

# Laminar Superconducting Windings

(LT windings free of degradation)

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### What is the degradation ?

Degradation problem (a discrepancy between short samples tests and magnet winding performance) is as old as applied superconductivity itself. The discrepancy is determined by some difference in magnetic and mechanical conditions. There are some thermal excitation in a winding, which could locally overheat the conductor and trigger a quench. Modern stability theory allows develop a conductor tolerant to external magnetic conditions. One of the main parameters controlling conductor stability is smoothness of a SC transition curve. Too high value of n-index kills stability. Mechanical disturbances as well as sensitivity of NbSn conductor to compression are the inner problems of a winding. It must be solved by corresponding design of it.

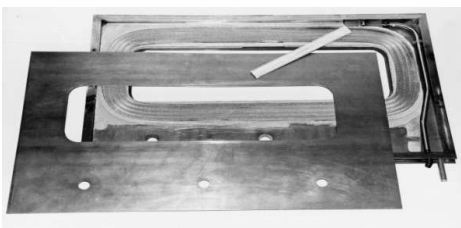
### Mechanical problems may be solved

It seems obvious that the mechanical conditions would be improved, if a conductor in a winding felt itself just as a sample at a holder, i.e. each turn should be rigidly supported along all its length and mechanical interactions between the turns should be excluded. It means that every large superconducting magnet must consist of a robust inert mechanical structure taken a whole magnetic force and unloaded conductor rigidly fixed at the structure. This task appeared not too complicated.

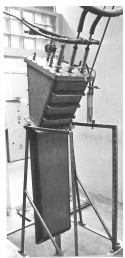
### Examples of laminar windings

Several this type magnets were manufactured and tested during the period 1985-2009. A set of stainless steel sheets were used as the robust structure. The SC pancakes were fixed with a strong LT adhesive. The windings were called "Laminar"

Nb-Sn inductor of a Linear Synchronizing Motor (Cryogenics ,v.32S, p.328-331 (1992))



( IEEE Transactions on Magnetics v.24, N2, p.882-885 (1988))



Specimen copy of toroidal 30 MJ SMES Sector(2004)



Fiberglass structures were used for magnets with fast changing fields



Set

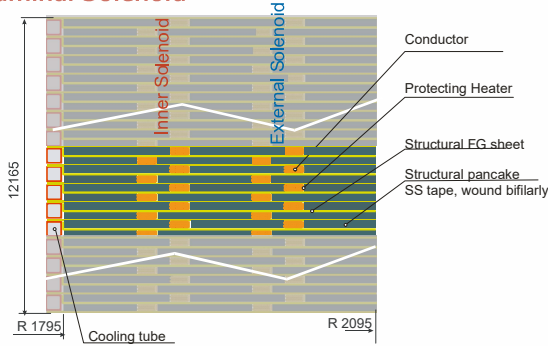
A laminar design appears quite simple in comparison with traditional magnets. There is no need in variety of fasteners and mounting hardware. The magnet components are rather simple and few in number. The laminar winding differs from impregnated one with the fact that neither the conductor nor the adhesive is subjected to critical strain in it. A strained object is the structure. Thus, there are no perturbations that can heat the conductor in the laminar winding.

### Aim of the presentation

We describe here a preliminary assessment of a very large winding utilizing laminar principle. We chose well known ITER central solenoid (CS) as a reference sample, considering that a speculation a certain abstract winding would not be interesting. By no means we intend to compete with this advanced project.

### Laminar Solenoid

A pair of electrically independent monolayer solenoids are energized by separate current sources in parallel . The subsequent turns are periodically shifted in both coils for better use of the structure. The adhesive bonded structure represents almost solid cylinder. It provides more homogeneous stress distribution than in traditional magnets. The solenoid is cooled indirectly owing to high temperature ( $\approx$ c) conductivity of the structure.



### Parameters of the solenoid and CS ITER

Parameter	Unit	Laminar CS	ITER CS	Parameter	Unit	Laminar CS	ITER CS
Height	mm	12 165	12 750	Inductance (internal coil)	H	1.953	7.29
Inner radius	mm	1 795	1 354.5	Inductance (external coil)	H	2.155	
Outer radius	mm	2 095	2 095.5	Mutual Inductance	H	2.147	
Number of turn (internal)		1 430	3 288	Operating current (internal coil)	kA	30	41.5
Number of turns (external)		1 430		Operating current (external coil)	kA	60	
Overall Length of conductor	km	34.83	35.64	Stored energy	GJ	8.62	6.28
Overall mass	t	282	650	Maximum Field at a winding	T	13.2	13,5
Mass of conductor	t	32.36	138	Operating voltage	kV	6.25/6.45	10
				Voltage between turns	V	4.5	20

### Structure components

Fiberglass sheets 2 mm thick (max. compression 245 MPa).

Functions:

1. Insulation,
2. Turns fixation,
3. Indirect cooling of turns. High thermal and temperature conductivities are provided with copper wires (and sapphire filaments) incorporated into fiberglass sheet.

Pancakes wound with insulated Stainless Steel tape 6.5 mm height.( max tensile stress 645 MPa)

Functions:

- 1.Winding robustness,
- 2.Preventing of conductor compression,
- 3.Eddy current limitation.

Film adhesive VK-36 ( 90 MPa shear)

Fixation of the conductor and structure elements. It allows dry manufacturing process.

Protecting heater (bifilar)

Discharge of a capacitor heats adjacent wires up to 20K and triggers a quench.



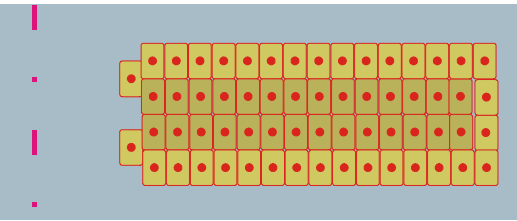
Well thermal conducting fiberglass



A bifilar pulse heater (40 nH/m)

### Conductor for laminar solenoid

The Laminar CS is wound with a heat treated niobium-tin conductor.



This is Röeble cable folded in two.\*

\*) Flat low-loss composite electric conductor made of electric conductive strands. EP 1 349 183 B1.

### Main parameters of the conductor

Parameter	unit	Value
Conductor cross section	mm2	6 x 16
Wire cross section	mm2	1 x 1.5
Number of wires in conductor		62
Transposition pitch	mm	240
Wire Critical current in 13.2/9.24 T	A	626/1196
Wire "n" index according to specification		40
Operating currents	kA	30/60
Conductor "n" index		20

### Main features of the conductor

1. The raw conductor manufacturing process does not damage Nb filaments.
2. Rectangular wires cross section provides high space factor without wire deformation and also flat conductor surfaces are favourable to adhesive bonding .
- 3.The folded conductor has a convenient aspect ratio in spite the large number of small cross section wires.
4. Coupling losses are limited inasmuch as there are not currents in the major folded loops with two contacts, and minor loops have four contacts.
5. An uniq feature of the conductor: each wire deforms independently during the winding process, when the conductor being wound flatwise around an axis, located on the other hand of a line of folding up (look at Fig). In this case the inner and external layers are slipping with respect each other.

### Conclusion

The presented preliminary assessment shows that the laminar principle promises considerable simplification of design and manufacturing of very large SC windings, reduction of margins and costs coming down.

The relatively cheap R&D program would be able to convince SC community in this statement, to check reliability of the method and to take off existing prejudices.