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A Conceptual Study on "Magnetic Dam" to Absorb Electric Quench Energy in NI HTS Magnet

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Abstract -When a quench occurs in a high field no-insulation (NI) high temperature superconductor (HTS) magnet that consists of a stack of double-pancake (DP) coils, a large amount of current is often induced in an NI DP coil that is electromagnetically coupled with neighbor DP coils. Depending on the strength of external magnetic field, the large induced current leads to an excessive magnetic stress and occasionally damages the magnet. In this paper, we propose a new quench protection concept to reduce the amount of induced current in an NI HTS magnet. The key idea is to use resistive copper in order to absorb a portion of electromagnetic energy that is initially stored in the magnet before the quench. We tentatively name these resistive coils or plates as a ``magnetic dam,'' as they may slow down the electromagnetic quench propagation speed among the NI DP coils, which may be beneficial to avoid the mechanical damage by the large over-current.

◆ Introduction: A Copper Coil to Slow Quench Propagation in NI HTS Magnet

- A conceptual design of copper coil to absorb some of the stored energy in NI HTS magnet to slow down quench propagation
- Performance evaluation of the protection coil using a case study of over-current quench simulation of 7 T/78 mm multi-width NI HTS magnet

◆ Concept of Magnetic Dam : Energy Transfer from NI Coil to Copper Coil

- A key idea of "magnetic dam" is using a copper coil to absorb the stored magnetic energy in NI coil and prevent mechanical damages in NI coil from large induced current
- The energy transfer between an NI HTS coil and a copper coil was analyzed using analytic calculation by our team.[1]
- By the analysis using lumped parameter equivalent circuit model (Fig. 1), a copper coil should satisfy the following conditions to absorb at least half of the stored energy in the NI coil

$$k \cong 1 \quad \cdots \quad (1) \qquad (k \text{ : magnetic coupling coefficient})$$

$$\frac{L_{sc}}{R_{sc}} \le \frac{L_{cu}}{R_{cu}} \quad \cdots \quad (2)$$

- In this study, it is assumed that these conditions can be directly adopted to a magnetic dam for n-subcoil magnet

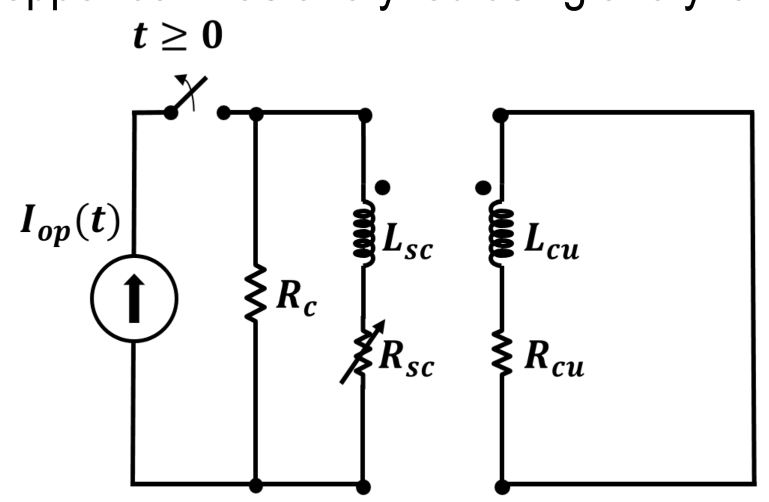


Figure 1. Equivalent circuit of a copper coil electromagnetically coupled with an NI HTS DP coil using lumped parameter circuit model.

I_{op} : operating current R_c : contact resistance
R_{cu} : copper resistance R_{sc} : superconductor resistance
L_{cu} : self inductance L_{sc} : superconductor inductance

◆ Case Study : Over Current Quench Simulation of 7 T/78 mm NI HTS Magnet

- The magnet was designed and constructed by Hahn *et al.* in MIT[2],[3], and its key parameters are shown in Table 1.
- It consists of 13 DP coils, five 4.1 mm width DP coils and 5.1, 6.1, 7.1, 8.1 mm width one by one as shown in Fig. 2.
- The over-current quench test of the magnet was performed by Song *et al.* in MIT[4], and the quench simulation was don by Bhattarai *et al.* in FSU[5].
- In this paper, the performance of magnetic dam was evaluated with this over-current quench simulation using the lumped parameter equivalent circuit model.

Parameters	C1	C2	C3	C4	C5
Average width [mm]	4.1	5.1	6.1	7.1	8.1
Inner diameter [mm]			78.0		
Outer diameter[mm]			101.8		
Number of DP[mm]	5×1	1×2	1×2	1×2	1×2
Turn per pancake			140		

Table 1. Key parameters of 7 T/78 mm multi-width NI REBCO magnet

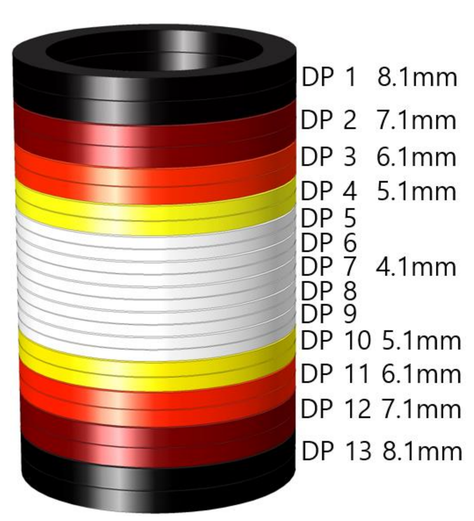


Figure 2. Configuration of 7 T/78 mm multi-width NI REBCO magnet

◆ Verification of Quench Simulation : Using Lumped Parameter Circuit Model

I_r : radial current I_θ : azimuthal current
R_c : contact resistance R_{sc} : superconductor resistance
L : self inductance M : mutual inductance

- The superconductor resistance, R_{SC} was represented using index value model where the index value is 20.
- The critical current density was calculated using interpolated and extrapolated experimental data of SuNAM HTS tape.
- It was assumed that R_{SC} saturates when it reaches stabilizer resistance of the tape.
- In thermal analysis, the following assumptions were used : (1) the simulation was performed in adiabatic condition; (2) the Joule heat from contact and superconductor resistance was only considered.

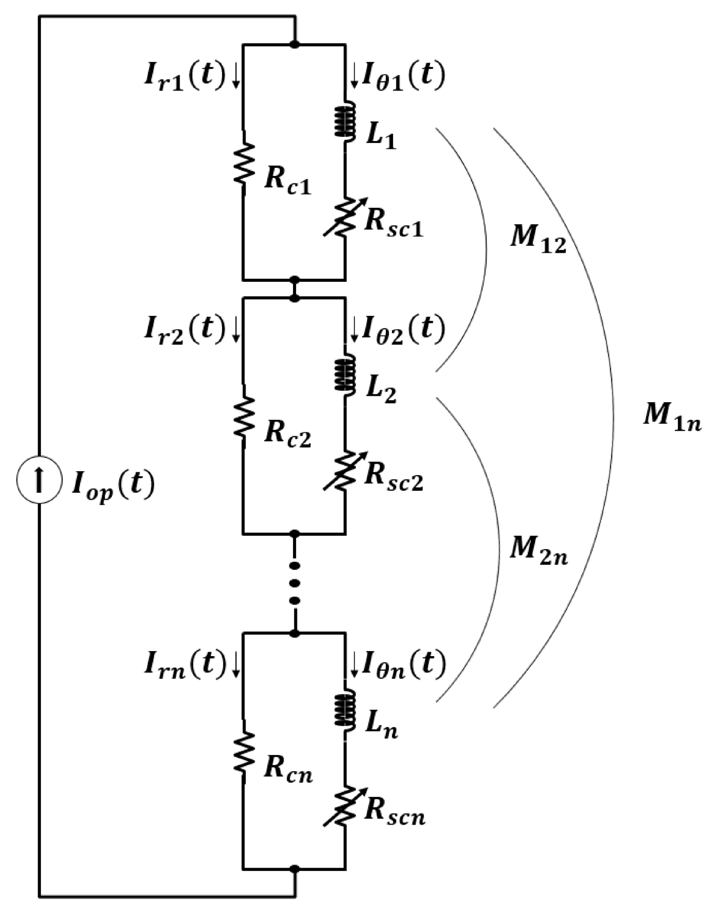
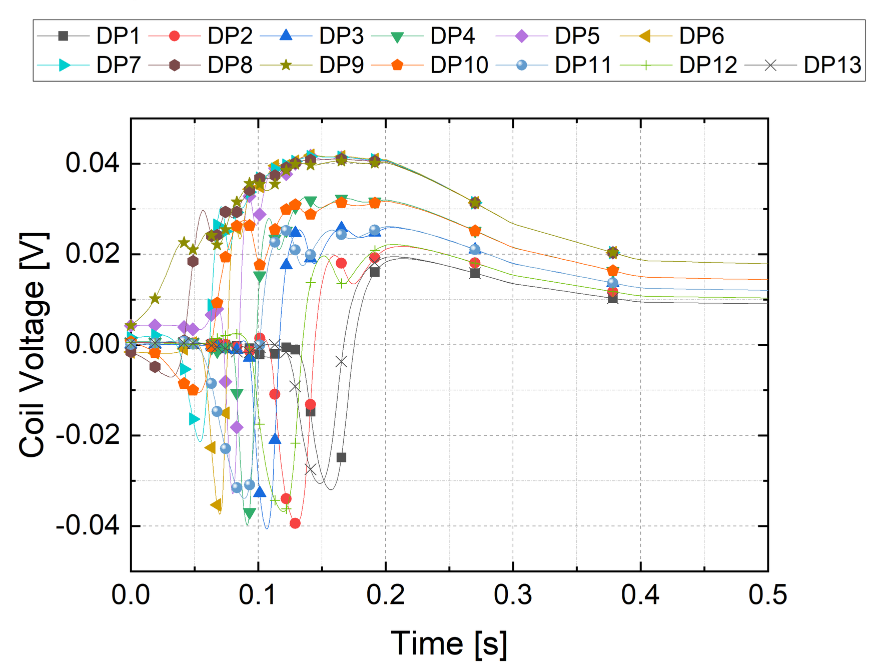
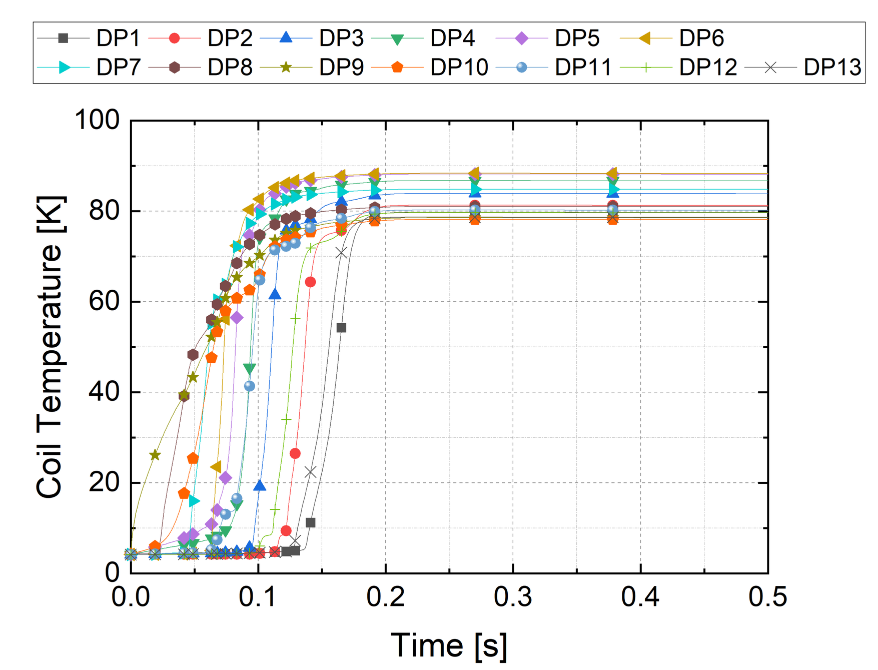


Figure 3. Equivalent circuit of 7 T magnet using lumped parameter circuit model





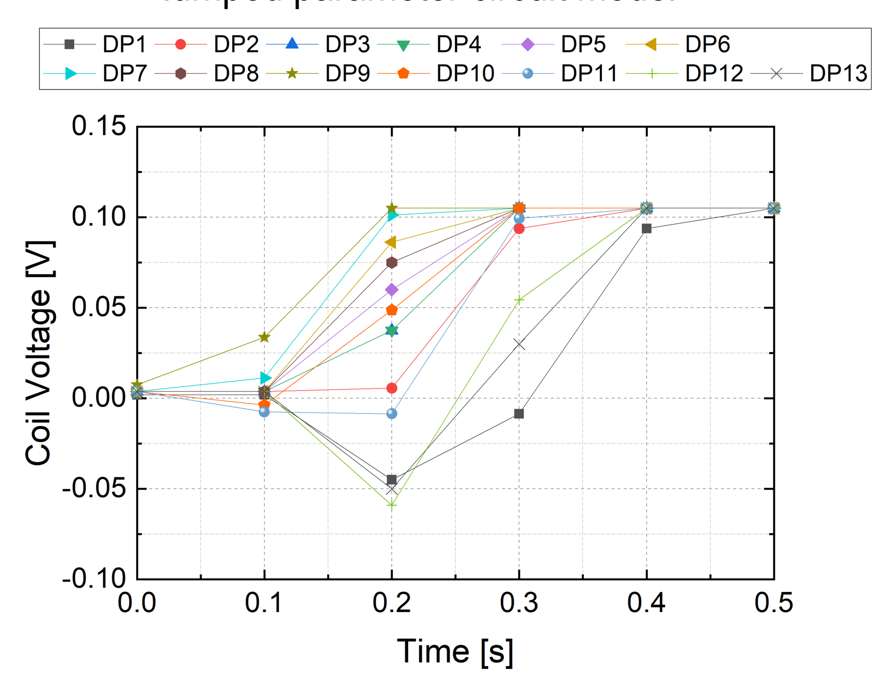


Figure 4. (a) Voltage and (b) rising temperature profiles from over-current quench simulation, and (c) measured voltages in over-current experiment.

- Compared to Fig. 4. (a) and (c), it can be shown that our simulation model well describes the quench behaviors

◆ Design and Constraints for Quench Simulation

Parameters		Values
Winding		Copper, RRR 300
Inner diameter	[mm]	101.82
Outer diameter	[mm]	110.94
Width	[mm]	9.68
Turns		710
Inductance	[mH]	97.76
Mutual inductance	[mH]	23.09
Coupling coefficient		0.72

Table 2. Key parameters of magnetic dam

- A copper coil which can satisfy (1) and (2) was conceptually designed, and its key parameters are shown in Table 2.
- It was assumed that the copper coil is thermally insulated from the magnet

◆ Results and Discussion

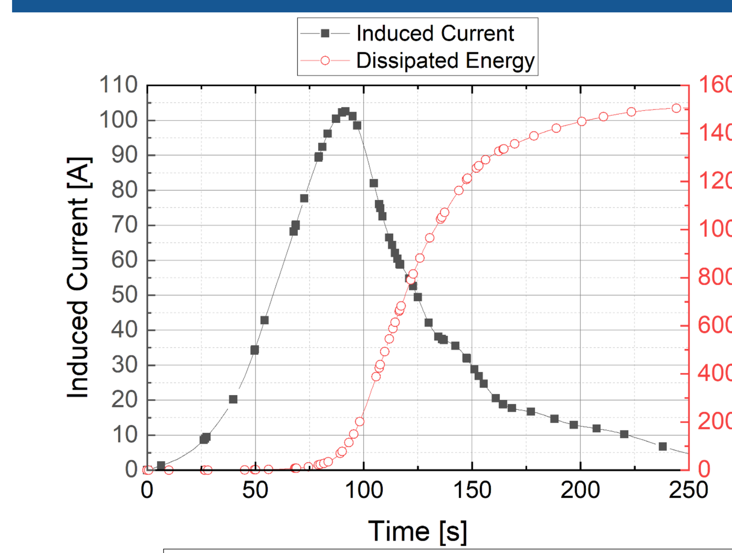
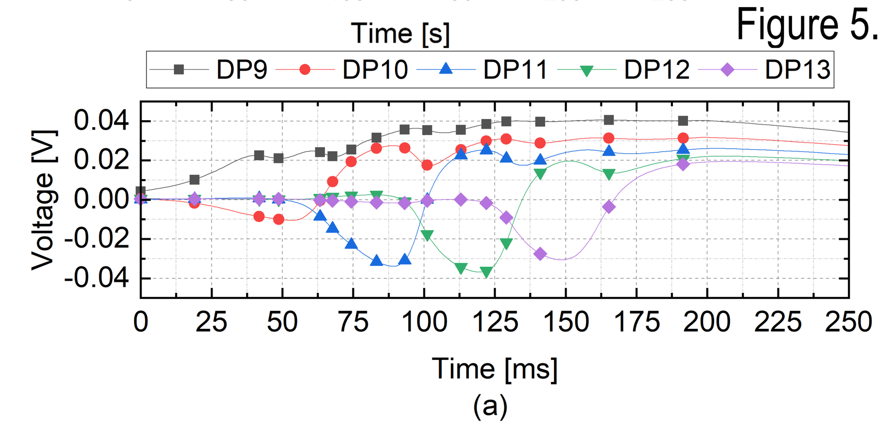


Figure 5. Induced current and dissipated energy in magnetic dam

- The DP coils which locate lunder DP 9 experienced quench late.
- Voltage and temperature of DP coils rose 10–50 ms later. (Fig. 6 and Fig. 7)
- The performance was not enough to protect a magnet because of thermal constraints to avoid fusing, but the quench propagation slowed down by "a" copper coil



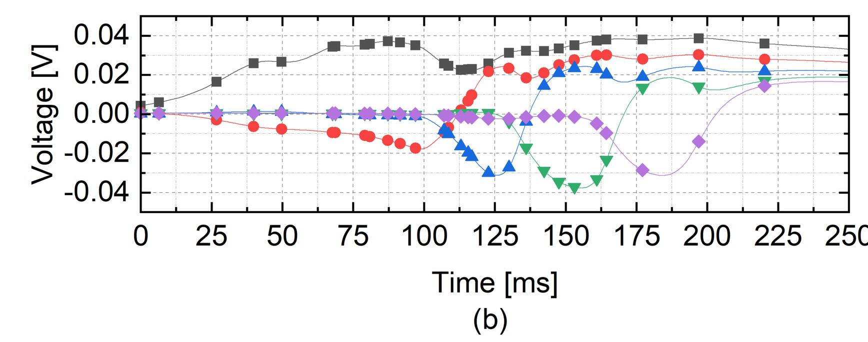
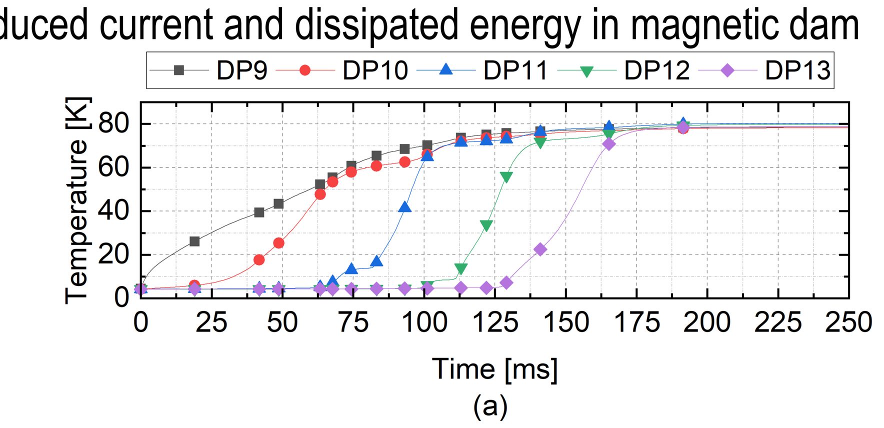


Figure 6. Voltage profiles :
(a) without; and (b) with magnetic dam



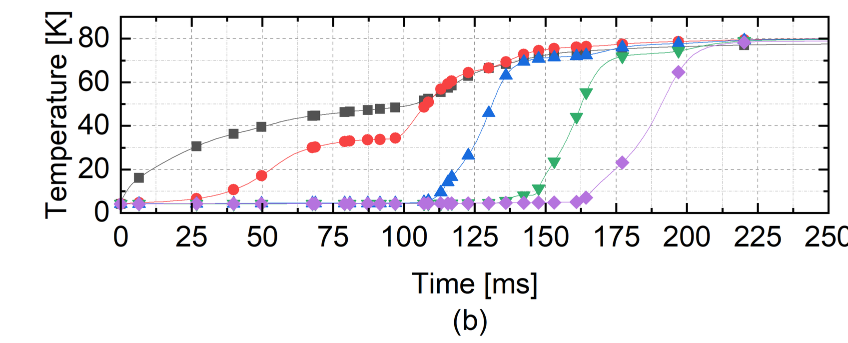


Figure 7. Temperature profiles :
(a) without; and (b) with magnetic dam

◆ Conclusion

- The performance of magnetic dam was evaluated with a case of over-current quench simulation of 7 T/78 mm NI HTS magnet using lumped parameter equivalent circuit model
- "A" copper coil can slow down a quench propagation in NI HTS magnet

References

[1] S. An *et al.* "Analytic equation to energy conversion between electromagnetically coupled superconducting and copper coils," Prog. Supercond. Cryogenics, vol. 21, no. 1, pp. 36–39, 2019.
[2] S. Hahn *et al.* "A 78-mm/7-T multi-width no-insulation ReBCO magnet: Key concept and magnet design," IEEE Transactions on Applied Superconductivity, vol. 24, no. 3, pp. 1–5, June 2014.
[3] S. Hahn *et al.* "Construction and test of 7-T/68-mm cold-bore multiwidth no-insulation GdBCO magnet," IEEE Trans. Appl. Supercond., vol. 25, no. 3, p. 4600405, 2015.
[4] J.-B. Song *et al.* "Over-current quench test and self-protecting behavior of a 7 T/78 mm multi-width no-insulation REBCO magnet at 4.2 k," Supercond. Sci. Technol., vol. 28, no. 11, p. 114004, 2015.
[5] K. R. Bhattarai *et al.* "Quench analysis of a multiwidth no-insulation 7-T 78-mm REBCO magnet," IEEE Trans. Appl. Supercond., vol. 27, no. 4, pp. 1–5, 2017.