Design and Performance Estimation of a 20 T No-Insulation all-REBCO User Magnet

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1. Introduction

This paper reports a design and performance estimation of a 20 T no-insulation (NI) high temperature superconductor (HTS) standalone user magnet currently being developed at the National High Magnetic Field Laboratory, hereinafter named '*NI20T*'. It consists of a stack of 18 double pancake coils wound with tapes from two different vendors, SuNAM and SuperPower, in consideration of their complementary in-field critical current and mechanical properties. The inner and outer winding diameters and overall winding height of the magnet are 46 mm, 102.6 mm, and 163.4 mm, respectively. The magnet is designed to generate a center field of 20 T at its nominal operating current of 316 A in a bath of liquid helium at 4.2 K. The inductance and stored energy are 1.89 H and 94.5 kJ, respectively. First, we report key design parameters followed by numerical simulations on: (1) Magnetic field performance, stress analysis; (2) NI charging behaviors and estimation of liquid helium consumption; (3) post-quench behaviors including a local temperature rise.

2. Magnet design

a. Key Parameters of NI20T

Parameter	Unit	Module-1	Module-2	Module-3
REBCO tape				
Manufacturer		SuNAM	SuperPower	
Width; thickness	[mm]	4.1; 0.12	4.1; 0.096	6.1; 0.096
Substrate thickness	[mm]	0.1	0.05	0.05
Cu stabilizer thickness	[μm]	7.5 (per side)	20 (per side)	20 (per side)
I_c at 77 K, self-field	[A]	150		
Equivalent Young's modulus (E_r, E_h, E_z)	[GPa]	107; 168; 168	72; 130; 130	
Equivalent Poisson's ratio (ν_{rh}, ν_{hz}, ν_{rz})		0.21; 0.33; 0.21	0.18; 0.33; 0.18	
Magnet configuration				
Inner; outer diameter	[mm]	46; 102.6		
Overall height	[mm]	163.4		
Turns per Pancake		236	295	
Number of DP coil		10	6	8
Total conductor per module	[m]	1,102	828	276
Estimated R_c[a]	[mΩ]	24.7	18.9	4.1
Operation				
Center field, B_c	[T]	20		
Operating current, I_{op}	[A]	316		
Operating temperature, T_{op}	[K]	4.2		
Conductor current density, J_e	[A/mm²]	642.3	802.8	539.6
Inductance, L	[H]	1.89		
Storage energy at I_{op}	[KJ]	94.4		
Estimated time constant, τ	[sec]	39.6		

[a]Contact surface resistance: R_{ct}=50 μΩ·cm²

b. Configuration of the NI20T

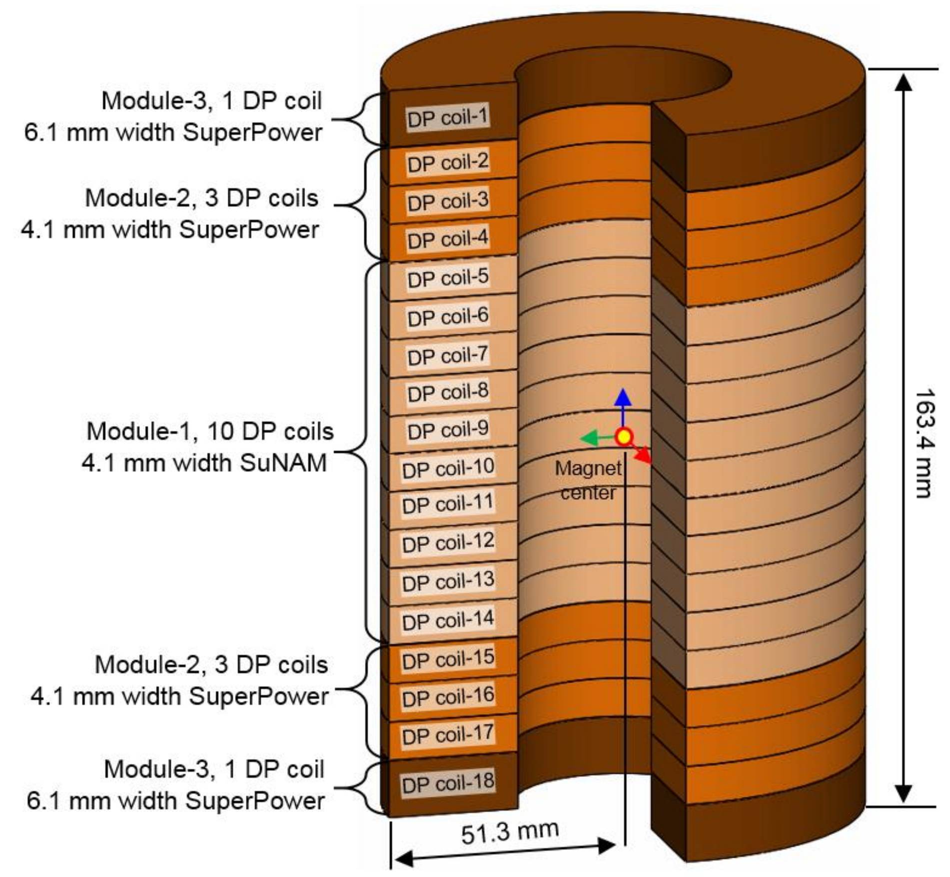

Fig. 1. To-scale drawing of the 20 T NI magnet.

c. Magnetic Field and Critical Current Distribution

- Estimated critical current (I_c) in consideration of B_{norm}, θ, and tape width at 4.2 K.
- The minimum I_c of modules-1, 2 and 3 are calculated to be 565 A, 436 A and 493 A, respectively.

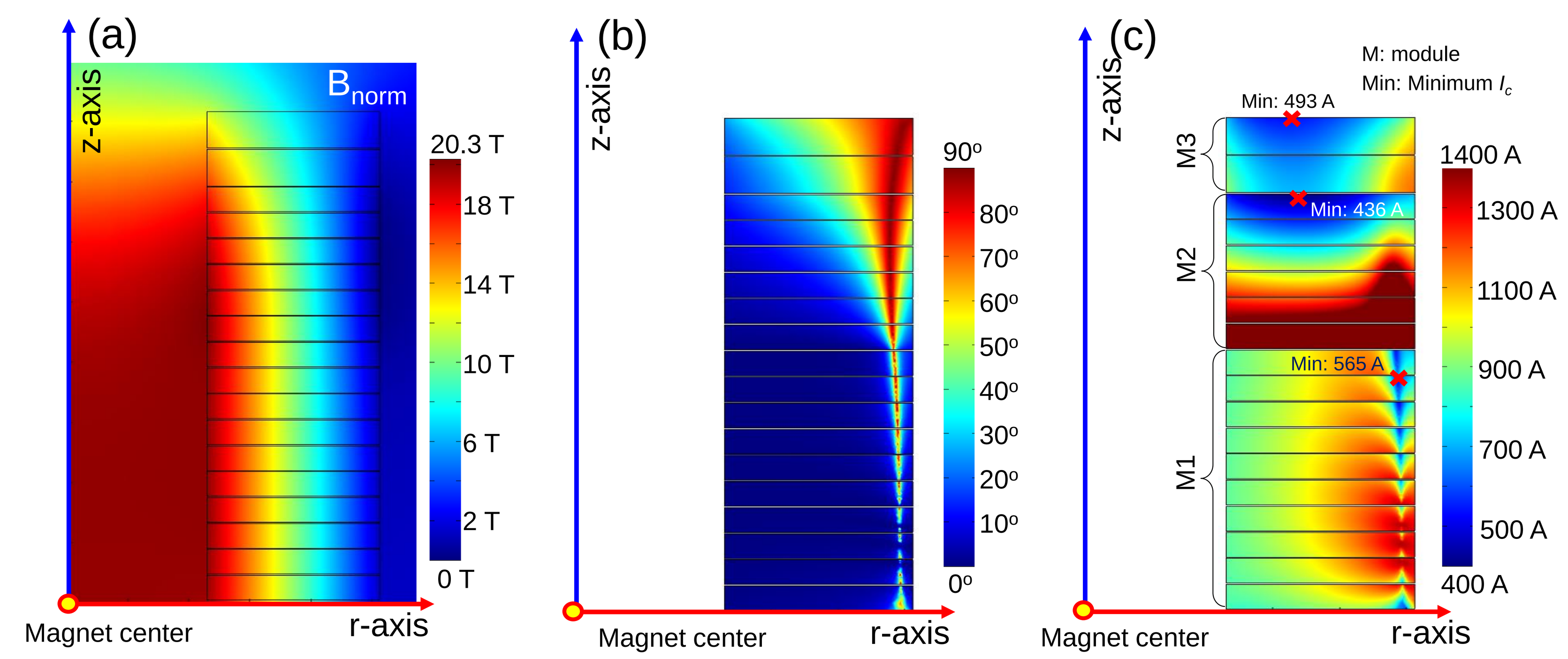

Fig. 2. Magnetic field distribution and critical current estimation of NI20T; (a) normal magnetic field distribution, (b) Field angle (θ) distribution, (c) critical current distribution.

d. Stress and Strain

- Force equilibrium and generalized Hook's laws were used.
- Since NI20T is expected to be "dry-wound" without using epoxy, the so-called "self-supporting-turn" characteristic of NI20T is also considered in the stress analysis.

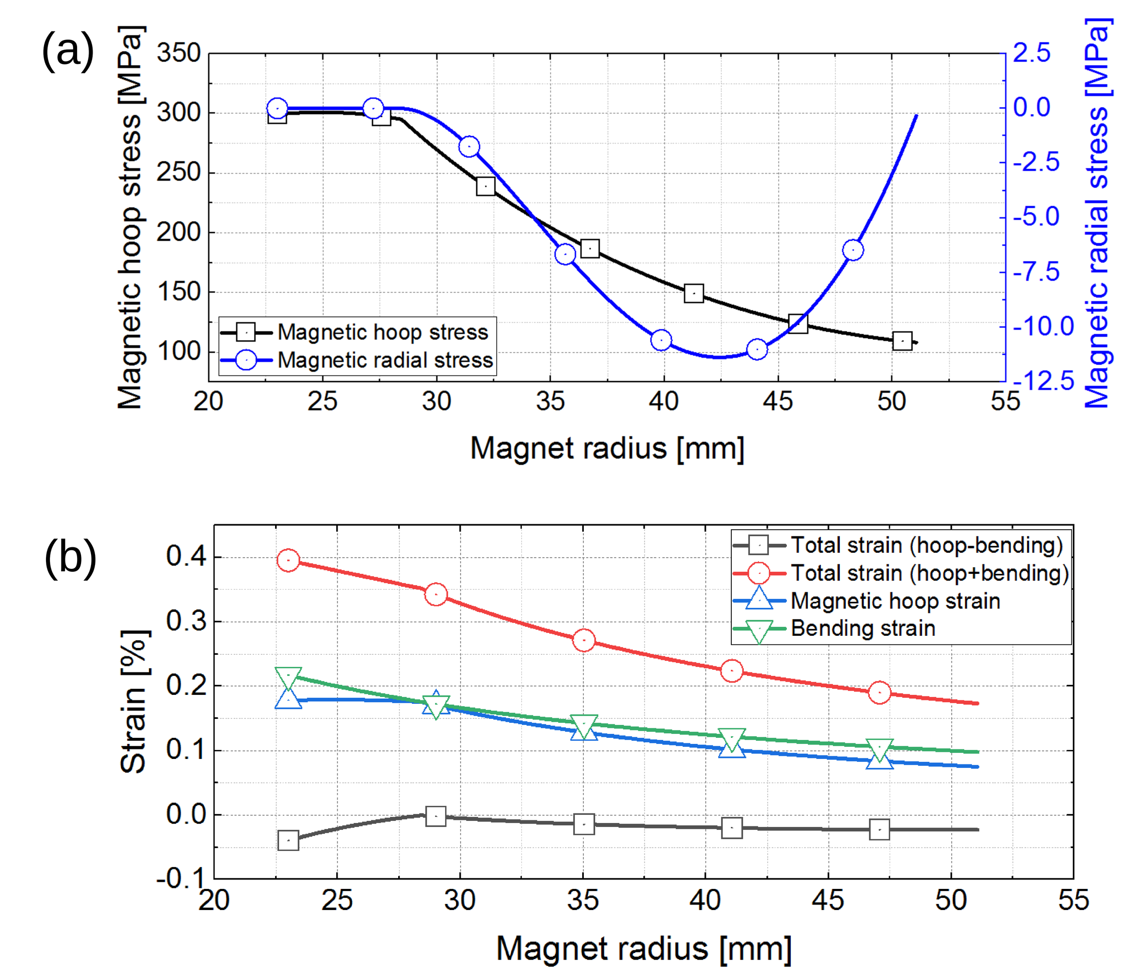

Fig. 3. Mechanical characteristics on axial midplane of NI20T; (a) magnetic hoop stress and radial stress, (b) overall calculated strains including magnetic and bending strains.

Performance Estimation of NI20T

a. Charging behaviors

- A lumped circuit model was used for charging and quench behavior analysis of the NI20T.
- The calculated τ_c was 39.6 seconds for NI20T. With a constant ramping rate of dI_{ps}/dt = 0.2 A/sec, the time to reach the target magnetic field after the power supply current reached 316 A is calculated to be ≈3.3 minutes for NI20T.

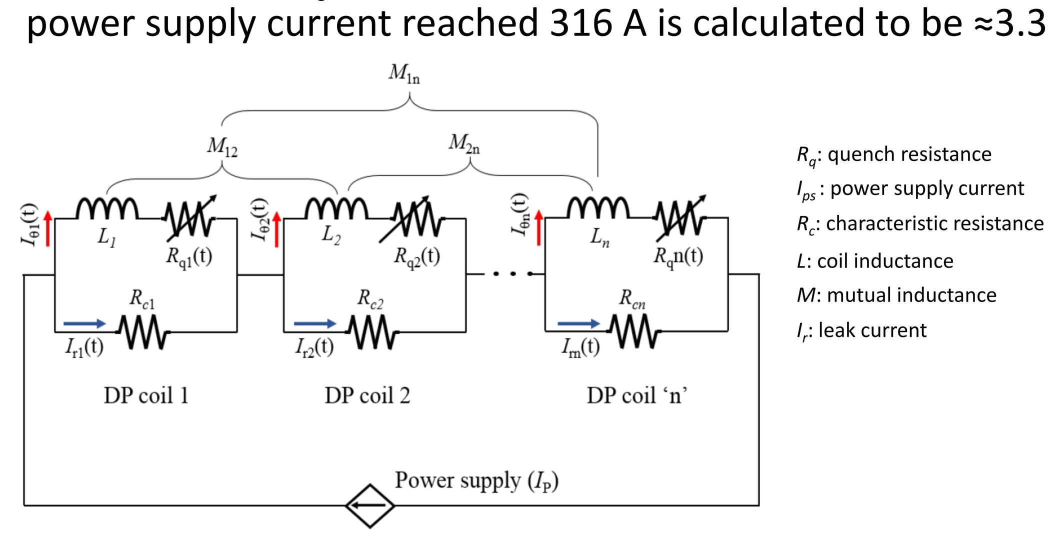

Fig. 4. Lumped circuit model for the charging characteristic and the quench simulation of the 20 T NI magnet.

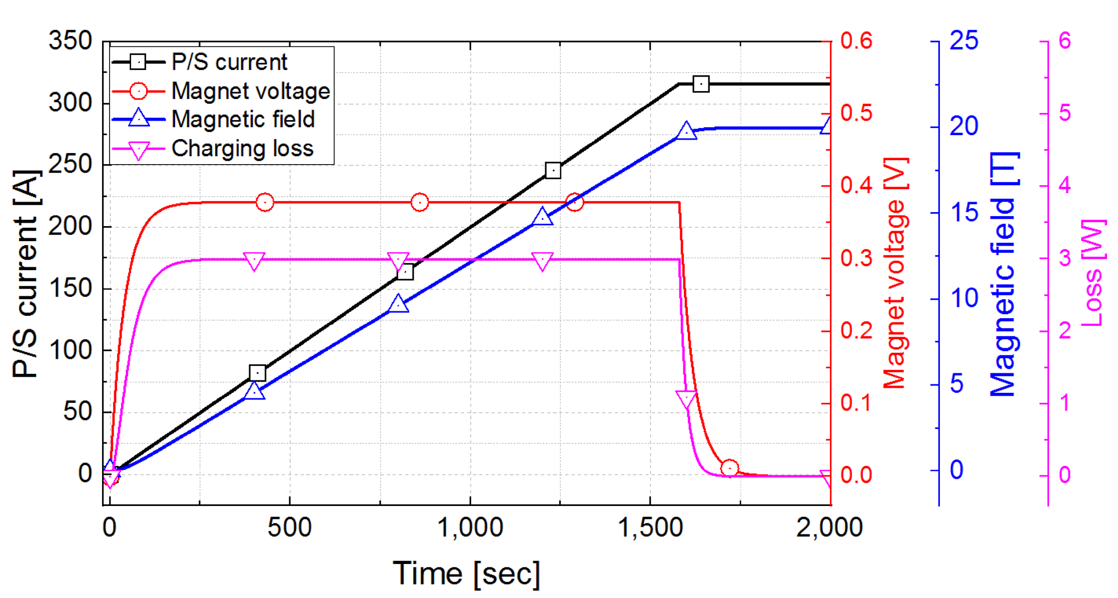

Fig. 5. Charging delay analysis results of NI20T (ramp rate: 0.2 A/sec).

b. Post-quench behaviors

- The quench propagates to all pancake coils in about 0.32 s
- During the quench propagation, some DP coils experience overcurrent (Fig. 6). The peak current is calculated to be 830 A in DP18 at t = 0.28 s.

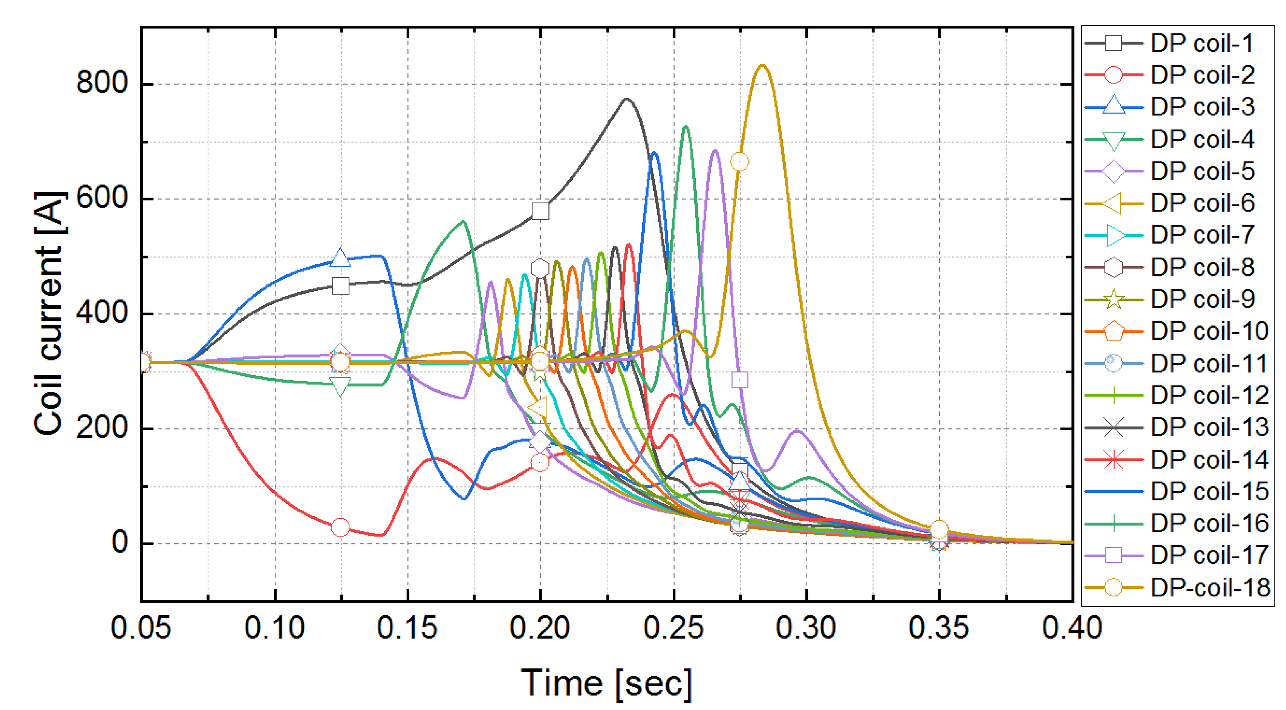

Fig. 6. Azimuthal current pattern of each DP coil during quench; (a) module-1, (b) module-2 and 3.

- After NI20T is completely discharged, the highest and lowest final temperatures of DP coils of NI20T are calculated to be 117 K (DP coil-16) and 88 K (DP coil-5), respectively.
- larger amount of energy is dissipated in the end DP coils.

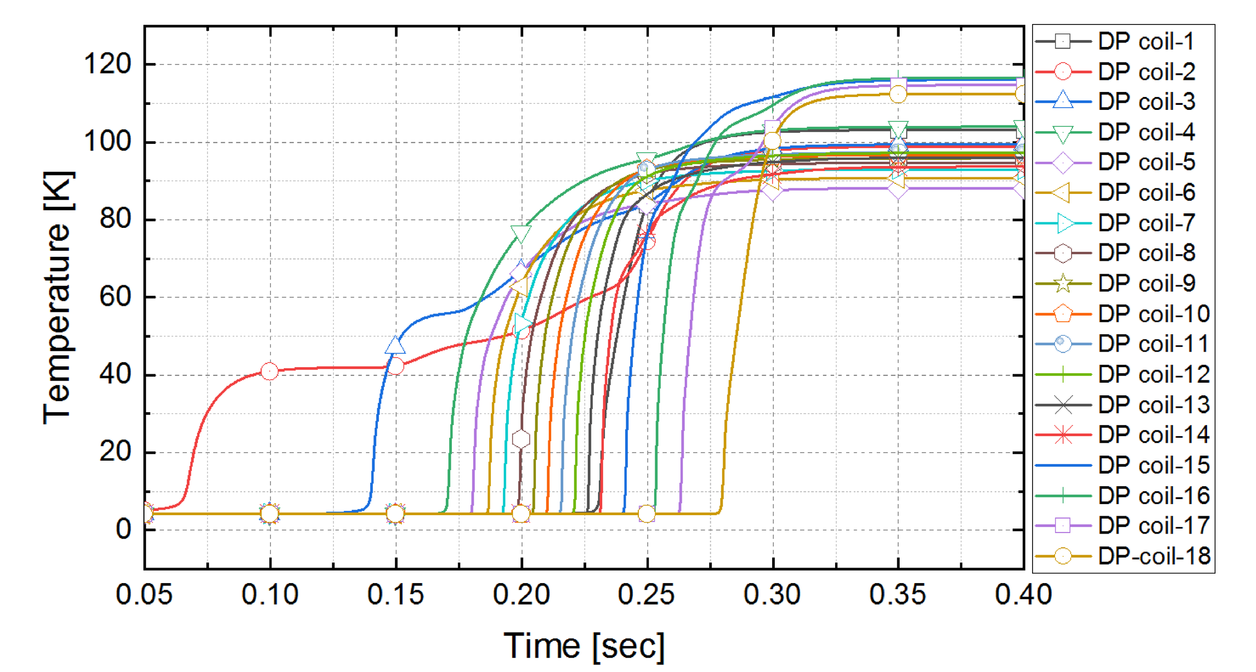

Fig. 7. Temperature variation of each DP coil during quench; (a) module-1, (b) module-2 and 3.

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