The Roebel Assembled Coated Conductor (RACC) cable, status of performance and prospects for further upgrades

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Roebel Cable (RACC)

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• Filaments and Inhomogeneities

Conclusions
Roebel Assembled Coated Conductors (RACC)
100 years birthday of an old idea

- Invention 1912-1914 Ludwig Roebel
- The LCT NbTi Roebel cable 1984/85
- Proposal for HTS-CC M.Wilson 1997
- Realisation KIT (W.G. et al.) 2005/06
- Commercialisation IRL-GC 2008 f.

LCT EURATOM cable NbTi
Transposition in the cable and in the strands!!
High current cable concepts with CC

- **Twisted Stacked-Tape Cable (TSTC)**
  

- **Conductor on Round Core (CORC) cable**
  

- **Roebel Assembled CC (RACC) at KIT**
  

- **Rutherford Cable + Roebel strands (CCRF)**
  
  A.Kario unpubl.

- **Cable EPFL: CC stacks in Cu**

- **CC stacks in blocks (Tohoku Univ., NIFS)**

- **ENEA cable RF with stacks**

The only concept with all CC axis aligned!!

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Short straight single RACC sample in self field 77 K

Non-homogeneous pattern of the magnetic self field in Roebel Coated Conductor cable cross section.

Current anisotropy not symmetric due to CC specific pinning, source of complex current distr.

- Current redistribution effects begin at $I > \frac{1}{2} I_c$
- Modelling shows influence of non-symmetric anisotropy
- $I_c$ in s.f. reduced by 40-60%
Anisotropy of Roebel cable at 4.2 K and B= 0 - 10 T (Test in FRESCA facility by CERN), CC from SuperPower

Transport currents: 14 kA at self field
4 - 12 kA at 6 T (4.2 K)

Enhancement factor 77K - 4 K factor 12!

Anisotropy factor 3 - 5! at 4.2 K

$L_p = 0.4 \text{ m} = 30 \text{ strands gives } > 40 \text{ kA s.f. (in work)}$

$L_p = 1.8 \text{ m} = 100 \text{ strands gives } > 80 \text{ kA at 13.5 T, } 4.2 \text{ K = DEMO}$

Cables with twisted CC along cable axis include worst field orientation (as CORC)

Roebel can take advantage of anisotropy

10 strands
12 mm cable width
2 m length
1.1 kA at 77K sf
Transpos.: 126 mm

J. Fleiter¹, A. Ballarino², L. Bottura², P. Tixador³, Superc. Science & Technol.

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Solenoid and pancake coils
Roebel (RACC) cable as pancake and layered coil (1 piece used)

Sample data
- SuperPower CC
- Length 5 m, width 12 mm
- Strand width 5.5 mm
- 10 strands
- Transposition 126 mm

Design value 1512 A
Model with sharing 1108 A
Straight cable 936 A (m.)
Solenoid coil 750 A (m.)
Pancake coil 460 A (m.)

Bending is excellent, Measured degradation of current stronger than modeled
= Influence of CC Inhomogeneity + complex current path
Modelling of self field effects in the coil arrangement

- FEM Modeling confirms measured influence on transport currents
- Stronger self-field interaction occurs between turns in a pancake coil
- Strong influence of current anisotropy

- Solenoid with cable monolayer
- 1 mm turn distance

- Dense packed pancake version shown
- 0.1 mm turn distance

Reference straight cable

F. Grilli, M. Vojenciak et al.
Bending properties and coil shape
Bending and influence of transposition in coils
Comparison stacked CC & Roebel cables

- Strands in the Roebel cable go through all positions
- The bending properties are similar to the single strand or CC

Stacked cable!
- Strong stresses if not stacked during winding

Solenoid Case!
- Stresses average out when transposition length smaller than wound length or in solenoids
Bending of HTS Roebel cable in solenoid shape

S. Otten et al. KIT unpublished

- Bending radii: 50, 33, 26, 20, 13, 10 mm
- Small degradation, < 6.5 % of total cable $I_c$
- Measurements on single strands show degradation in the bent section by < 1%
- Cable degradation was not caused by bending (current redistribution event !)

![Graph showing critical current vs. bending radius for two cables](image1)

- Bending like CC !

![Image showing bending at different radii](image2)
Edge Bending of cable

- Variable angle between cable axis and bending direction
- Fixed bending diameter

Roebel cable 4 mm width
For 0-5° no degradation
Degradations depend on orientation of cable (REBCO inside / outside)
CC layer orientation inside gives mechanical reserve
Bending of a Roebel cable in non-solenoid shapes

The coil has straight and round sections

2 strands discussed in Roebel cable at end turn

Blue strand is longer than red one for 1.25 Lp  Stresses

Coils with many turns:
• Avoid cumulative deviations from bent strand lengths and resulting stresses
• Designing the transposition length and coil dimensions together is necessary!

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ICEC25 - ICMC TWENTE Netherlands July 7th-11th, 2014
Interplay of transposition length and magnet design

Case 1
\( L_t = \) bent section

Case 2
\( L_t > \) bent section

Find a way to unload the stress!
Cable design
Winding technology

Experiments in work with dummy cables

Winding experiments necessary!
Not all strands have the same length
Situation changes turn by turn
Option: Striations for lower Losses
Option for lower AC losses: Striated CC or strands:

Up to 120 Filaments (12 mm) prepared and analyzed, moderate current degradation from CC inhomogeneity, full separation with post annealing achieved (filled symbols in figure)
Striated RACC cables (earlier results)

Magnetization AC loss measurements

- Systematic investigations with up to 20 filaments (samples exist) in work
- AC loss investigations
- Modeling will follow


Striations made by psec-IR laser at KIT

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Striated RACC cables (under Investigation)

Magnetization AC loss measurements are actually performed

Filament numbers
0, 5, 10, 20

Shape oriented at inner edge radius
Filaments and Inhomogeneities
Filaments as measure tool for CC homogeneity

- Defect size can reach 0.2-0.3 mm
- Narrow filaments reach defect size
- Defects are thermal hot spots
- Striations can be used as quality test

Summary & Conclusions

- The only flat concept with full transposition
- High engineering current density
- Current anisotropy in fields still given
- Excellent bending behavior
- Current anisotropy as CC
- Longitudinal defects in CC a severe hint
- All CC suppliers actually under test
- Conduit as option is no problem (in the road map)
- Stabilisation can be applied as parallel Cu strand
Thank you for your attention!