MT25

Lessons learnt by manufacturing > 100 km of varied type of Cable-in-Conduit-Conductors

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who we are

Italian Consortium for Applied Superconductivity

- **ENEA:** *know-how on* superconducting materials, cables, magnets
- **TRATOS:** cabling and winding technologies
- **CRIOTEC:** cryogenics, welding techniques, engineering

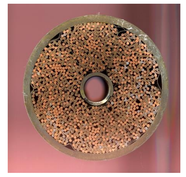
what we've done so far

Wide range of CICCs:

- Nb_3Sn, NbTi, MgB_2, ReBCO;
- Very large (DEMO TF) to relatively small (NAFASSY);
- Final rectangular or round shape;
- Al-coextruded structures;
- Round or Circle-in-Square tubes;
- Long and Short twist pitch cables;
- Central or distributed cooling channel;
- Short samples or 800 m Unit Lengths.

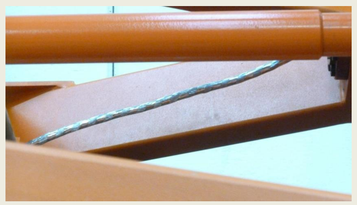
FUSION FOR ENERGY	Europe	2010	Supply of ITER TF conductors, ITER PF1/6 conductors and JT-60SA TF conductors	~ 72 km
NFRI	South Korea Rep.	2011-2014	All the Korean portion of the ITER TF conductor supply (jack. only)	~ 20 km
iter	International Body (France)	2012-2013	8 x ITER CS samples for the "crash-program"	
VNIIKP	Russian Federation	2013-2015	Manufacturing of 3 ITER PF samples for test in the SULTAN facility	
	Italy	2013	Manufacturing of Nb_3Sn CIC conductors for the NAFASSY large bore magnet	~ 2.5 km
HFML	The Netherlands	2014	Manufacturing of Nb_3Sn CIC conductors for the 45T Hybrid Magnet project	~ 5 km
Ioiswire	South Korea Rep.	2014-2015	Manufacturing of 1 x ITER TF conductor (jacketing only)	~ 0.8 km
NFRI	South Korea Rep.	2015	6 ITER TF conductors supply	~ 4.5 km
ENEA	Italy	2016	Manufacturing of 6 x JT-60SA TF additional lengths	~ 1.5 km
ENEA EUROfusion	Italy	2016	Manufacturing of Nb_3SN Samples for EU-DEMO TF Coils	
	International Body (Switzerland)	2016-2017	Manufacturing of MgB_2 sub-cables for the SC links (LHC/Hi-Lumi project)	
iter	International Body (France)	2017	ITER In-Vessel coils Conductors	
			TOTAL > 105 km	

our CICC production zoo



Short samples vs. long length production

CABLING: short samples may not be **fully representative** of manufacturing process on large-size industrial machines, owing to: Cu-to-s.c. transition regions, stresses distribution and relaxation, etc.



SQUARE TO SQUARE

JACKETING: the **flow of material** within the conductor cross-section during the lamination process is influenced by the cable-jacket engagement.

Cabling is a standard process, but handling of superconductor is not

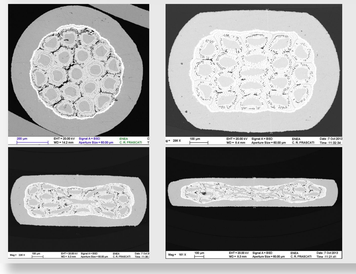
In principle, cabling SC is a standard process for any cabling company. BUT **handling of SC wire** requires adequate skills and attitude (*mechanical stress limits; full traceability; relatively short unit lengths; management of leftovers; no joints and no breakages allowed; etc.).*

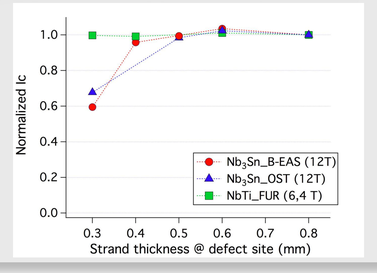
In addition, the **risk in cabling SC** is high in term of money and compared with transformation cost, so that a very specific control system and manufacturing process must be put in place.

Impact of cabling process and cable layout on SC strands

Possible defects may be caused to strands during cabling, in particular when very short Twist Pitch values are chosen. **Measurements showed that only very large defects cause performance degradation.**

(R. Freda et al., "Performance Test of Superconducting Wires Subject to Heavy Deformations", http://hdl.handle.net/10840/6538)





Dummy and qualification lengths are never enough

Qualification of a conductor design and a manufacturing process can only be conclusively assessed by the **manufacture of a complete unit length** using the **actual material**.

The successful accomplishment of **QA/QC programs** (as *e.g.* those demanded by ITER Organization) ensure conductor production uniformity and full traceability of intermediate assemblies across numerous suppliers.

How to keep industry involved?

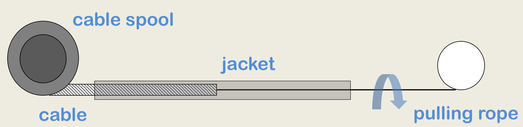
transfer of know-how from applied research to industry, leading to the set-up of production lines for CICCs in kilometric scale for large experiments as ITER, JT60-SA.
Challenge: keep up the cabling and jacketing lines after that ITER procurement is over. Build-up and expertise, as well as confidence from industry to research have to be maintained to grant continuity for future purposes.
Is it a real business?

Connect industry & applied research

Industrial expertise is highly effective during conceptual phase to find the best and simplest manufacturing solution for innovative CICC design, thus avoiding useless and time consuming prototyping iterations.

Cable Insertion can partially affect last stage TP

When inserting long (400 m or higher) cables into jacket assemblies, large pulling forces in combination with large friction factors may easily cause **rotation of the cables**.



A **twist pitch elongation** at cable head is thus often found and may exceed nominal tolerances. This is an aspect which has been subject of several publications in the last years, especially concerning CICC procurement for ITER.

THE LESSON – FLEXIBILITY

Manufacturing **flexibility** plays a key role.

- address technical issues on a case-by-case basis.
- manage unpredictable obstacles arising in the conversion of conductor design to prototype and then to actual production unit length