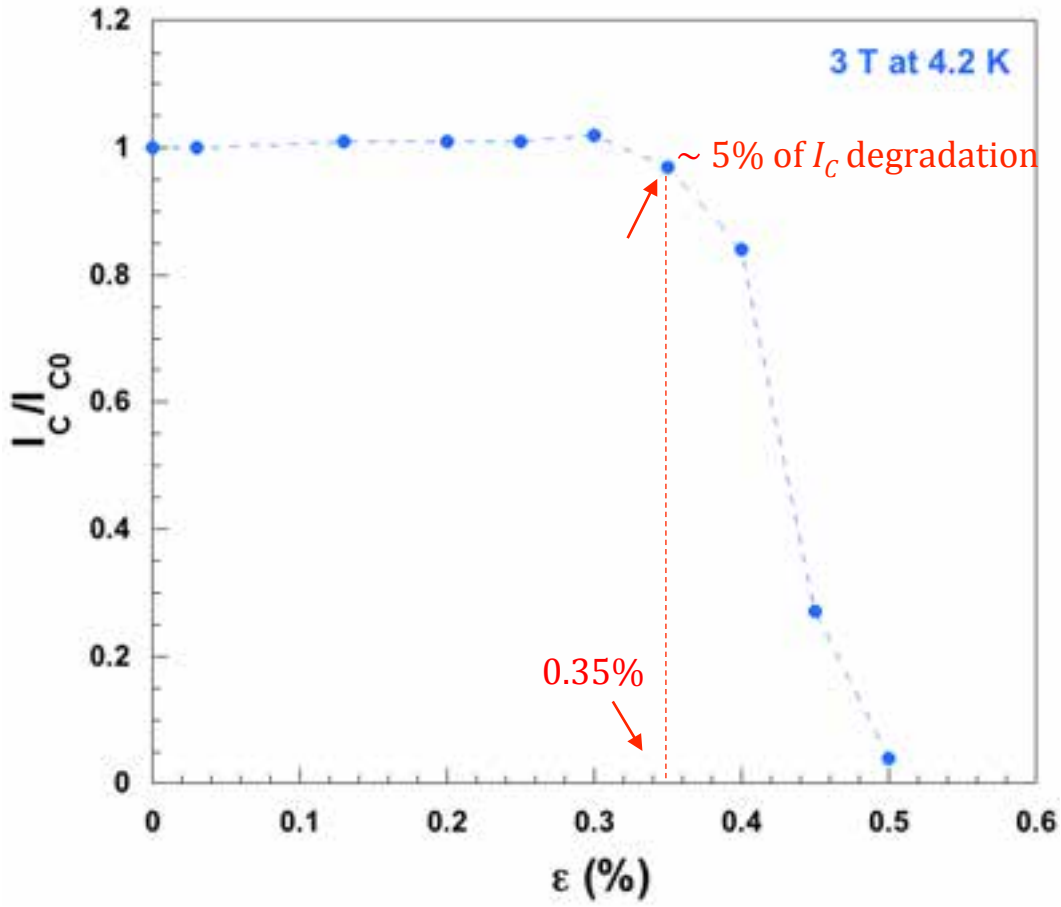


MgB_2 superconducting wire

Electromechanical characterization

Tensile test at 4.2 K

External field of 3 T perpendicular to the longitudinal axis of the wire

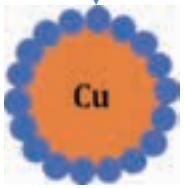


MgB_2 superconducting cable

Bending radius

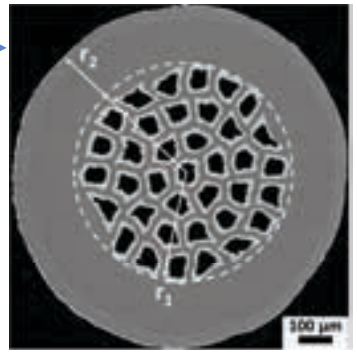
Cable design parameters - MgB_2 strand

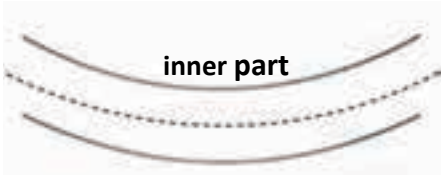
	MgB_2	Nb	Ni	Nb-Ni	Monel	Cu
E (GPa)	97	103	207	230	179	118



Cable

MgB_2 strand



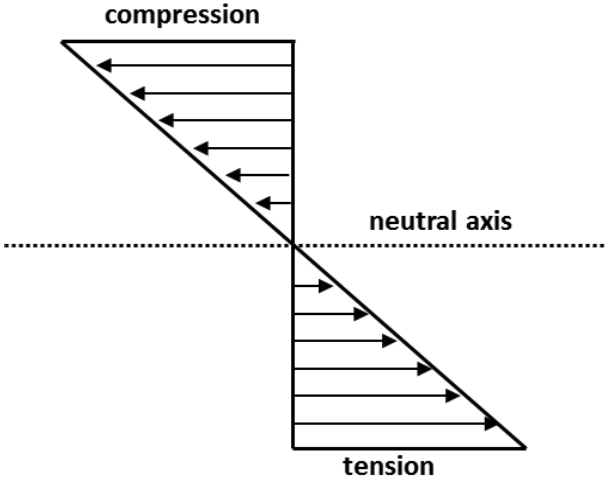


neutral axis

symmetric cross section $\varepsilon t = r1/Rb + r2$

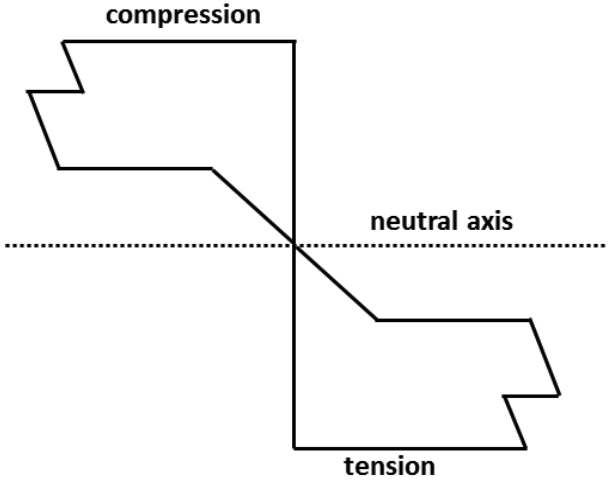
$r_1 = 0.328$ mm, $r_2 = 0.5$ mm

Linear approximation



Strain distribution

Non linear approximation

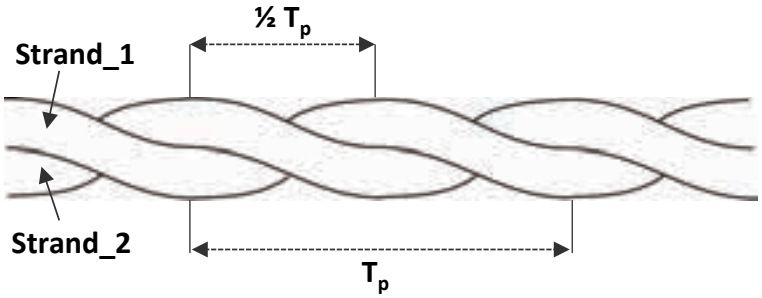


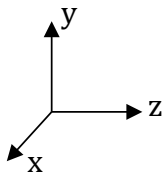
Stress distribution

MgB_2 superconducting cable

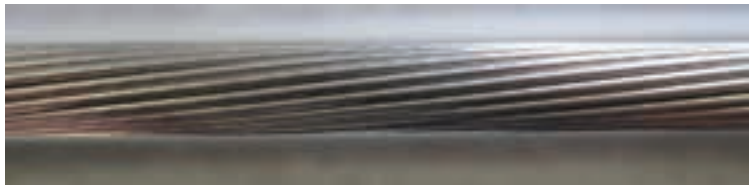
Twist pitch

Cable design parameters - MgB_2 strand





Cable (Cu core and 18 MgB_2 strands)



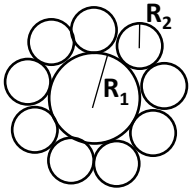
$$K = a/a2 + b2$$

$$a = R'' = R1 + R2$$

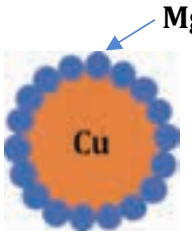
$$K = 1/Rb$$

$$x(\theta) = a\cos(\theta)$$
$$y(\theta) = a\sin(\theta)$$
$$z(\theta) = b\theta$$

$$b = Tp/2\pi$$



Twist pitch (T_p) of a helix is the width of one complete helix turn, measured parallel to the axis of the helix (z axis).



R_{Cu} (mm)	$r_{MgB_2\ wire}$ (mm)
1.95	0.5

$$T_p = \sqrt{4\pi^2[(R'' * R_b) - R''^2]} \qquad R'' = R_{Cu} + r_{MgB_2,\ wire}$$

Kline M. (1998) Calculus: An intuitive and physical approach, 2nd edition.
Costello G. A. (1997) Theory of wire rope, 2nd edition, Springer Science, New

MgB_2 superconducting cable

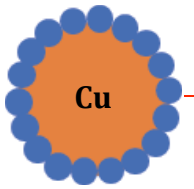
Cable design parameters - MgB_2 strand

ε_t (%)	R_b (mm)	T_p (mm)
0.05	656	252
0.1	328	177
0.15	218	144
0.2	164	125
0.25	131	111
0.3	109	101

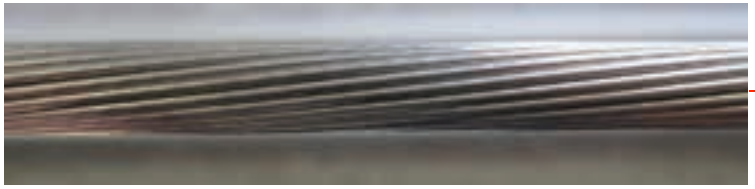
200 mm

170 mm

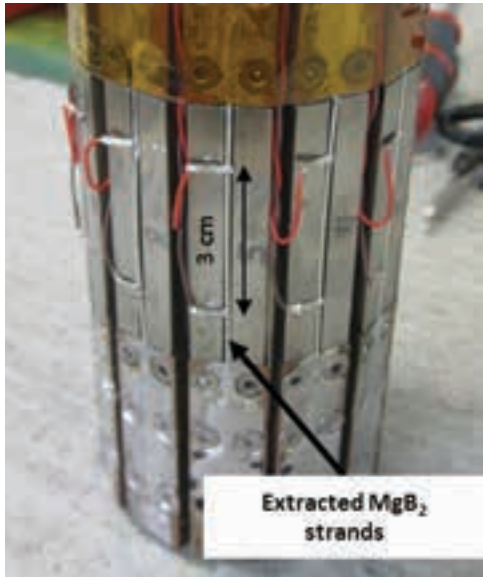
Preparation of one meter long cable with T_p of 170 mm and 200 mm



Cable



Cable



MgB_2 superconducting cable

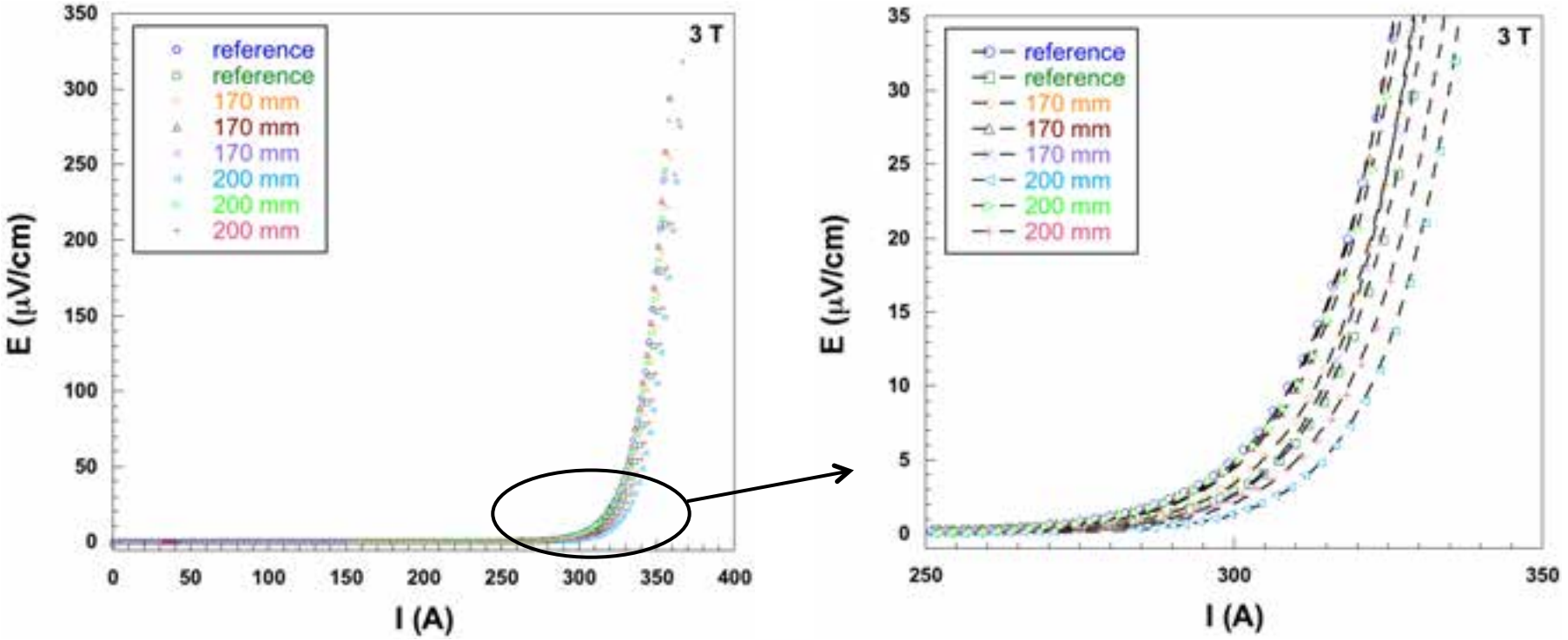
I_C measurement at 4.2 K

Electromechanical characterization of extracted strands

- I_c at 1 μV/cm
- *n*-value in the range of 5-10 μV/cm

T_p (mm)	I_C (A)	n-value
reference	288 ± 2	26 ± 1
170	286 ± 2	25 ± 1
200	289 ± 3	26 ± 1

External field of 3 T parallel to the longitudinal axis of the wire



Conclusions

- A bespoke device was designed and built up for the study of the I_C-ε dependence of superconducting wires. The current capacity is up to 2 kA and external field up to 13 T can be applied perpendicular to the wire.

- The ε_{crit} of a MgB_2 wire was obtained by means of tensile tests at 4.2 K and in 3 T external field applied perpendicular to the longitudinal axis of the wire.

- The R_b and T_p limits of the MgB_2 strands were estimated for a superconducting cable configuration (Cu core and 18 MgB_2 strands) taking into account the mechanical performance of the MgB_2 wire at RT and 4.2 K.

- One meter long cable was prepared with two different T_p: 170 mm and 200 mm. The I_C of extracted strands was measured at 4.2 K and in 3 T external field applied parallel to the longitudinal axis of the strand. No I_C degradation was found up to 170 mm of T_p.

Thank you for your attention

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