



low loss wire design @ Luvata Fornaci di Barga

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SC Rutherford cable for magnet winding contract



Tenders were received from:

- Luvata Fornaci di Barga
- EAS

The latter tender offered the manufacture of 80 km of wire of 2nd generation only and without cabling.

This offer could not be considered since it was not technically complete, but it is important to know that there could be a second player.

Conclusion: Contract was awarded to Luvata Fornaci di Barga

Final wire design now being finalized.



Wire specifications



Table I. Wire Main Characteristics.

Wire			Notes
Diameter after surface coating	0.825 ± 0.003	mm	
Filament twist pitch	$5 +0.5 -0$	mm	
Effective Filament Diameter for 1st Generation wire	3.5	μm	a)
Effective Filament Diameter for 2nd Generation wire	2.5	μm	a)
Interfilament matrix material	Cu-0.5 wt% Mn		
Filament twist direction	right handed screw (clockwise)		
I_c @ 5 T, 4.22 K	> 541	A	b)
n-index @ 5 T, 4.22 K	> 30		
Stabilization matrix	Pure Cu		
Strand transverse resistivity at 4.22 K	$0.4 + 0.09 B$ [T]	$\text{n}\Omega\cdot\text{m}$	
Cu+CuMn:NbTi ratio (α ratio)	>1.5		c)
α ratio tolerance	± 0.1		
Surface coating material	Staybrite (Sn-5 wt% Ag)		d)
Surface coating thickness d	0.5	μm	e)

Notes:

- a) As measured from magnetization.
- b) This is the primary value for virgin wire. It is 5% higher than the cabled values, to take into account degradation during cabling. It amounts, e.g., to 2.529 A/mm² for $\alpha = 1.5$ or 2.832 A/mm² for $\alpha = 1.8$, @ 5 T, 4.22 K.
- c) The supplier may propose an alpha value, provided it is larger than 1.5. Tolerance during the production must remain between ± 0.1 from the nominal value.
- d) Same coating material used for LHC dipoles.
- e) This is a preliminary value, to be better defined later.



Rutherford cable specifications



Table II. Cable Main Characteristics.

Geometrical			Not
Strand Number	36		a)
Width	15.10 +0 -0.020	mm	
Thickness, thin edge	1.362 ± 0.006	mm	
Thickness, thick edge	1.598 ± 0.006	mm	
Mid-thickness at 50 MPa	1.480 ± 0.006	mm	
Edge radius	≥ 0.30	mm	
Core material	AISI 316 L stainless steel, annealed		
Core width	13	mm	
Core thickness	25	μm	
Transposition pitch	100 ± 5	mm	
Cable transposition direction	left-handed screw thread		
Electrical			
Ic @ 5 T, 4.22 K	>18,540	A	b)
Stabilization matrix RRR	>70		

Notes:

- a) The geometrical layout is the same as that of the LHC dipole outer cable design. Dimensions are specified at 20 °C.
- b) Ic @ 5 T, 4.22 K for the extracted strand must be equal to or above 515 A.



Basic wire design



two stage re-stacking

1st stacking, elements with 367-1075 NbTi filaments in CuMn matrix and Cu or CuMn in the outer sheath, manufactured by **hot extrusion**

2nd stacking, performed by means of **cold drawing**.

Two stage re-stacking with cold drawing at the second stage

has been recently tested on other contracts with appreciable results

1 st generation

no CuMn in the element outer sheath
"A-like" according Wilson report

Average geometric filament diameter...
2.58 μm

...effective diameter
x 1.3 = 3.35 μm

Filament diameter spread
2.92 %

α ratio **1.56**

I_c @ 4.2 K, 5 T
(assuming 2600 A/mm²)
543 A

2 nd generation

CuMn in "D" element outer sheath similar to a "B-like" design according Wilson report

Average geometric filament diameter...
2.15 μm

...effective diameter
x 1.3 = 2.80 μm

Filament diameter spread
4.91 %

α ratio **1.56**

I_c @ 4.2 K, 5 T
(assuming 2600 A/mm²)
543 A



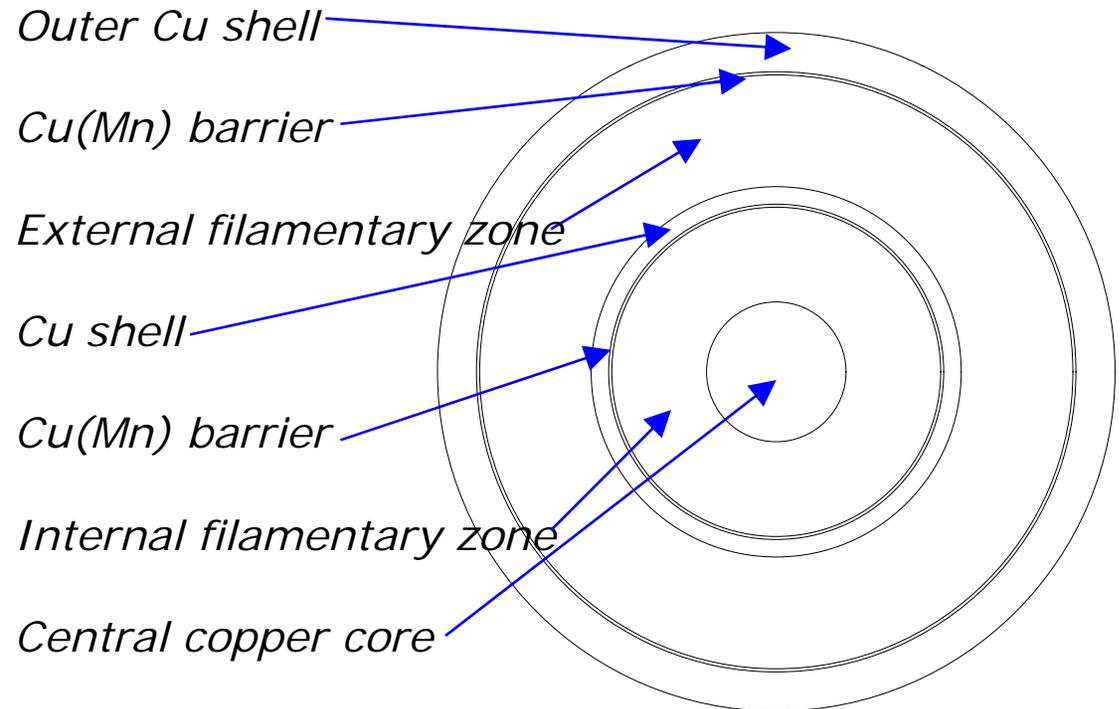
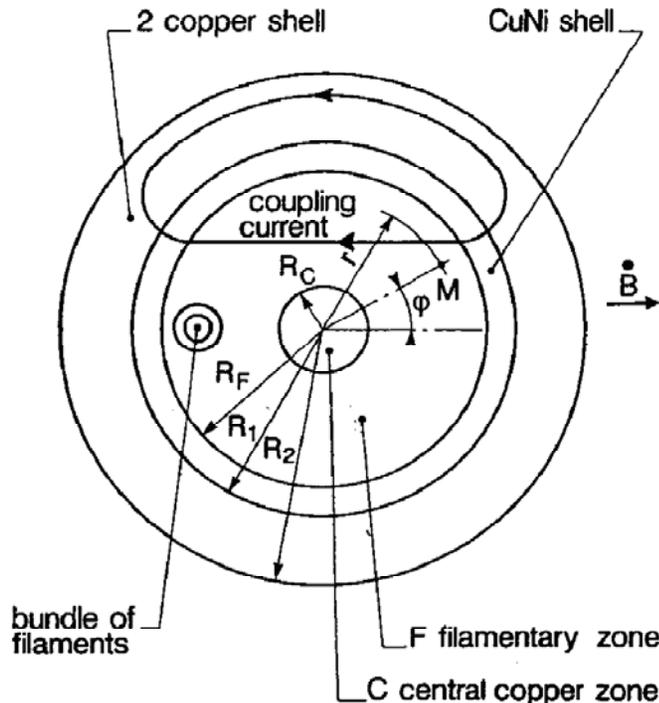
Transverse Resistivity



Wilson approach has been followed

Wilson has used the formulae computed by Duchataeu, Turck & Ciazynski, which assumed a four shell structure (left)

To take into account the more complex structure of our design, starting from the same physical assumptions, we have computed the **formulae for a 7 shell structure** (right).



We have also included the **eddy current loss in the Cu zone inside the wires**, which accounts for 20÷25 % of the wire losses (previously not included).



Filamentary zone resistivity



The resistivity of the filamentary is the averaged sum of the different zones: bulk Cu, bulk CuMn and filamentary zone.

For the filamentary zone we have considered the Carr approach, with the two extreme hypotheses of bad and good coupling.

-good coupling

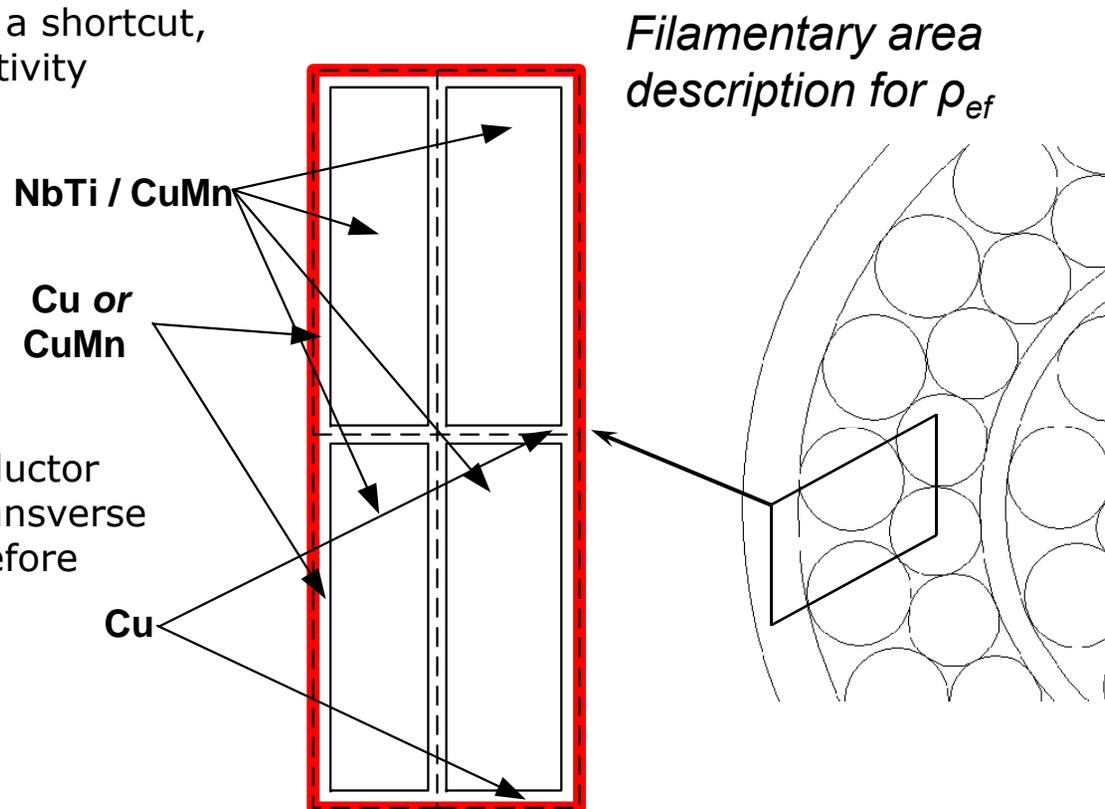
The superconductor effectively acts a shortcut, reducing therefore the matrix resistivity

$$\rho_t = \rho_m \frac{1 - \lambda}{1 + \lambda}$$

-bad coupling

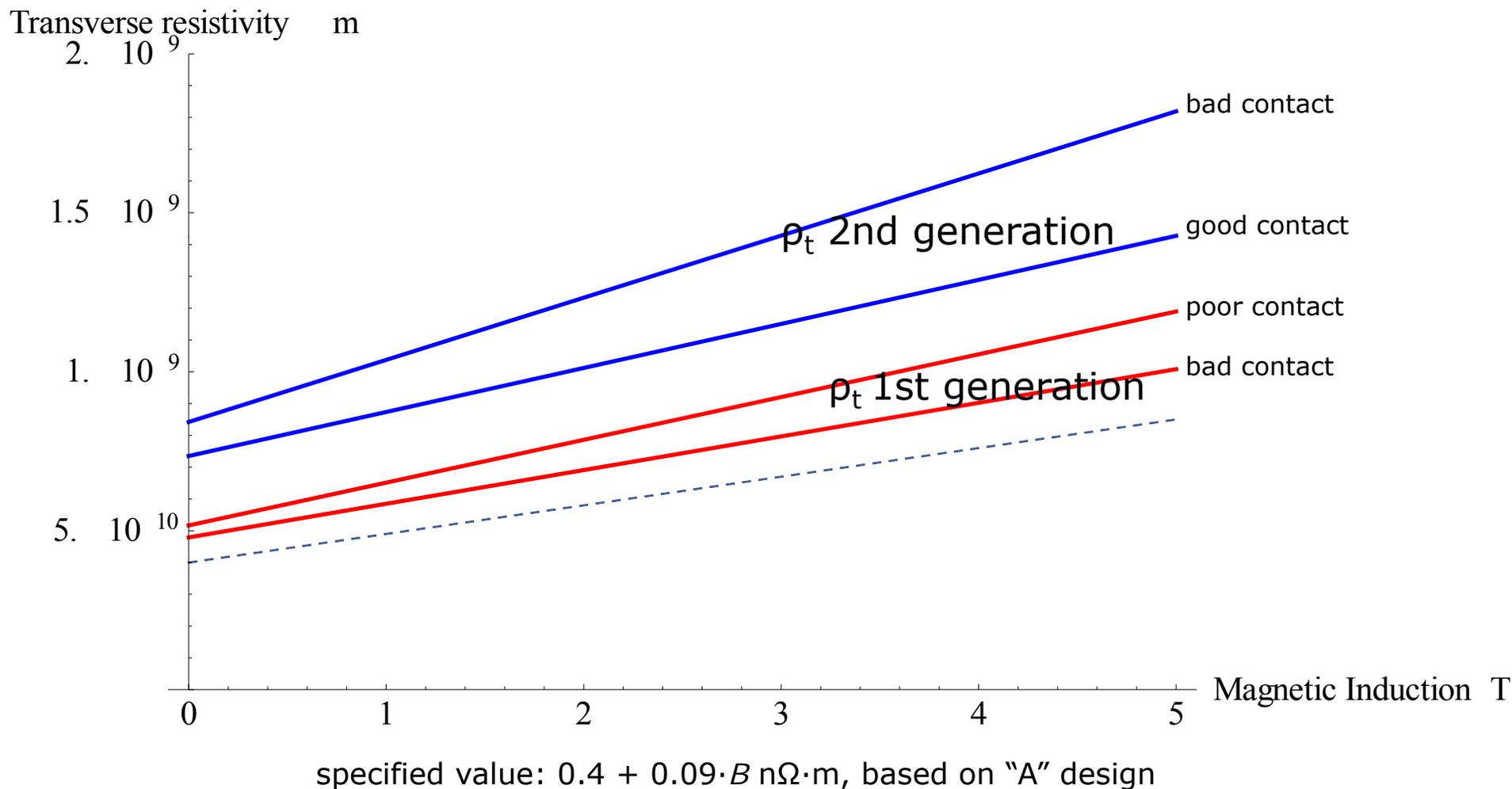
The high contact resistance between the matrix and the NbTi, prevents the current from flowing through the superconductor which does not contribute to the transverse current flow. The resistance is therefore enhanced.

$$\rho_h = \rho_m \frac{1 + \lambda}{1 - \lambda}$$





Expected transverse resistivity





Dynamic stability



The stability criterion seems satisfied

Thermal conductivity

Weighed average between NbTi and CuMn 1.87 W/mK

Approach "à la Carr" 1.14 W/mK

λ (NbTi fill factor in the bundle)

0.588

J_c @ 4.2 K, 5 T

2700 A/mm²

ρ_{Cu} @ 4.2 K, 5 T

$3.5 \cdot 10^{-10}$ ohm·m

$$d_{st} = \sqrt{\frac{k \cdot (\theta_c - \theta_o) \cdot (1 - \lambda)}{\lambda \cdot J_c^2 \cdot \rho}}$$

Characteristic length 32 μ m

Round filament factor form $4\sqrt{2}$ " 137 μ m

equivalent diameter $\ll 4 \cdot \sqrt{2} \cdot d_{st}$

Equivalent macrofilament diameter

Inner, Outer 60, 70 μ m (was 63-140 μ m in first design)

So the margin for stability seems comparable to the layouts envisaged by MNW in Rep 29. This issue was more doubtful in the first design (May '07)



Open issues



Cold drawing/extrusion

- is it really reliable?
- less bonding?, more prone to degrade at smaller twist pitch?

On the other hand, reportedly, cold drawing leads to:

- less sausaging
- smaller alpha variation along wire length

ρ_t is now close (higher) to specs for 1st generation and 2 times higher for 2nd generation

Dynamic stability better than the first design

Issues related to coating not yet considered