Superconducting Detector Magnet Workshop

12–14 Sept 2022
CERN

Cable-in-Conduit Conductor (CICC) experience in ITER

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CICC Compact History

Original ‘true’ CICC produced and tested in 1970s by MIT (Mitch Hoenig, Yuki Iwasa, Bruce Montgomery) as a way of stabilising premature quench of NbTi. Derived from earlier work and ideas and there is evidence that it appeared more or less simultaneously in several applications……not all with the same reasons for using it

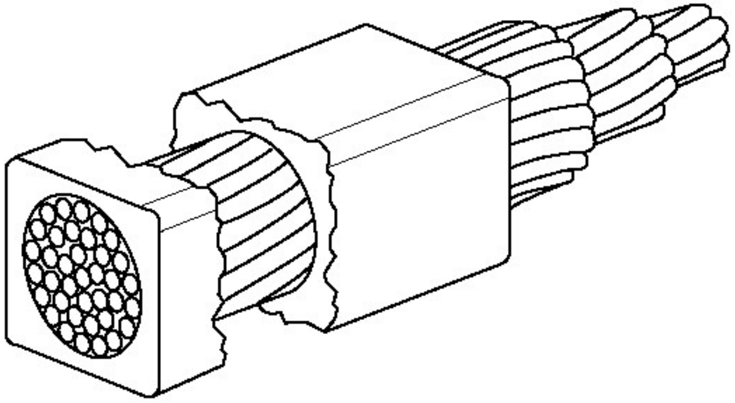
At the time, stability to small disturbances was part of the theoretical basis, with the well cooled concept being developed as a critical design parameter. Much effort spent on trying to develop/demonstrate the theory in tests in the 1990s but (my personal view) *it is not the correct basis to design CICC and leads to design distortions (incorrect role of copper stabiliser, ignores strand transition behaviour & ignores current uniformity).*

Exceptionally CICC was used by Airco for the only Nb3Sn conductor in the LCT project for the Westinghouse coil in late 1970s. This conductor…..despite many loops and diversions en route….is clearly the direct ancestor of the ITER conductors (including probably its tendency to degrade)

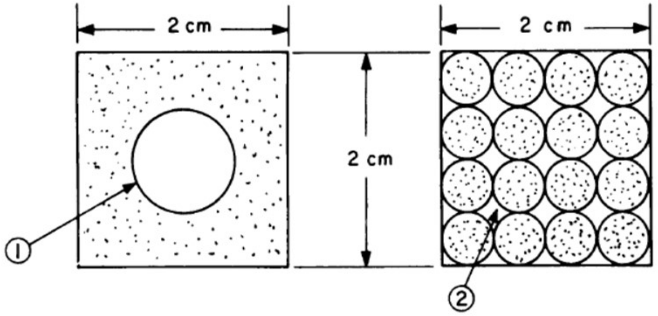
Nb3Sn CICC concept was imported to Europe by NET (Salpietro, Minervini, Mitchell) in 1980s following meetings with Mitch Hoenig, Bruce Montgomery at MIT in 1985

Much dispute 1990-92 on CICC vs Rutherford & Monolithic type conductors within Europe, resolved by 1992 in favour of CICC with ITER final circular CICC chosen in 1993 (by Paul Rebut and Bruce Montgomery)

Original CICC Design Justification



ROUND BUNDLE WITH 37 STRANDS ENCLOSED IN RECTANGULAR CONDUIT - SHOWING TRANSPOSITION OF STRANDS



HOLLOW CONDUCTOR

2 x 2 cm COPPER WITH FILAMENTARY SUPERCONDUCTOR AND 1-05 cm DIA COOLING PASSAGE

① COOLING PASSAGE

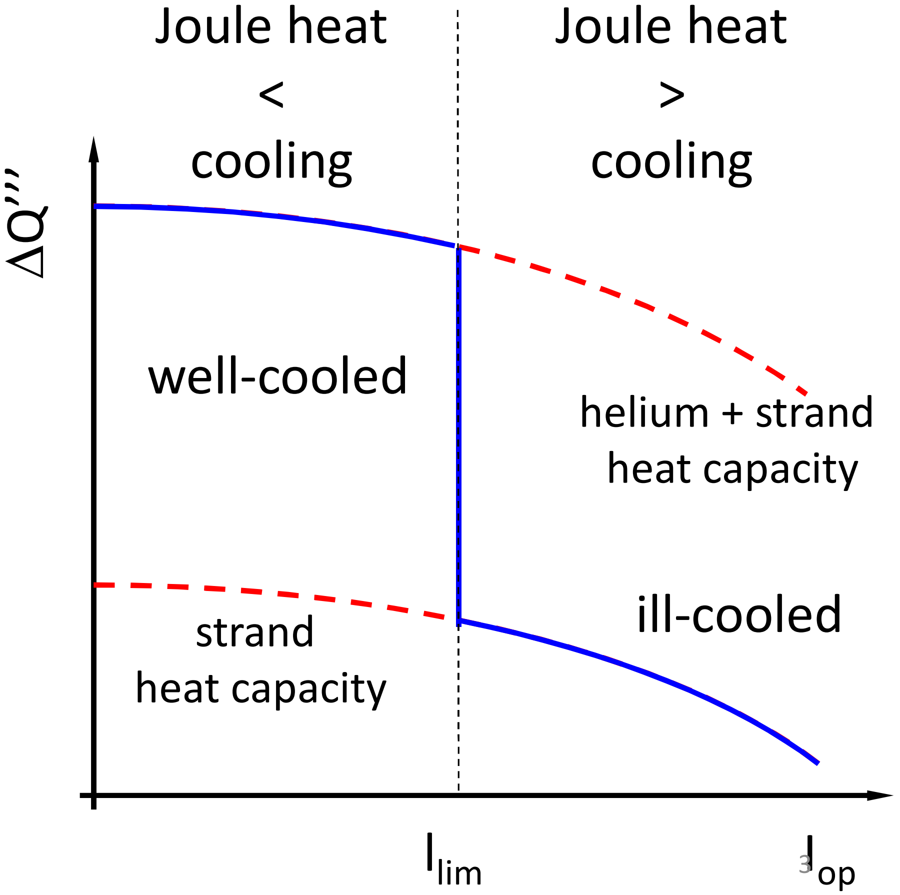
BUNDLE CONDUCTOR

2 x 2 cm HYDRAULIC ENCLOSURE WITH 16 COPPER STRANDS, 0.5 cm IN DIAMETER WITH FILAMENTARY SUPERCONDUCTOR

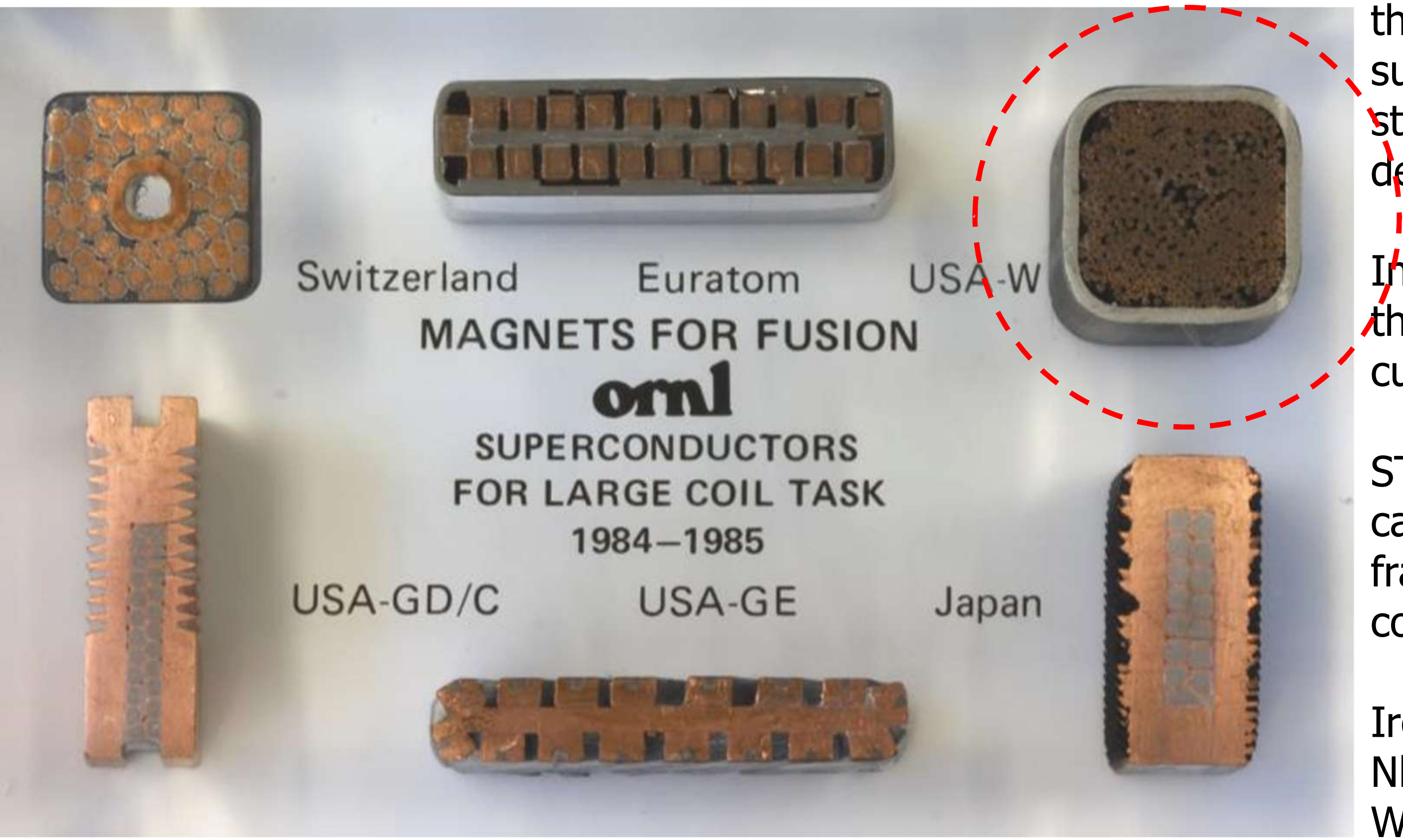
② INTERSTITIAL COOLING PASSAGES

SINGLE-PHASE HELIUM AS COOLANT FOR SUPERCONDUCTING MAGNETS*
M. O. Hoenig, Y. Iwasa, D. B. Montgomery, and M. J. Leupold

Well cooled – ill cooled theory developed in 1980s for CICC



First ITER CICC Ancestor



Rutherford cable ancestry of 2/3 of these is clear

The LCT project started in 1977 and was completed in 1988. By mid 1980s it was clear that some of the coil technologies (although successful in LCT) were not relevant for next step fusion machines but many different developments started/continued

In the early 80s Nb3Sn react and wind was the lead coil concept. Limited size (and current) to keep low strain on Nb3Sn

STRAIN as a cause of LOSS of critical current capacity (due to lattice distortion not fracture) was dominant focus of 1980s conductor design, along with R&W vs W&R

Ironically nearly 40 years later our base Nb3Sn conductor is quite similar to the USA-Westinghouse…..*and has the same resistive behavior (low n) that was seen as a cause for failure in the 1980s*

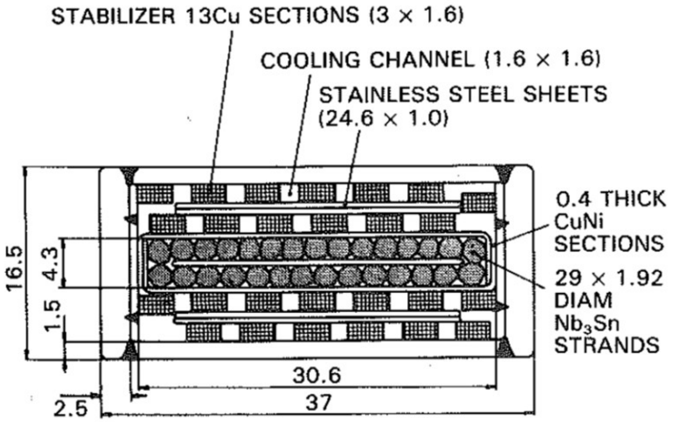
NET TF Conductor Options 1988

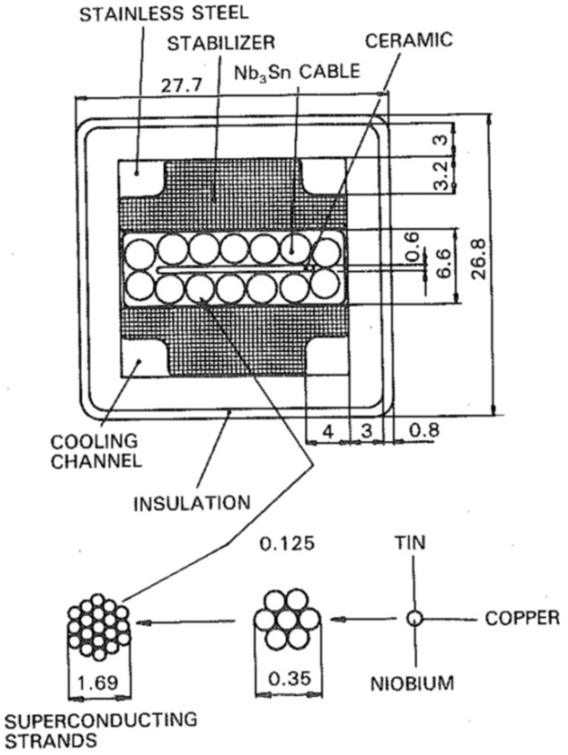
Monoliths

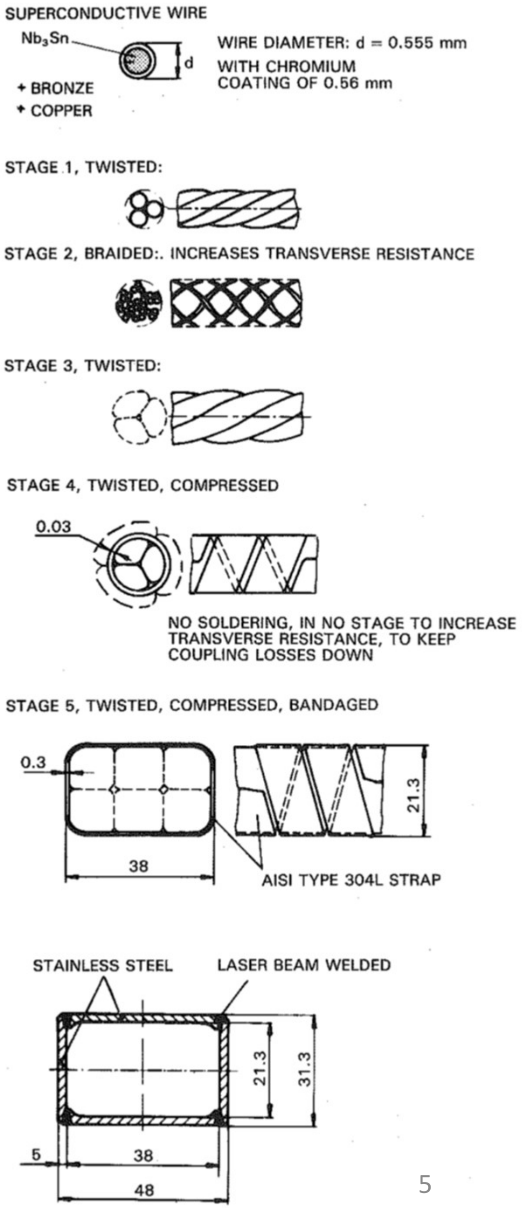
20kA R&W

CICC

40kA W&R







NET in 1988 was basis for ITER design in 1991 which then became ITER in 2001

One way to look at this is as the moment that Fusion rejected HEP type conductors

Convergence to Final ITER Conductor Design in 1993

Cable in Conduit 1991

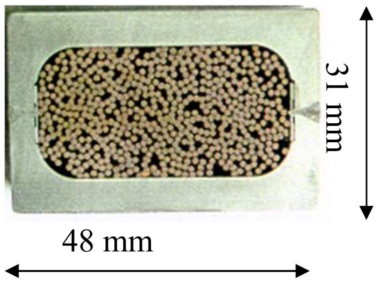
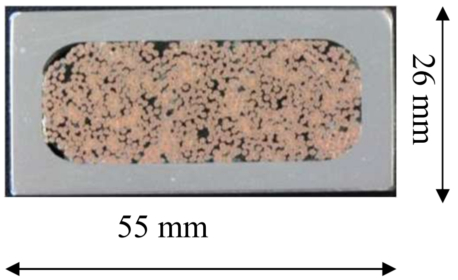
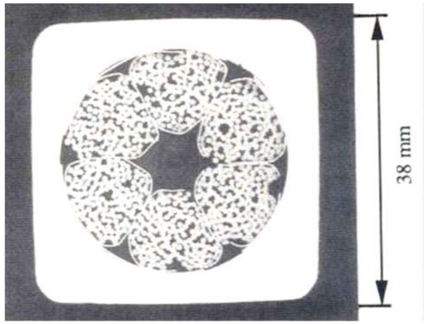


ABB – 1990 Laser welding

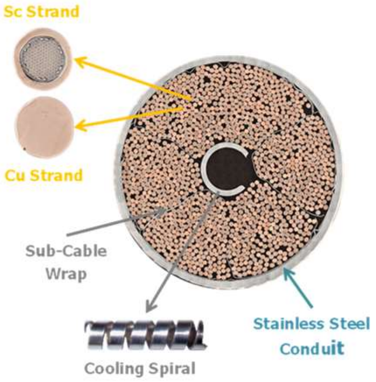


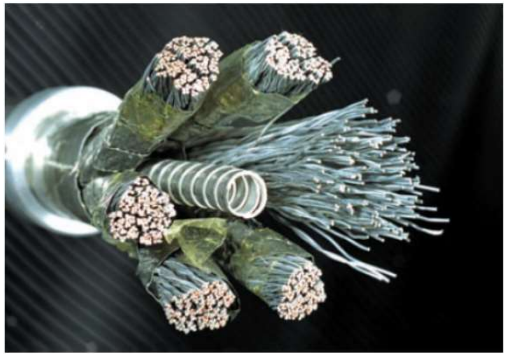
LMI – 1992 Extruded conduit



CEA NbTi – 1992 Central hole

DPC Nb3Sn cable in conduit 1985





1993 70kA TF

Left open until the 2000s

- Strand coating (Cr vs oil/carbon), interstrand resistance, current uniformity and control of AC losses)

Left open until the 2010s

- Cable patterns (and degradation)

Extruded jacket, pull through of cable, central open channel

EASY MANUFACTURING, MANY SUPPLIERS FOR CABLE AND JACKETING. ANY SPECIAL EQUIPMENT IS SIMPLE

The open central channel has saved ITER 2010-2022 because adaptable to handle the large increase in nuclear heating (14kW=>36kW) due to shielding design failures

Why did ITER Choose CICC?

Focus was Nb3Sn. NbTi design was not a passionate issue for ITER during 1990s.

- Up to 1993, argument was the high stability of CICC compared to monolithic conductors due to high helium contact. Many papers on ‘limiting current’ and cryostability
- Much concern about AC losses
- Well cooled-ill cooled concept was accepted. Some conductor testing was carried out but focus was on making Nb3Sn strands and the pull through method.
- Void fractions were large (36%) to provide He contact

Not until much later (1990s-2000s) that current uniformity and the ability of current to redistribute inside the CICC was recognised as reason for its success in NbTi

In 1980 several NbTi coils failed because of insulated strands and even in 2000s, CICC with insulated strands were being proposed for ITER (John Miller and the CS conductor)

It is also likely that for the ‘degraded’ CICC (due to filament fracture) found in the ITER TF conductor, current transfer between strands is mitigating the problem (this has not been studied)

Gradually AC losses have been accepted as much less serious (in CICC) than originally thought

- ☐ ITER changed to accept high hysteresis loss strands (HEP goes much further)
- ☐ Void fractions crept down, ITER reached 32% in TF (to try to improve mechanical support)

In ITER Nb3Sn and NbTi diverged but in a way both benefit from use of CICC

Nb3Sn

- Subsequently 2000s-2010s discovered poor mechanical robustness of Nb3Sn strands leading to filament fracture
- Obvious CICC not an ideal environment to provide interstrand support. ITER and Devred found a solution at least for CS conductors using a short twist pitch. However a clear warning that Nb3Sn strand support in CICC a critical design consideration
- Now it appears that Nb3Sn filament fracture a critical issue also in what should be monolithic conductors. Possible that push to high jc Nb3Sn creates larger areas of Nb3Sn which are more liable to fracture (note that high jc actually refers to non-Cu jc and some of the improvements come from cutting non-Nb3Sn material which could have been mechanically more robust)

NbTi

- Some NbTi CICC showed gross instability in 1980s, due (we now know) to high strand-strand contact resistance
- High cryogenic stability not enough to save them
- In the 1990s we quantified premature quench which is dominated by current uniformity and solved by a combination of low resistance joints and control of interstrand resistance (coating and VF). Final understood after ITER PF insert test

This then brings us 360 degrees back to the original ‘raison d’etre’ of the CICC….in a situation where individual strand performance may have issues (originally current non-uniformity, now filament fracture) the CICC is robust due to its current transfer properties

Final ITER Conductors 2003

Conductor meeting at Garching in 2003 (and a later meeting in October) attended by Robert Aymar agreed significant changes to the CICC ITER conductors, as a result of the EDA R&D. Attempt to balance issues against cost concerns….all possible in CICC

- TF temperature margin reduced from 2K to 0.7K
- 3 s/c triplet in TF and CS changed to 1Cu and 2 s/c strands, strand Cu:non Cu ratio dropped from 1.5 to 1. 33% saving in strand cost…..made a huge (but largely unnoticed) contribution to cost reduction of >100Meuro
- PF temperature margin dropped to 1.5 from 2K
- Incoloy eliminated, steel jacket as baseline for CS and TF
- Reduction in void fraction from about 36% to about 34%

However this was not the end of the story

2003 Meetings Marked a major change in the conductor design criteria (with the introduction of 'hope' as a major item)

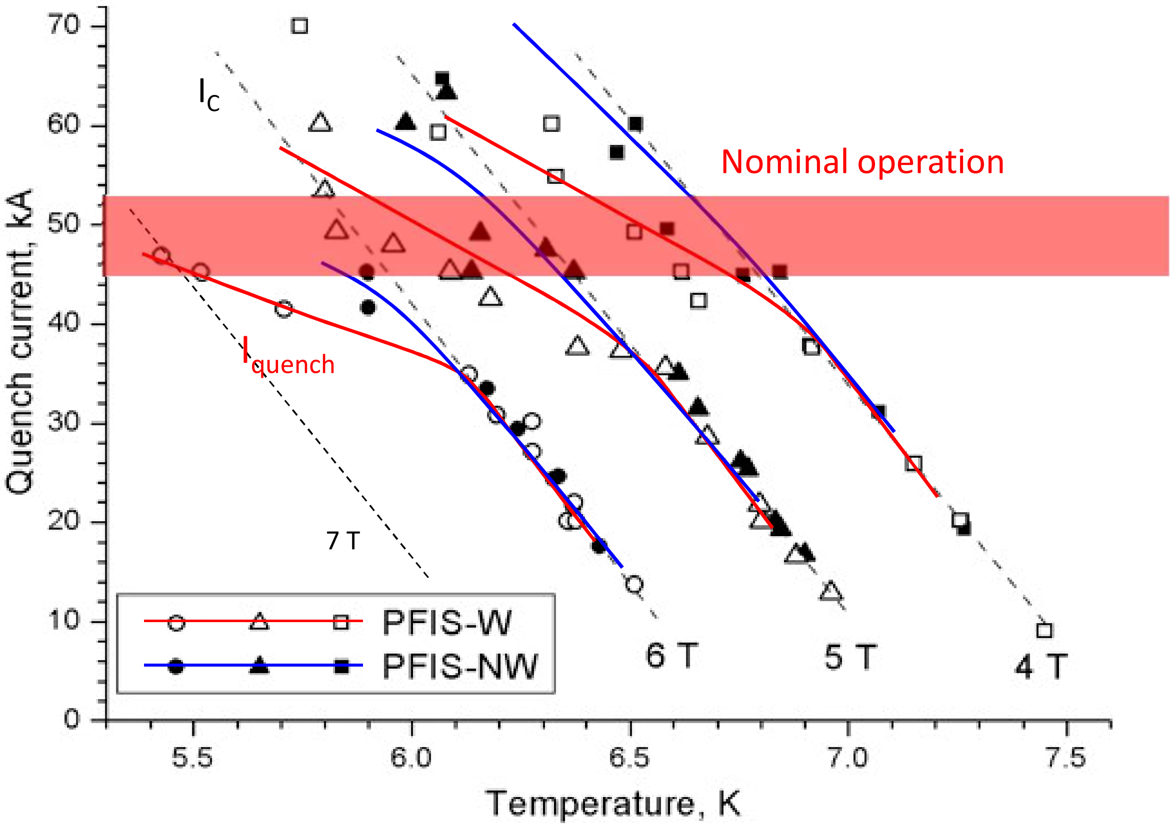
- Degradation of Nb3Sn acknowledged and allowed as a margin. It was hoped that lower void fraction would solve the issue
- Reducing the number of s/c strands substantially increased the load on individual strands (but not the overall load on the cable. It was hoped that cumulative pressure not local BI was causing degradation
- The end of the well cooled requirement. Cu:non Cu fixed at 1.0 mostly for cost and fabrication reasons
- Current uniformity. It was hoped that instability seen in conductor samples would disappear in long lengths
- Performance tests foreseen in 2003
  - ☐ NbTi: Sultan samples and the PF Insert (already under manufacture)
  - ☐ Nb3Sn: Sultan samples

What the 2003 meetings did NOT do was initiate an R&D programme to prove that the modified conductor would work

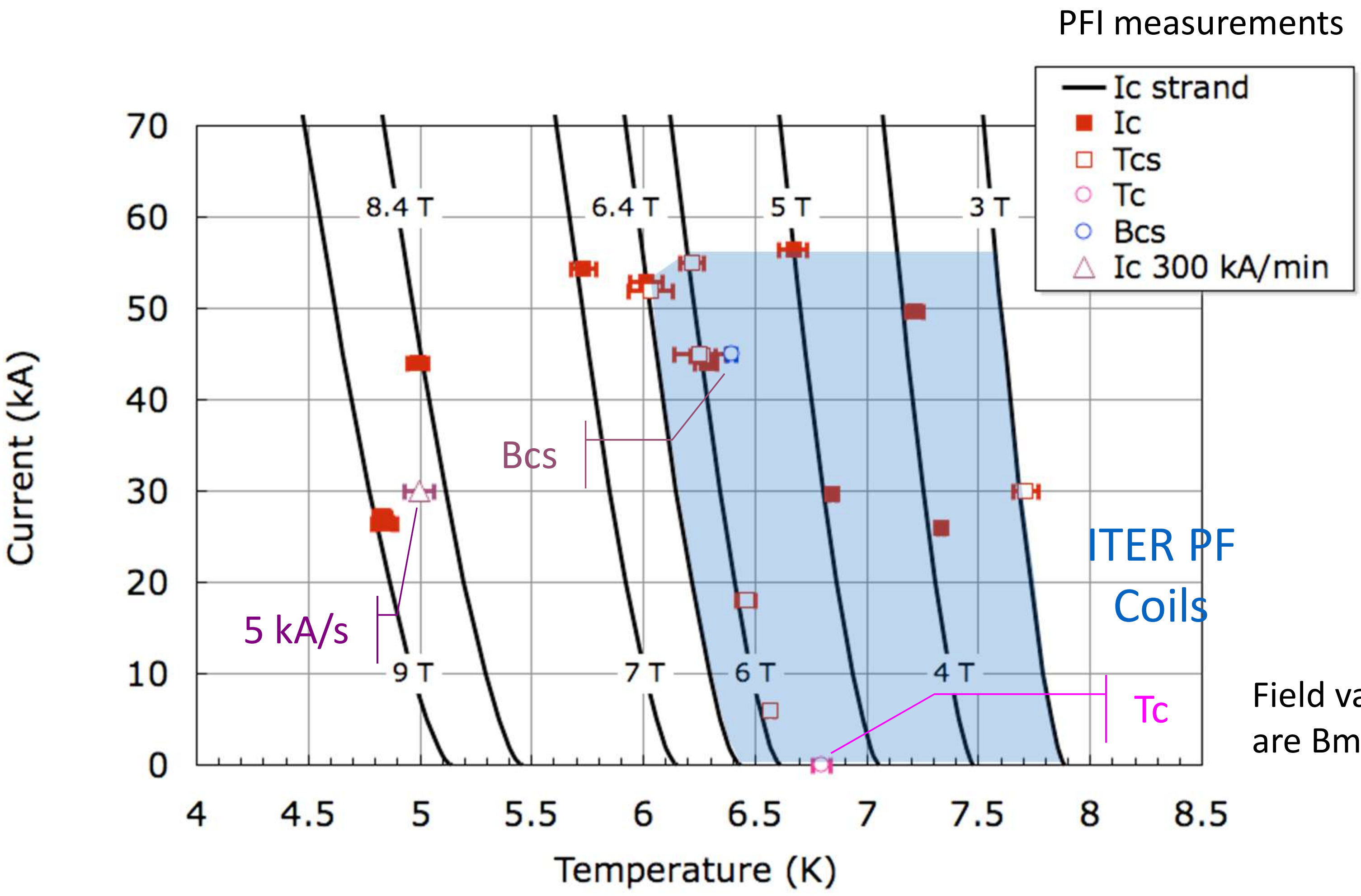
- The Nb3Sn design didn't resolve degradation and the NbTi design showed premature quench in short samples………

PFI Sultan Sample DC Performance: Quench current

- Current overload in + voltage drop across strands gives power dissipation early in the measurement, with early quenches as a result.
- Dashed lines in figure are linear extrapolation from lower quench currents.
- B field values are from SULTAN field.
- Significant influence of wraps (still present in joint)



Overview of PF Insert Current Sharing Results



Solid lines: predicted from strand data

Field values are Bmax

Nb3Sn CICC conductor tests in 2006 by EU indicated possibly more severe degradation than anticipated

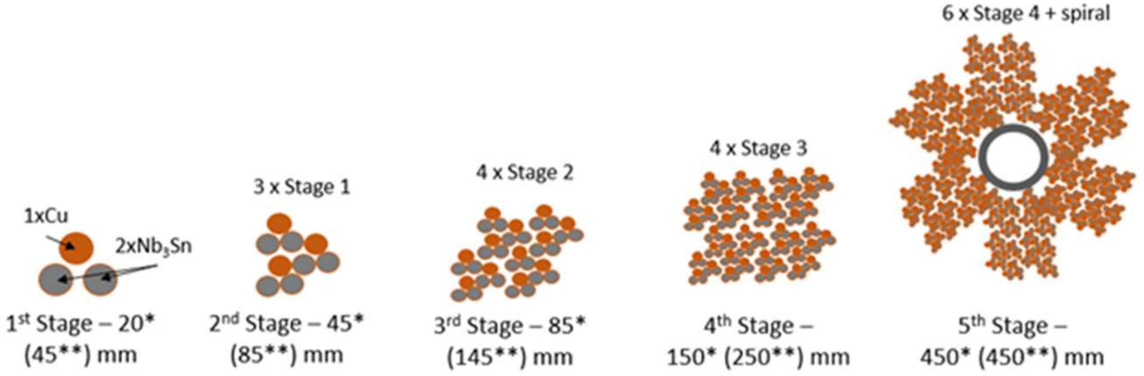
TFAS1, 2 Samples

- The "*advanced Nb_3Sn strands*", with J_c @12T/4.2K > 700 A/mm^2 (compared to 550 in the Model Coils) were qualified in 2003-2005.
- The test results of the four TFAS conductors, with electromagnetic and thermal cycles, were disappointing
  - Low initial performance
  - Sensitive to cyclic loading.
- Indications that some of the poor initial performance dominated by joint non-uniformities and the short SULTAN samples

	ITER spec	TFMC	OST	EAS	OKSC	OCSI
Before cyclic load	**5.7 K**	5.52 K	6.63 K	4.93 K	5.29 K	5.77 K
After cyclic load	**5.7 K**	-	5.81 K	4.72 K	**5.09 K**	**5.53 K**
3rd Campaign after warm up	**5.7 K**	-	**5.44 K**	**4.57 K**	-	-

ITER Cables

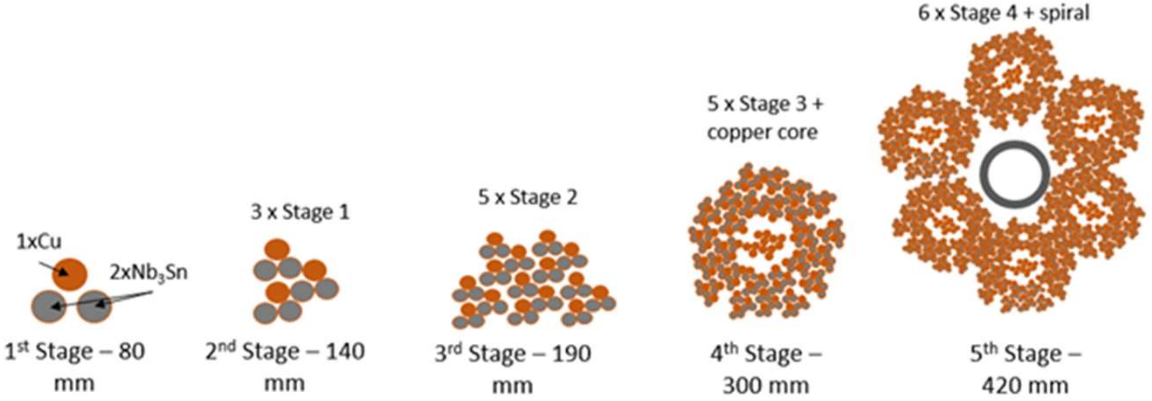
CS Cabling Diagram



*final configuration that shows no degradation
**original configuration that demonstrated significant degradation

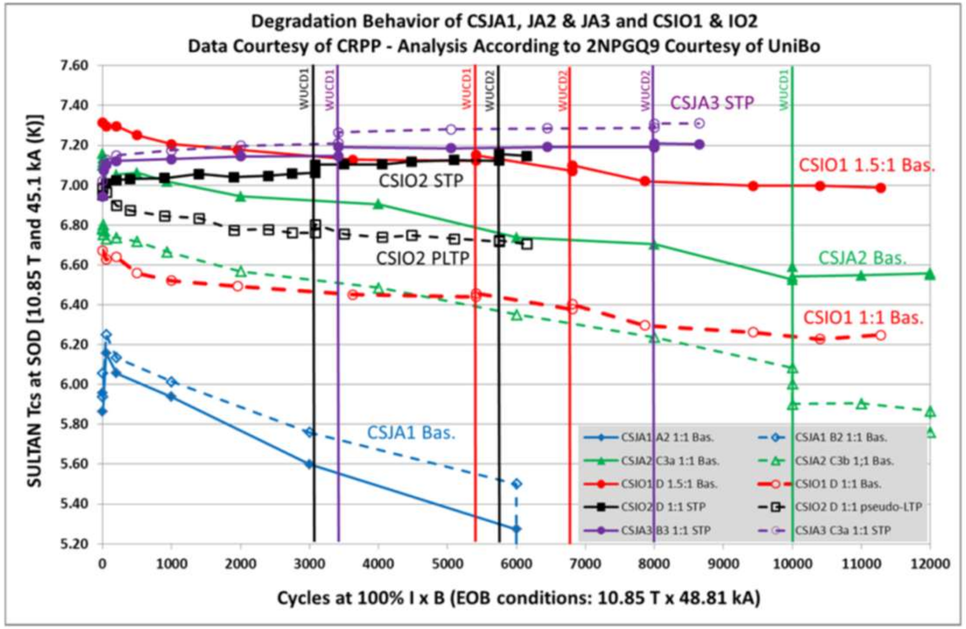
CS conductor (short twist pitch)

TF Cabling Diagram

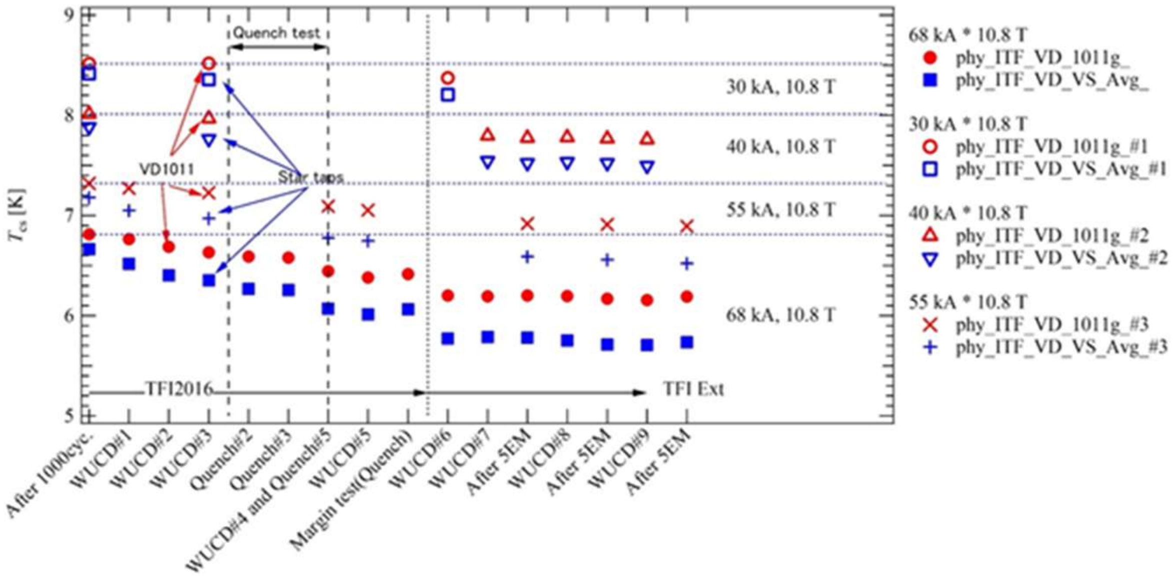


TF conductor (pseudo long twist pitch)

Note: These cables (and many variants) all produced on same industrial tooling



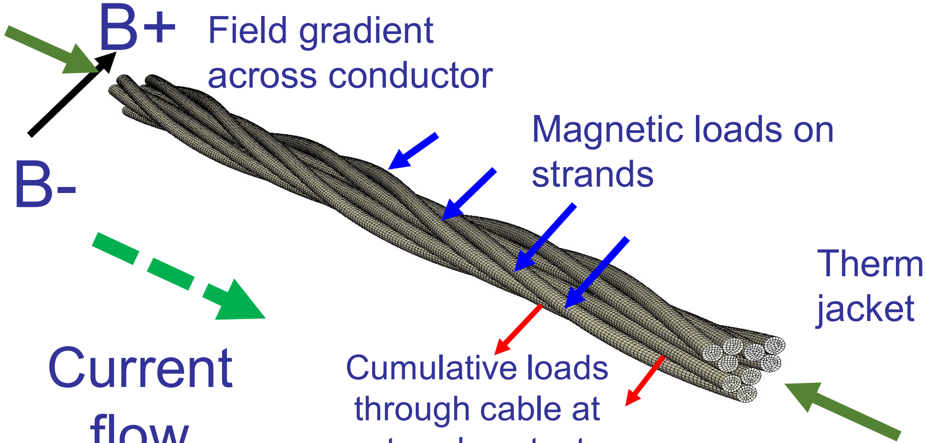
Summary of the CS Conductor SULTAN Tests that show the progressive resolution of the degradation issue through CSJA1, CSJA2, CSIO1, CSIO2 and CSJA3.



Evolution of the current sharing temperature (T_{cs}) of the TFI on completion in 2018

Causes of Nb3Sn Filament Fracture: Magnetic Loads

Solved at Cable Level --- did not look at strands (filament fracture behaviour, internal stress system, strength)



B+

B-

Field gradient across conductor

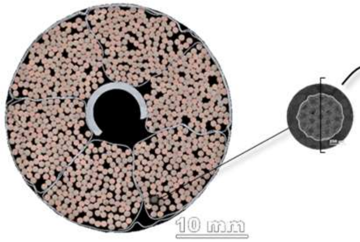
Magnetic loads on strands

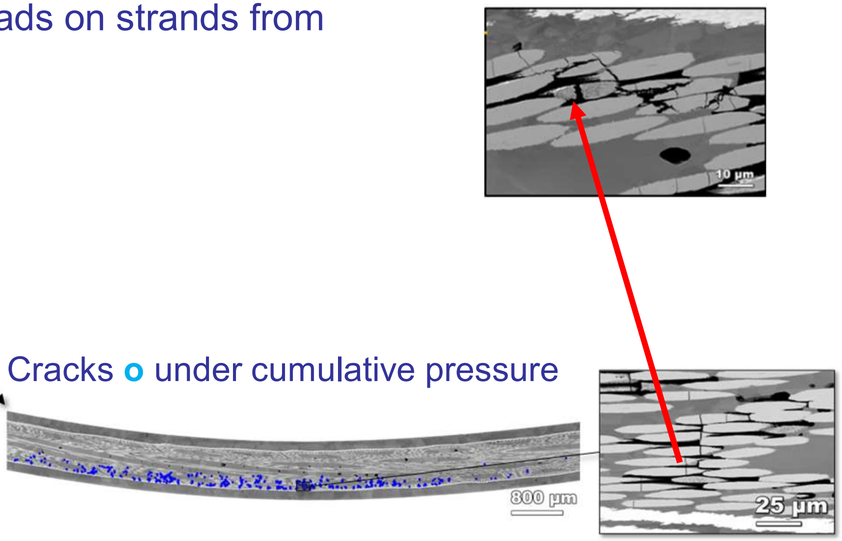
Thermal loads on strands from jacket

Current flow

Cumulative loads through cable at strand contact points

ITER solved this for jc ~800A/mm2 at 12T…strands with reasonably discreet filaments. High jc (3000 A/mm2) may behave differently as CERN Hi Lumi experience shows





Nb3Sn filament cracks

Cracks o under cumulative pressure

The ITER CICC work because

- Even with low void fraction, the helium provides good cryogenic stability. The CICC is a much more robust conductor than expected, even with NbTi (to the extent that AC losses not a stability issue).
- Good quality controls on void fraction & strand coatings gives a Goldilocks transverse resistivity (not too high, not too low, but just right). Too low gives high AC losses, too low stops easy current transfer. The cables are very tolerant of strand damage (including breakage) and (in long lengths) are insensitive to current non-uniformities
- In Nb3Sn the degradation due to filament breakage produces a very gradual superconducting transition which (by allowing current redistribution without local runaway instability) gives very stable conductors. CSI up to 50microV/m, even PFI up to over 10microV/m
- The cable allows limited flexing of the strands under longitudinal strain that reduces the degradation due to the differential contraction with the still. The flexing has to be well controlled (void fraction and cable parameters) since too much flexibility allows strands to bend under the transverse loads and leads to filament fracture. Another Goldilocks situation which we have discovered empirically
- There has been a lot of work by a lot of people over a lot of years to solve a lot of problems

The ITER Experience: NbTi

Large conductors…more or less as large as possible (50kA) and driver not cable but jacket once the manufacturing route (extruded sections, butt weld, pull through, roll down) was selected

Research into strand coatings (resistance, manufacturability and especially chemical stability) led to Nickel selection

Little work on strand diameter. Value of about 1mm seemed to condense out of air in 1980s and we never tried to change it significantly (partly because it could be delivered by suppliers directly, in useful unit lengths, and was easy to cable)

Short sample results (Sultan) showed premature quench. Large efforts to improve joints on Sultan samples in early 2000s but for NbTi it was ITER PF Insert coil in 2008 that finally showed full performance

Issue was (and is) current uniformity and ability of cable to allow current redistribution (strand-strand contact resistance reproducible not too low (high AC losses) not too high (no current redistribution).

Limited trials with void fraction and cable pattern

The ITER Experience: Nb3Sn

Large conductors…more or less as large as possible (50kA) and driver not cable but jacket once the manufacturing route (extruded sections, butt weld, pull through, roll down) was selected

Research into strand coatings. Multiple concerns, manufacturability, chemical stability, resistance to strand heat treatment ➔ lead to selection of Cr option

Little work on strand diameter. Value of about 1mm seemed to condense out of air in 1980s and we never tried to change it significantly (partly because it could be delivered by many suppliers directly, in useful unit lengths, and was easy to cable)

Lots of bad experience on strand stresses and filament fracture. Eventually (and too late for TF) clear solution found: cabling pattern. With analysis tool development, we could avoid this issue in future CICC (Nb3Sn)

HEP Rutherford Cables vs CICC with Aluminium Stabiliser

What are the basic functionalities of these cables

Main Reason for Al: Transparency to Particles invariably required for thin (transparent) Solenoids, in case of the detector solenoid placed in the middle layer of the detector. *If this is not needed, seems much simpler not to use Al!*

- ❑ In HEP cables are 'Rutherford type' with no local helium content. In such cases sc stabilisation against small disturbances (EM or mechanical) is required. This comes from the current transfer to an Al 'stabiliser' and also from the thermal capacity of the Al. For both, a very good contact between the Al and the superconductor is required (electrical and thermal)
- ❑ The Al functions also as a quench protector. HEP magnets have low voltage capacity and therefore fast discharge to external resistors is very slow. So to provide 'self protection' the Al has the function of an alternate current path, a thermal capacitance for heat absorption and a thermal conductance to spread the quench rapidly through the coil (reducing heat localisation). It also provides mechanical support

In a CICC (or at least all those used up to now) the functionality is different. The cable is inherently high stability because of the presence of helium in well-distributed contact (even with low void). Current can be redistributed between strands in the cable and there can be additional protection (copper or presumably Al) within the cable. The jacket has only a function of He containment, structural support and (to a minor extent) thermal inertia during quench

- Is there any way to find an advantageous synergy between these different functionalities that would allow CICC to be efficiently applied in HEP in a way that brings an advantage over present solutions?
- ***It seems (to me) that easy and flexible manufacturability is a key issue for NbTi cables, but there are several other potential advantages to CICC***

One overall pointer from ITER CICC to potential HEP application

ITER CICC allowed a wide base of industrial suppliers of strand ‘building blocks’ to be developed. Same strand (even NbTi & Nb3Sn) can be used and adapted within CICC

CICC provides flexibility to solve a range of issues (some unexpected)…there are several (or many) controllable engineering parameters that allow it to be adjusted without changing the basic concept (and without changing the basic manufacturing)

Of course CICC allows specific ‘strands’ to be developed and applied but this deviates from the original principle of a building block. REBCO CICC seem an example of this deviation. Here I will stay with purist approach for CICC for HEP

The answer to the question of why we would want to use CICC in HEP seems to be not because of technical advantages but because of manufacturing adaptability. It allows many specific issues to be solved (it can be tuned) with fairly well understood and widely available processes (cabling, coating etc) while working with basic strand building blocks and industrial tooling.
We do not have to adapt strands with specific manufacturing processes, nor develop expensive highly specialised tooling.

HEP Application 1

Al stabilised low(ish) field for transparent applications

A CICC cable would presumably consist of NbTi strands with minimum copper required for ingot construction and drawing lubrication….perhaps a Cu:non Cu ratio <0.1 (???). Many (many) suppliers for circular cables

There are two ways to add the Al stabiliser *if we are not going to change strand manufacturing process*

- As wires within the cable
- As a co-extruded jacket, using Wendelstein method OR as ITER method (pull through a (very) long tube and draw/roll down and shape)

Strand diameter would be small (target 0.5mm?) in order to achieve a low void fraction (<30%, target 27%) without major strand damage

- Low void fraction will give good electrical contact to the jacket and good electrical contact between strands
- High AC losses so low current ramp rates
- On the other hand low VF and high strand to strand conductance minimises current non-uniformity problems…major concern on NbTi conductors
- High(er) current density which is presumably an HEP requirement

Need to look at strand coatings. Conventionally on NbTi for ITER CICC we use nickel…plates well to copper, stable to oxidisation and gives ‘reasonable’ contact resistance to other nickel coated strands. 3 year development programme, well repaid effort

- Should we Al coat NbTi strands? Thin layer, intention to allow good contact to Al wires and to other strands. Or other materials would be better? Which?

HEP Application 1 (continued)

- ❑ Presence of He in CICC will provide high stability and could (maybe) give sufficient cooling through He flow but this depends on configuration of cooling channels
- ❑ In the event of quench dominant propagation is likely to be through the He expansion. Probably faster than thermal conduction along the conductor

Potential Gains

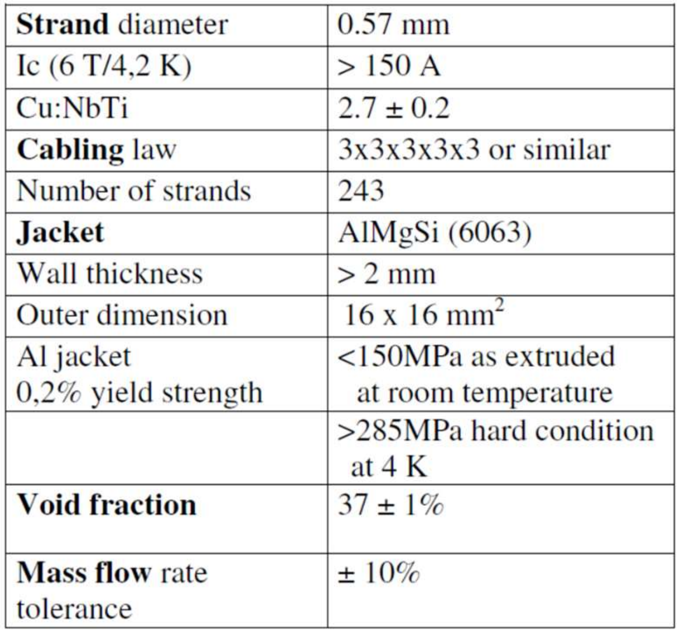
- ❑ The technology of adding the Al is separated from the strand manufacture
- ❑ The use of CICC allows 2 potential routes (jacket and extra strands) and likely a range of options to improve coupling via strand coatings
- ❑ Also potential route to avoid costly/difficult co-extrusion
- ❑ None of this is really related to the original concept of a CICC but more exploits the flexibility of the concept

In Wendelstein conductor

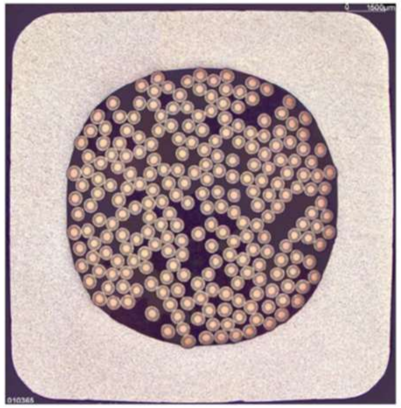
- Jacket is Aluminium, co-extruded onto a cable through a modification of a Al extrusion process (technology is Al fabrication not superconductors)
- Alloy is initial soft for extrusion but then is hardened through a heat treatment so can function structurally
- As far as I know, strands were uncoated

For HEP we would need

- Soft high RRR Al
- Much lower void fraction



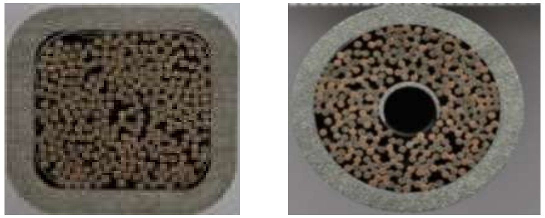
Strand diameter	0.57 mm
Ic (6 T/4,2 K)	> 150 A
Cu:NbTi	2.7 ± 0.2
Cabling law	3x3x3x3x3 or similar
Number of strands	243
Jacket	AlMgSi (6063)
Wall thickness	> 2 mm
Outer dimension	16 x 16 mm^2
Al jacket 0,2% yield strength	<150MPa as extruded at room temperature
	>285MPa hard condition at 4 K
Void fraction	37 ± 1%
Mass flow rate tolerance	± 10%



In ITER CC feeder and CC conductors

(NbTi, about same dimensions as W7, 316LN jacket)

- Manufacturing route is pull through of cable into a pre-assembled jacket, followed by roll-down in compaction rollers
- Jacket can be circle-in-square or circle-rolled-into-square or circle-in-circle
- Lengths of several 100m manufactured



Not to scale

HEP Application 2

Medium to high field applications, no transparency requirement

This appears to be a ‘standard’ high field high current density application where we want to achieve a high current density and (therefore) operate close to maximum performance of individual strands

What can CICC offer here in comparison to Rutherford cables?

Assume that we are now at Nb3Sn level. REBCO would be a further step but we start getting substantial concept variations from the old NbTi CICC and REBCO is generally tapes, not strands, not very suited to CICC. So stick to Nb3Sn.

One of the areas of investigation will also include non- or partially-insulated coils. Would these be conceivable with CICC?

What we want to achieve with NI or PI coils is low voltage and self protection from intense local hot spots during a quench with current transfer inside the winding. How could CICC help in comparison to HTS tapes or Nb3Sn Rutherford cables

CICC considerations:

- ☐ Better mechanical support of strands: probably not but with care could be equivalent
- ☐ Strand damage tolerance, multiple paths for current to transfer especially with low void fraction: could be a critical improvement over Rutherford cable

What could be a CICC for HEP

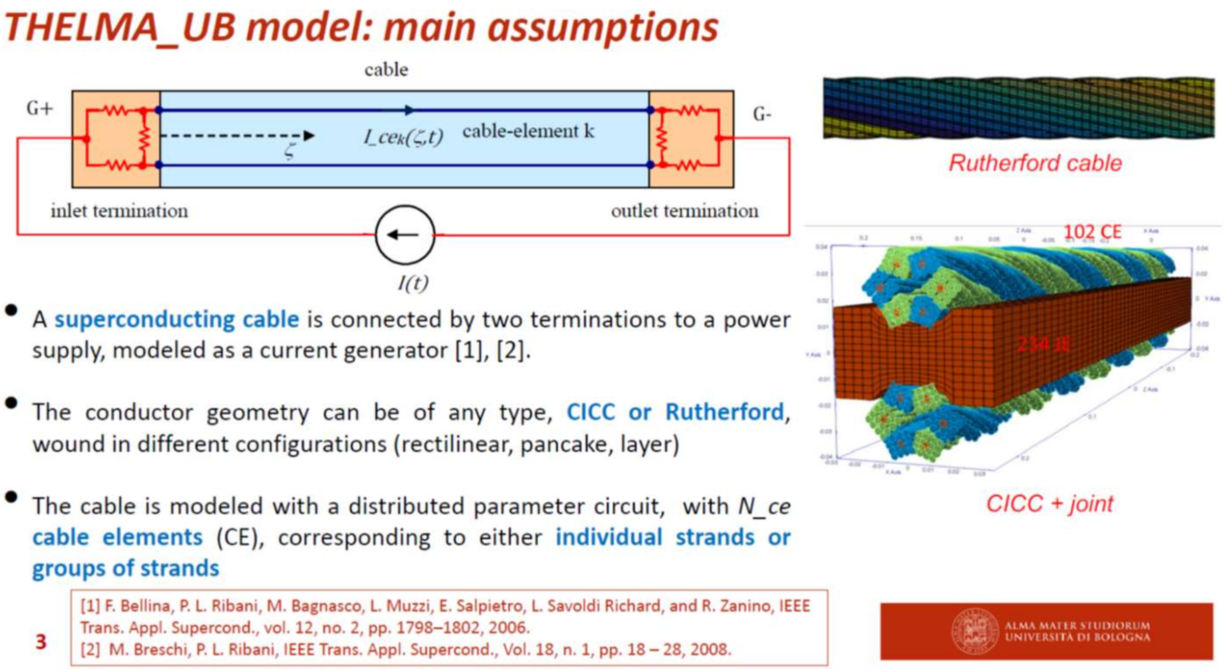
- ☐ Smallish current, say 15-20kA (to keep cable size limited)
- ☐ For Nb3Sn usual issue with wind & react or react & wind. CICC is well suited to W&R, and for dipoles and the like, R & W doesn't look feasible due to curvature range

Key Tools

Fusion and ITER have driven sophisticated tools for CICC assessment

Structural: Multifil and work of Damian Durville, Hugo Bajas, Rebecca Riccioli and many others (next slide)…strand breakage and contact resistance

Current distribution: Thelma and work of Fabrizio Bellina, Marco Breschi, and many others



THELMA_UB model: main assumptions

- A **superconducting cable** is connected by two terminations to a power supply, modeled as a current generator [1], [2].
- The conductor geometry can be of any type, **CICC or Rutherford**, wound in different configurations (rectilinear, pancake, layer)
- The cable is modeled with a distributed parameter circuit, with *N_ce* **cable elements** (CE), corresponding to either **individual strands or groups of strands**

[1] F. Bellina, P. L. Ribani, M. Bagnasco, L. Muzzi, E. Salpietro, L. Savoldi Richard, and R. Zanino, IEEE Trans. Appl. Supercond., vol. 12, no. 2, pp. 1798–1802, 2006.
[2] M. Breschi, P. L. Ribani, IEEE Trans. Appl. Supercond., Vol. 18, n. 1, pp. 18 – 28, 2008.

3

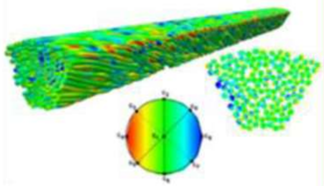
Tools have been applied to analyse assorted conductors, also for HEP but have not (as far as I know) been applied as a design tool to derive a new conductor

Perhaps a coordinated conceptual analysis could be tried

Timeline of MUTLFIL evolution for fusion cables

2011

H. Bajas Ph.D.



Development of a first mechanical model to simulate fusion sub-cables based on MULTIFIL code developed by D. Durville:

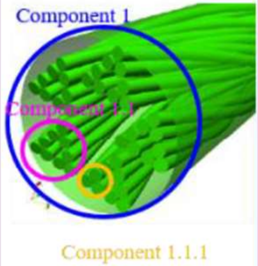
- Material constitutive laws implementation;
- Axial and transverse validation;
- Deep analysis of the ITER CS CICC and main mechanical phenomena.

But missing numerical tools and phenomena: representability ?

2017

MULTIFIL upgrade

Passage from pseudo-periodic BCs to **hierarchical handling of BCs**: Independency of the ends BCs

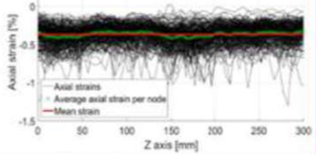


2019

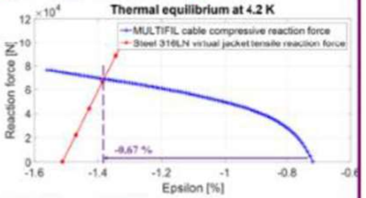
MULTIFIL upgrade & Model improvement

Further developments of the single sub-cable model:

- MULTIFIL upgrade: deformable "jacket" during CD;



- **Jacket-cable thermal equilibrium during CD**;



- **"Multi-petal" models** during EM cycles.

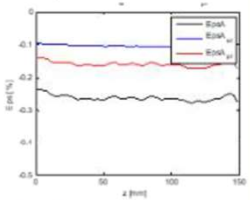
2020

MULTIFIL upgrade & Model improvement

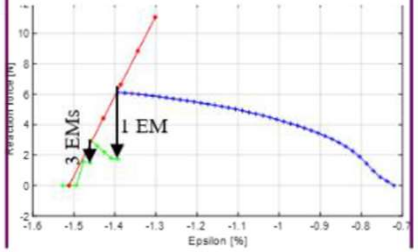
MULTIFIL upgrades:

- **Twisted single sub-cable**;

- Discrimination between plastic and elastic strains over strands;



Adding the **jacket-cable equilibrium for EM cycles**.



2021

MULTIFIL upgrade & new models

- MULTIFIL upgrade: **full ITER TF CICC simulation**;

- **Other Nb_3Sn cables simulation**: DTT TF cable, JT60SA CS cable, ITER CS STP cable.

Conclusions

Try to summarise NbTi +/- Application 1 in table (encouraged by Akira)

CICC seems to have quite a lot of potential in HEP. Of course this comes at the cost of increasing complexity but it can address some concept limitations in conduction cooled Al stabilised conductors (and if the same performance is required, increased complexity is limited). Manufacturing advantage seems clear

The table is obviously very subjective and debatable

Conclusions 1

HEP Application 1: *Al stabilised low(ish) field for transparent applications*

ISSUE	HOW CICC COULD PERFORM	Improvement over conduction-cooled Al-stabilized Cond/Coil?
Conductor fabrication tooling: availability and cost (including strands)	Tooling (cabling and jacketing) can be simple (easy to make complicated too….) using standard manufacturing sub-steps, tooling available. Much flexibility to adapt composition with materials	Yes
Manufacturing process of the magnet (coil winding)	Conventional, CICC has more flexibility to choose X sections and aspect ratio. Even locked hexagonal shape! And X section can vary (with joints)	=
Operational performance of the conductor	Normally more stable than Rutherford cable due to He, more resistant to local damage. Issue is what is required, HEP generally low disturbance	Maybe more compact
High-voltage sustainability	W&(R)&I route would be conventional insulation. More scope for more insulation with convection cooling, scope for shaped conductors to reduce insulation loads	Maybe
Cooling scheme during pre-cooling and in steady state	CICC could have very low in-channel flow and be substantially conduction cooled, or use intermediate He inlets to increase convection cooling	More complex, likely better performing
Physical envelope including cooling path and joints of conductors	Cooling paths can be separated from electrical paths which allows design flexibility. Experience (ITER CS Nb3Sn) on very compact in line joints	More complex, likely better performing
Quench protection	Fast discharge based similar, probably higher internal propagation with convective cooling. Maybe more scope to embed quench triggers in cable	=