HFM
High Field Magnets

Modelisation of impregnated Nb_3Sn cable composite at CIEMAT

Jesús A. García Matos, Carla Martins, Fernando Toral

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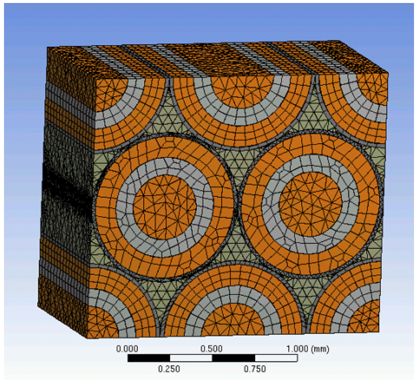
Outline

- Previous experience (NbTi)
  - Cyclotron AMIT
  - MCBXF
- Approach foreseen for Nb_3Sn cables
- Conclusions

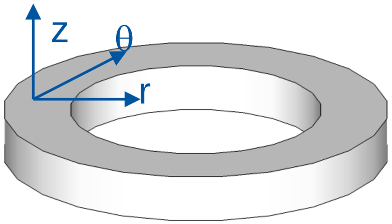
Previous experience (NbTi): Cyclotron AMIT

Cable smeared properties obtained through FEA



Winding smeared-out properties (4.2 k)

	Young's modulus [Gpa]	Poisson ratio	Shear modulus[Gpa]	Integrated contraction @296-4.2K [mm/m]
θ	94			2.99
r	35			3.90
z	35			3.93
rθ		0.08		
zθ		0.08		
rz		0.35	24	

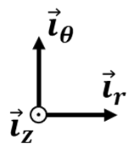


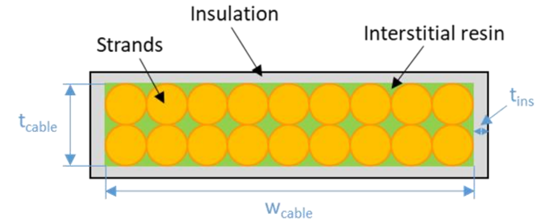
Courtesy J. Munilla, CIEMAT

J. Munilla, 'Development of a novel concept of efficient superconducting magnet for radioisotope production cyclotron', Universidad Pontificia de Comillas, Madrid, 2020.

Previous experience (NbTi): MCBXF cable

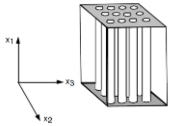
Smeared properties obtained analytically (law of materials)





$$E_{thickmix} = \frac{t_{cable} + 2t_{ins}}{\left\{\frac{t_{cable}}{E_{T,cable}} + \frac{2t_{ins}}{E_{ins}}\right\}} = 20.1/26.1\ GPa$$

$$E_\theta = \frac{E_{thickmix} w_{cable} + E_{ins} 2t_{ins}}{\{w_{cable} + 2t_{ins}\}} = 19.7/25.8\ GPa$$



Parts	Material	E [GPa]	υ [-]	Secant coefficient of thermal expansion [10^{-5}/K]	Integrated contraction (295/4 K) ε_{int} [mm/m]
Strand	Cu + NbTi	110(Transverse) 114(Longitudinal)	0.381	0.92	2.68
Epoxy resin	Cured CTD-101K	4/5	0.37/0.4	4.14	12.05
Impregnated insulation	CTD-101K + S2 Glass	13/20	0.35	3.1	9

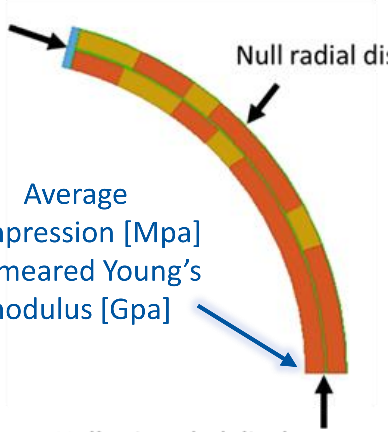
Property	Nomenclature	Value (295/4 K))	Units
Young's modulus (Radial)	E_r	**20.7/26.2**	GPa
Young's modulus (Azimuthal)	E_θ	**19.7/25.8**	GPa
Young's modulus (Longitudinal)	E_z	72.4/74.5	GPa
Secant coefficient of thermal expansion (Azimuthal)		1.44	10^{-5}/K
Integrated contraction	$\varepsilon_{int,Cables}$	**4.19**	mm/m

J. Á. García-Matos, 'Nested Cos-Theta Superconducting Accelerator Dipoles with High Radiation Resistance: Application to the HL-LHC Orbit Correctors', PhD, E.T.S.I. Industriales (UPM), 2022. doi: 10.20868/UPM.thesis.72080.

Previous experience (NbTi): MCBXF coils

Smeared properties obtained trough FEA (+ analytical cross-check)

- Assume **20/20 GPa** (295/4K) due to experimental results and safety margin for preload calculations.
- Smeared azimuthal stiffness of the impregnated coil was 29 GPa (FEA)
- Due to convergence issues (low Young's modulus of the Kapton), ground insulation is included in the mix, yielding **25 GPa, 4.22 mm/m**



Parts	Material	E [GPa]	υ [-]	Secant coefficient of thermal expansion $[10^{-5}/K]$	Integrated contraction (295/4 K) ε_{int} [mm/m]
Coil block (smeared)	Impr. & ins. cables	**20/20**	0.35	1.44	4.19
Wedges	Cu-ETP	127/138	0.344/0.338	1.064	3.1
Interlayer & outer insulation	Impregnated Nomex®/S2-glass	13/20	0.35	3.1	9
Loading plates	Stainless steel	196/210	0.3	0.997	2.9

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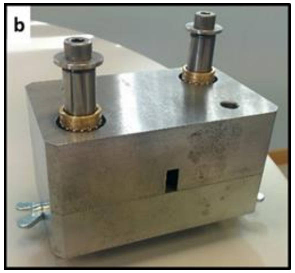
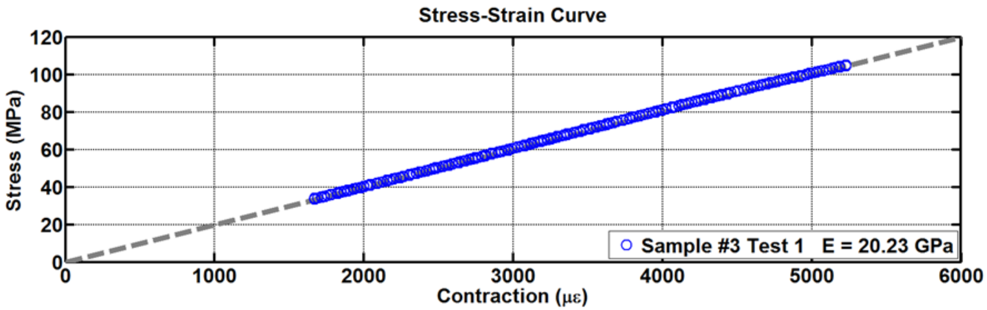
Previous experience (NbTi): MCBXF empiric validation

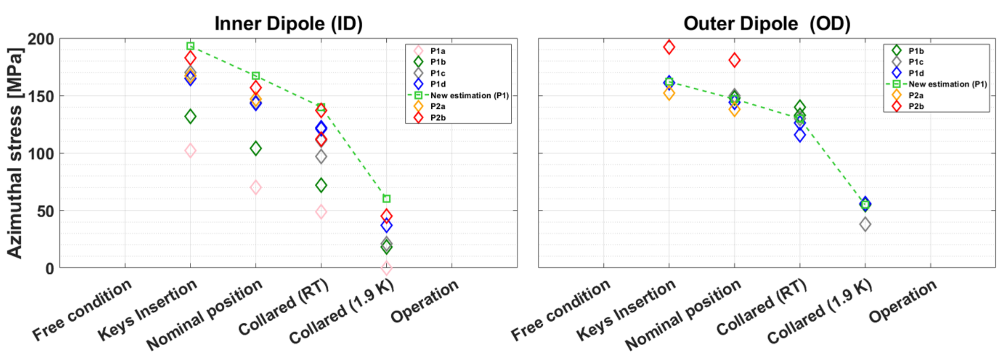


Ten-stack compression test:

20 GPa impregnated cable (RT)



Power tests: Coil = 23-24 GPa, 5.8 mm/m



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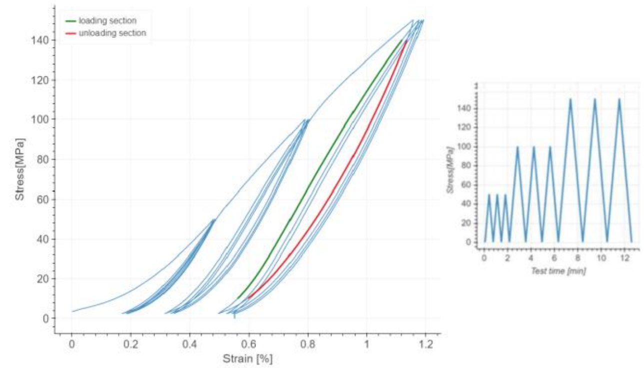
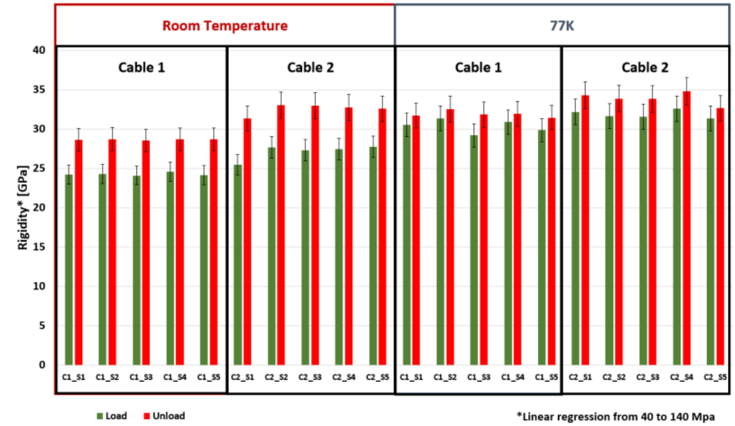


Compressive tests at RT and 77 K:

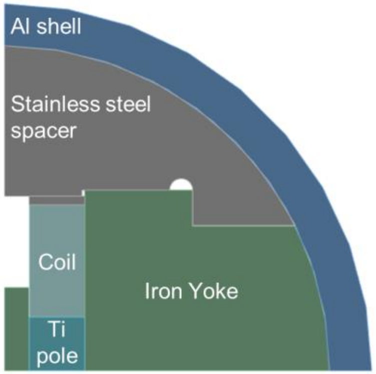
Slightly higher stiffness but close to the previous results using linear regression despite non-linearity.



Ó. Sacristán, 'MCBXF Magnet Cablestack Compressive Tests at Room Temperature and 77K', CERN, EDMS 2706612, Mar. 2021. [Online]. Available: https://edms.cern.ch/document/2706612/1

Approach foreseen for Nb_3Sn cables

- Early stages of the simulations due to parallel activities.
- Combination of previous analytical and FEA approaches will be explored to obtained the smeared properties of the cable.
- ISAAC, using RMCs made with well-known MQXF cable, will help to find the proper approach for the cable of the future 14 T common coil demonstrator.



ISAAC (**I**nvestigating **S**uperconducting **A**ssembly to **A**dress **C**ommon coil mechanics)

Conclusions

- Validated experiences with NbTi using analitycal and FEA approaches for the Young's Modulus. Some uncertainties in thermal contraction.
- Similar approaches will be applied to Nb_3Sn cables, taking advantage of well-known MQXF strands as first step on ISAAC.

Thanks for your attention