Optimal Design Methodology of Multi-Width HTS Magnet for Minimum Wire Consumption

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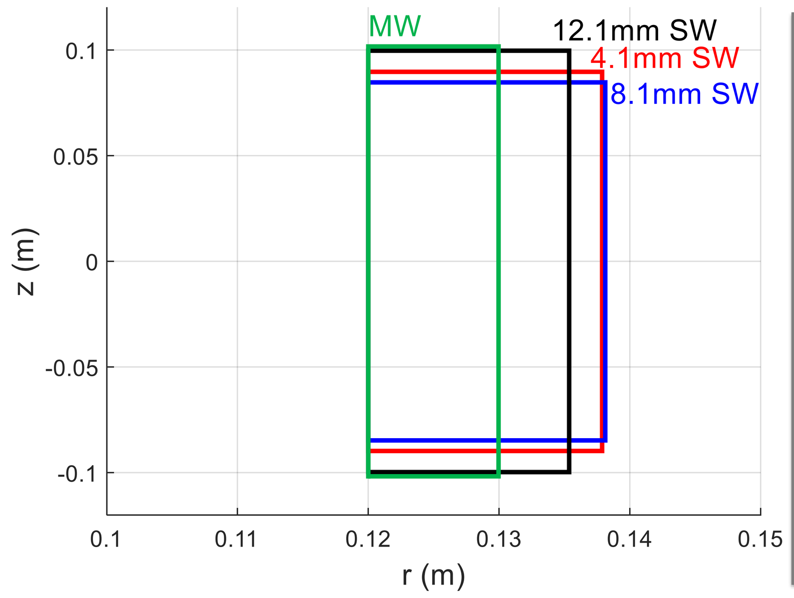
Background

- It is well known that critical current (I_c) of an high temperature superconductor (HTS) magnet comprising a stack of pancake coils is limited by that of "one" pancake, while the rest of the pancakes still have substantial margin to their own I_c.
- This unfavorable design issue is often mitigated by the so-called *multi-width* (MW) technique, where pancake coils wound with the narrowest tapes were placed at and near the magnet center and those with progressively wider tapes toward the top and bottom of the magnet.

Objectives

- This paper investigates an optimal design methodology for MW HTS magnets.
- For a given design target of field strength and winding bore, input parameters include tape width, number of grading tapes, and number of pancakes coils for each tape, while the main objective is to minimize the magnet volume, i.e., essentially the stored energy and thus the cost.
- A magnet with a single-width tape is also designed as a control sample for comparison.

Conclusion



- Optimal design process of Multi-Width (MW) magnet was proposed and verified.
- A 3-T/ 240-mm HTS magnets, both MW and SW, was designed as a case study. In this case, wire consumption was reduced by 40% from 4.9 km (SW) to 3.1 km (MW).
- The results are expected to be beneficial to determine the practical level of HTS tape grading and estimate a volume of an MW magnet.
- Further grading of the tapes, say in every 0.5 mm, may be beneficial in terms of mitigating the tape's angular dependency in the magnet.

Design method

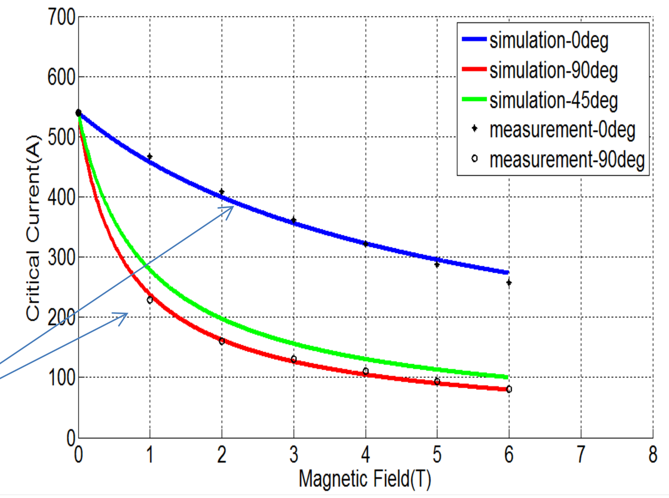
Estimation of critical current

Considering parallel $B_\parallel$ and perpendicular $B_\perp$

$$I_c(B_\parallel, B_\perp) = \frac{I_{c0}}{\left(1+\frac{\sqrt{k^2 \cdot B_\parallel^2 + B_\perp^2}}{B_0}\right)^\beta} \quad (1)$$

where I_{c0}, k, B_0, and β are determined by fitting the two lines.

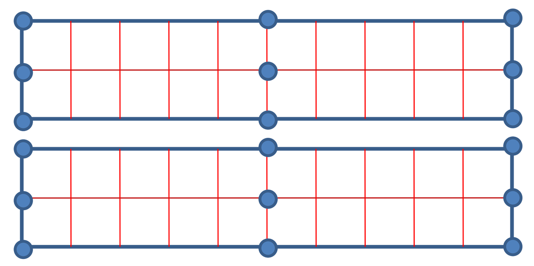
In this case, I_{c0} = 540, k = 0.1241, B_0 = 0.4981, β =0.7444.



I_c vs. B for REBCO tape (4-mm width) @20K

Curve fitting graphs.

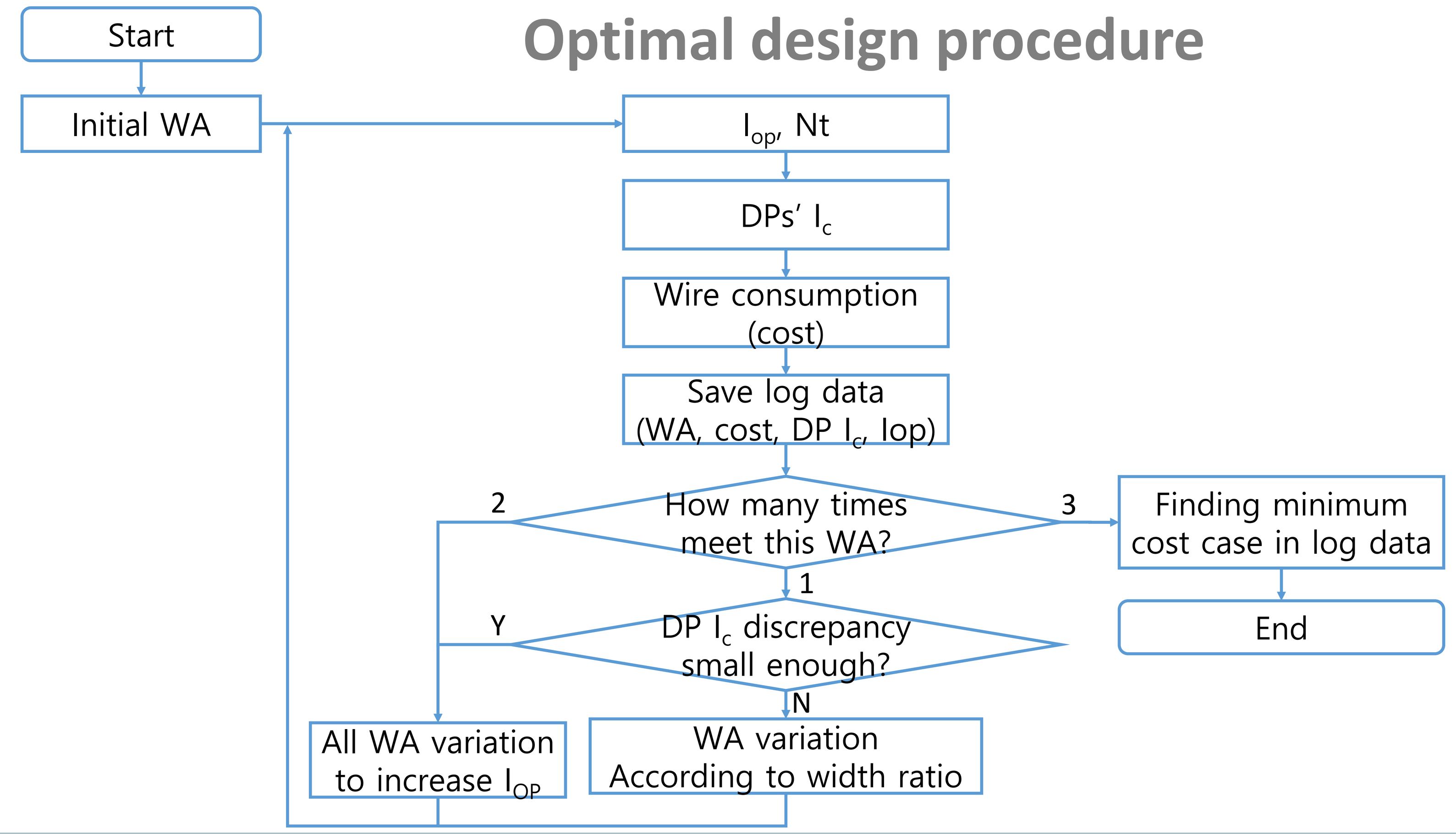
Calculation of DP's Ic



1) Calculation B_r and B_z at the edges and midpoints (18 blue dots)
2) Calculation B_r and B_z at 60 points by polynomial curve fitting
3) Estimation I_c at 60 points using Eq. (1)
4) Finding minimum I_c among 60 points

Optimal design

Optimal design procedure



#	Width Arrangement (WA) From central DP to uppermost DP						DP I_c						Cost (km)
1	8	8	8	8	8	8	648	591	525	452	369	255	4.94
2	6	6	7	8	10	12	439	342	364	378	455	428	3.47
3	6	7	8	9	9	11	387	409	445	492	406	375	3.29
4	7	8	8	8	10	12	486	550	490	393	458	418	3.4
5	7	7	8	10	10	12	515	409	416	552	465	417	3.33
6	7	8	9	9	10	12	467	493	554	477	462	415	3.39
7	6	7	7	8	9	11	397	451	378	398	397	373	3.12

Example of optimal design process; 3-T 240-mm case.

Results

Case study of a 3-T 240-mm HTS magnet

# of DPs	Length (km)	I_{op} (A)	B_0 (T)	Width Arrangement (WA)
8	3.422	374.9	3.011	7 8 10 12
10	3.274	313.7	3.007	6 6 7 8 10
12	3.121	373.3	3.012	6 7 7 8 9 11
14	3.201	400.1	3.019	6 7 7 8 9 9 12
16	3.173	382.4	3.028	6 6 7 7 7 8 9 11
18	3.235	415.8	3.027	6 7 7 7 7 8 8 9 12
20	3.315	390.9	3.034	6 6 6 7 7 7 7 8 9 11

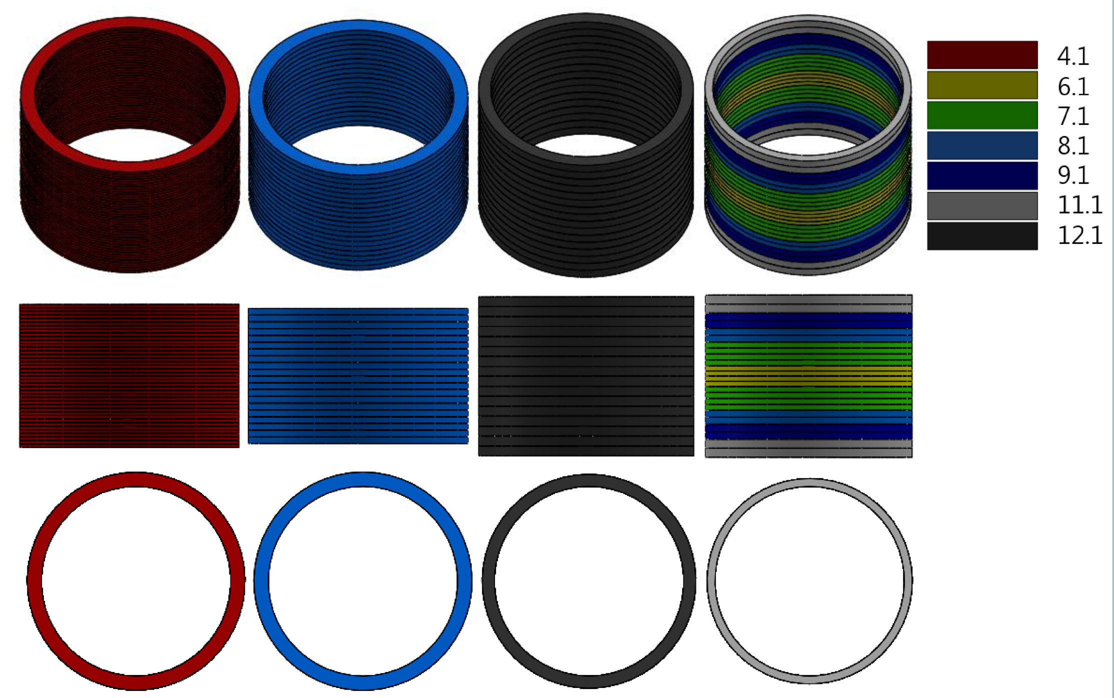
Minimum length case with respect to number of DPs.

Starting case	4.1-mm SW						Length (km)	8.1-mm SW						Length (km)	12.1-mm SW						Length (km)
Initial	4	4	4	4	4	4	5.373	8	8	8	8	8	8	4.942	12	12	12	12	12	12	5.434
Process	4	5	6	7	9	11	4.223	6	6	7	8	10	12	3.468	5	5	6	6	8	12	3.862
	5	6	7	7	7	9	3.423	6	7	8	9	9	11	3.290	5	6	7	8	9	10	3.488
	6	6	6	7	9	11	3.488	7	8	8	8	10	12	3.398	6	7	7	7	8	11	3.373
				⋮			⋮	7	7	8	10	10	12	3.329	6	6	7	8	10	12	3.468
	6	6	6	8	9	10	3.753	7	8	9	9	10	12	3.390	6	7	8	9	9	11	3.290
	7	7	7	9	10	11	3.566	6	7	7	8	9	11	3.121	7	8	8	8	10	12	3.398
	6	7	9	9	10	12	3.485								7	7	8	10	10	12	3.329
	7	8	10	10	11	12	3.620								7	8	9	9	10	12	3.390
	6	7	7	8	9	11	3.121								6	7	7	8	9	11	3.121

Process of finding the optimal case with various starting cases.

Comparison with single-width magnet

Parameter	Single-Width			Multi-Width
	4.1	8.1	12.1	
Inner Diameter (mm)	240			
Target Field (T)	3			
Wire thickness (mm)	0.12			
Operating temperature (K)	< 20			
Outer Diameter (mm)	275.76	276.24	270.72	259.92
Height (mm)	179.4	169.4	199.4	203.4
Number of DPs	20	10	8	12
Operating current (A)	126.3	245.2	378.2	373.3
Magnetic field (T)	3.009	3.012	3.002	3.012
Total wire consumption (km) (4.1mm equivalent)	4.912	4.923	4.921	3.121



Comparative schematics among 3 SW cases and MW.

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