MT25

The Effect of Winding Condition on the Stress Distribution in the 10.7 T REBCO insert for the 25.7 T Superconducting Magnet

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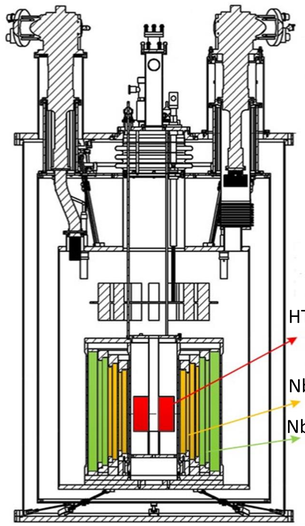
Abstract

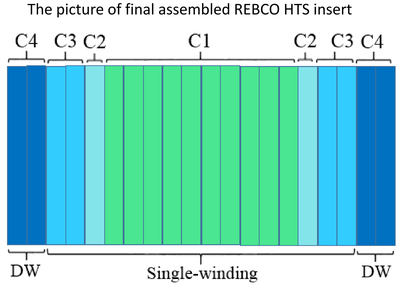
A 25.7T all-superconducting NMR magnet, consisting of a 10.7 T REBCO high temperature superconducting (HTS) insert and 15 T low temperature superconducting (LTS) outer coils, has been achieved at Institute of Electrical Engineering, Chinese Academy of Sciences. To avoid the mechanical failure in the HTS insert, the effect of pretension load applied on the REBCO tape and overband conditions outside of the HTS insert on the stress distributions in the HTS magnet has been investigated in this paper. A check test conducted after the superconducting magnet quenched at 25.7 T show that there is no mechanical failure. The optimized pretension and overband process could protect the HTS insert from the excessive electromagnetic force when the central field beyonds 25 T.

Magnet Construction



The schematic of the 25.7 T all-superconducting magnet

The picture of final assembled REBCO HTS insert



The schematic drawing of 20 DP coils assembly

SPECIFIC PARAMETERS OF C1-C4 DP COILS

Parameters	C1	C2	C3	C4
	GdBCO	YBCO		
Manufacture	SuNAM	Superpower		
Tape width/ mm	4.1	4.1		
Tape thickness /mm	~0.155	~0.0967		
Copper Layer /um	~30	~40		
Thickness of SSL /um	45	--	--	--
Winding type	SW*	SW	SW	DW*
DP coil I.D. /mm	36	36	36	36
DP coil O.D. /mm	103	103	103	103
DP height /mm	9.2	9.2	9.2	9.2
Number of DP	10	2	4	4
Turns per DP	226	247	293	111
Conductor per DP	100	100	120	100
Ic @ 77 K, self filed	>150 A	>120 A		
95% Ic retention stress @77K/ Mpa	>550	>700		

*** SW: single-winding technique** *** DW: double-winding technique**

Stress Distribution Analysis

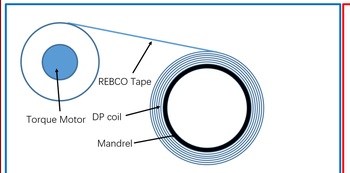


Fig.4 The schematic of single-winding technique

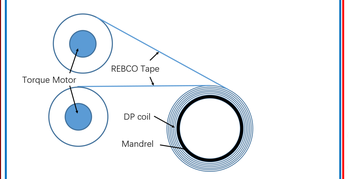
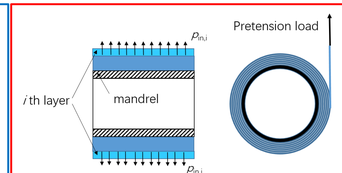


Fig.5 The schematic of double-winding technique



$$p_{ou,i-1} = -p_{in,i} = -\frac{\sigma_{pr,i} d_i}{r_{ou,i-1}}$$

$$\sigma_{rc}(i) = \sum_{n=i+1}^{M} \sigma_r(n,i)$$

$$\sigma_{hc}(i) = \sigma_{pr,i} + \sum_{n=i+1}^{M} \sigma_h(n,i)$$

$$\sigma_r = k_1 r^{-1+\sqrt{E_h/E_r}} + k_2 r^{-1-\sqrt{E_h/E_r}}$$

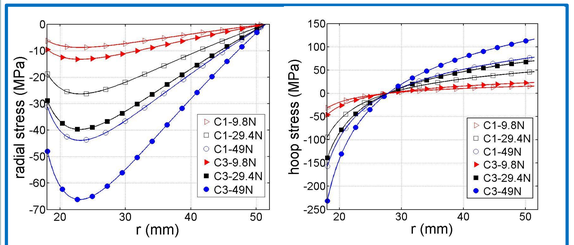
$$\sigma_h = k_1 \sqrt{E_h / E_r}\, r^{-1+\sqrt{E_h/E_r}} - k_2 \sqrt{E_h / E_r}\, r^{-1-\sqrt{E_h/E_r}}$$

- The combined homogeneous cylinder method is adopted in the analysis
- Each turn in a DP is modeled as a concentric ring and numbered as *i*=1,2,3, … ,M from the inner to the outer part.
- The plane stress condition was adopted and shear stress was neglected in the calculation

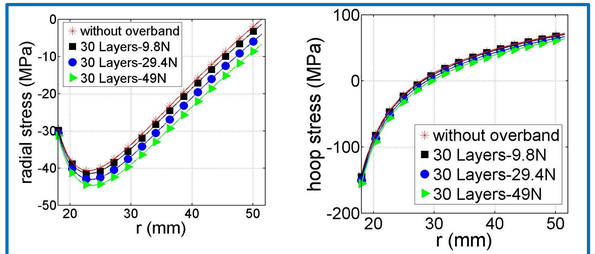
- The σ_r on the *i*th layer is the accumulation of the radial stress from winding the M-*i* layers outside of the *i*th layer.
- The σ_h applied on the *i*th layer is the accumulation of the pretension stress applied on the *i*th layer and the hoop stress induced by the winding of (M-i) layers

- The Stainless steel tape with a thickness of 0.1 mm and a width of 4.1 mm is selected as the overband.

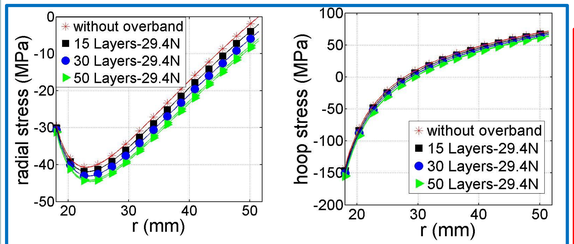
Results



- The C1 and C3 DP coils are selected to be compared
- There is no overband outside of the DP coil for this case
- The pretension load on the REBCO tape varied from 9.8 N to 49 N.



- The C3 DP coils are selected to analyze the effect of pretension load on the overband (SS tape).
- The pretension load applied on the SS tape varied from 9.8 N (1 Kg) to 49 N (5 Kg).
- The layers of overband are restricted to 30.



- The C3 DP coils are selected to analyze the effect of the layers of overband (SS tape).
- The layers of overband varied from 15 to 45.
- The pretension load applied on are restricted to 29.4 N (3Kg).

The comparison of final stress after the superconducting magnet is energized to 25.7 T

	Without pretension load and overband	Pretension load: 29.4 N Overband: 30 layers_29.4 N
Maximum tensile hoop stress	430.1 Mpa	270.77 Mpa
Maximum tensile radial stress	58.91 Mpa	12.31 Mpa

Checking Test

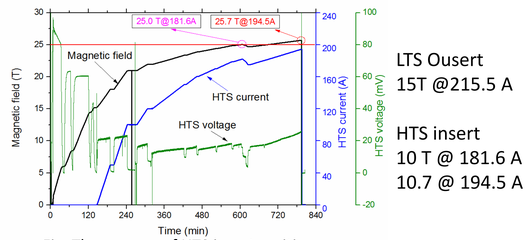
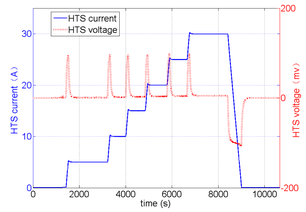


Fig. The process of HTS insert exciting

LTS Ousert
15T @215.5 A

HTS insert
10 T @ 181.6 A
10.7 @ 194.5 A



An operating current of 30 A was ramped into the HTS insert at 35 K. The results show that the superconductivity of the HTS insert is not deteriorated after it quenched at 25.7 T.

Conclusion

- The effect of winding process on the stress distributions in a 10.7 T HTS insert for the 25.7 T all-superconducting magnet was investigated in this paper.
- A pretension load of 29.4 N on the REBCO tape, and 30 layers of SS tape with pretention load of 49 N wounded on the HTS DP coils were selected while the HTS insert was manufactured.
- The decreasing of hoop and radial stress in the HTS insert after it is energized to 25.7 T is significant.
- A damaging check test conducted after the superconducting magnet quenched at 25.7 T verify the effectiveness of the analysis.