MT25

25th International Conference On Magnet Technology

Analytic Study of the Active Quench Detection Method for the HTS Magnet using Resonance circuit

Seunghyun Song[1], Yojong Choi[1], Woo Seung Lee[2], Kideok Sim[3], Young Jin Hwang[4], Jae Young Jang[4], and Tae Kuk Ko[1]

1. School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea.
2. Korea Electrotechnology Research Institute, Changwon-si, Korea.
3. JH Engineering CO., LTD., Gunpo, Korea.
4. Korea Basic Science Institute, Ochang-eup, Korea.

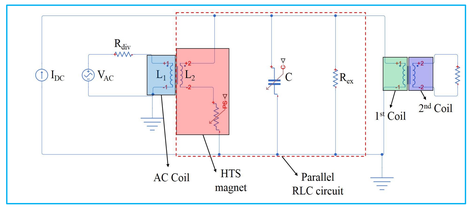
Applied Superconductivity Lab, School of Electrical and Electronic Engineering, Yonsei University

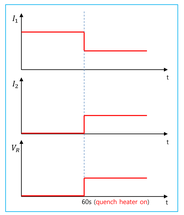
1. Introduction

- Generally, quench detection of high temperature superconducting (HTS) rotating machinery is difficult. Because the monitoring signal involves noise due to interaction with industrial environments.
- Moreover, the normal zone is hardly to dissipate in HTS because of its slow normal zone propagation (NZP) velocity.
- Therefore, HTS rotating machine can be damaged by stored magnetic energy before the quench voltage is detected.
- Also, signal wires for voltage tap can be twisted as the field coil rotates to generate the magnetic flux.
- Therefore, this paper suggests quench detection method using R-L-C resonance circuit and electromagnetically coupled coil for sensitive quench detection in HTS rotating machinery.
  - ✓ R-L-C resonance circuit plays a role as a bandpass filter to reduce the noise.
  - ✓ HTS field coil generates voltage by interacting with a stator.
  - ✓ And generated voltage has angular frequency which is the resonance frequency of R-L-C resonance filter.

2. Simulation Results and analysis

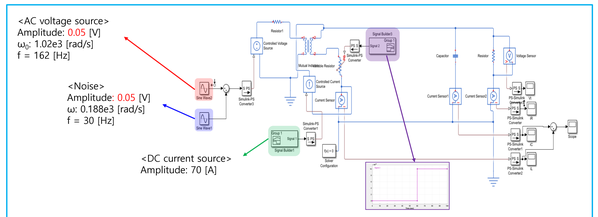
1) Equivalent circuit of proposed system



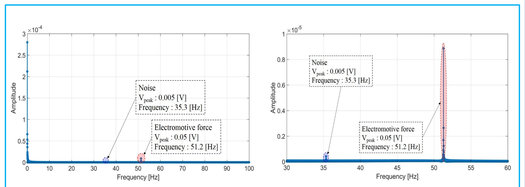


Parameters		Values
V_{AC}	Electromotive force	0.05 Vpeak
		322.15 rad/s
	Noise	0.005 Vpeak
		222 rad/s
Self inductance	AC Coil	11.4 mH
	Field Coil	0.1 mH
	First Coil	6.53 mH
	Second Coil	28.26 mH
R_{div}		1 kΩ
C		10 Ω

- Quench can be detected using electromagnetically coupled coils.
- Noise(source) can be filtered using RLC parallel resonance circuit.
- This proposed system is designed to applied to the HTS rotating machinery.
- Resonance frequency can be adjusted by varying capacitor.

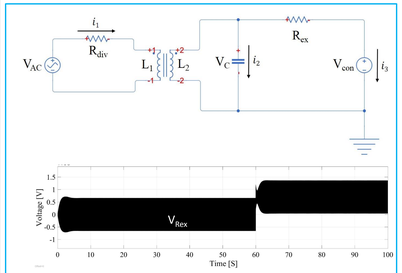


Simulation is performed using MATLAB simulink
- **It is assumed that the quench occurs by heater trigger from 60s to 100s.**
- **To clarify the filter characteristic of proposed system, noise is applied to the source.**

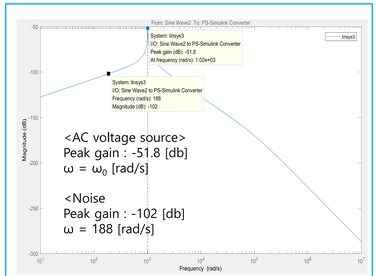


Fast Fourier Transform analysis
- **As shown the result, noise is filtered by RLC resonance filter.**
- **Using designed system, 71.4% of noise is filtered.**

2) Power converged equivalent circuit



From the V-t curve of R_{ex}, it is verified that the quench can be detected using proposed method



< Transfer function >

3) Circuit equation

$$V_{AC}(t) = i_1(t)R_{div} + L_1\frac{di_1}{dt} - M\frac{di_2}{dt} \quad (1)$$

$$L_2\frac{di_2}{dt} - M\frac{di_1}{dt} + V_C(t) = 0 \quad (2)$$

$$V_C(t) = i_3(t)R_{ex} + V_{con} \quad (3)$$

$$V_{con} = I_{DC}R_{ex} \quad (4)$$

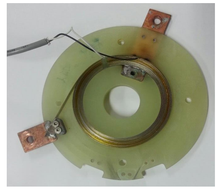
$$|H(\omega)| = 20log_{10}\left|\frac{V_{AC}(\omega)}{V_{R_{ex}}(\omega)}\right| \quad (5)$$

$$V_R = \frac{R_{S/C}R_{ex}}{R_{ex} + R_{S/C}}I_T \quad (6)$$

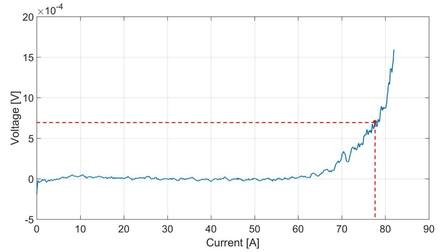
$$I_2 = \frac{V}{R_{ex}} = \frac{R_{S/C}}{R_{ex} + R_{S/C}}I_T \quad (7)$$

3. Experimental analysis and results

1) Field Coil

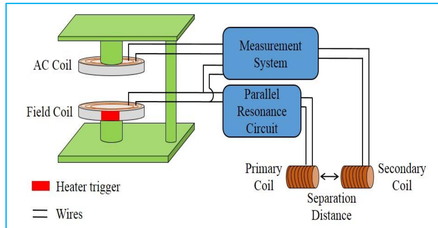


Quench occur at 78A with criterion of IEC 61788-3 (1μV/cm)
- **Nichrome heater wire is placed at the outmost turns which is impregnated with epoxy.**
- **The quench occurs by heating up the nichrome wire during maintaining the field coil current at the level of 50A.**

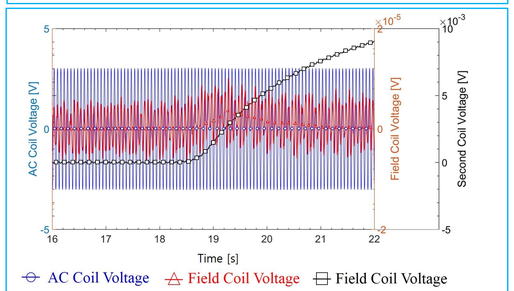


Parameter	Value
Superconductor	SuNAM (SUS stabilizer, HTS)
Inner diameter	65.4 [mm]
Outer diameter	83 [mm]
Superconducting wire length	6.9663 [m]
Turns	30 [turns]
Inductance	0.096357 [mH]
Quench voltage (IEC 61788-3)	0.69663 [mV]
Ramping rate	1 [A/s]

2) Quench test



Schematic drawing of active quench detection system using resonance circuit



Secon coil voltage can be detected after the quench occurs at the field coil

TABLE I
SPECIFICATIONS OF THE SIMULATION PARAMETER

Parameters	Values	
	AC Coil	Field Coil
Superconductor	GdBCO	Bi2223
Width	12 mm	4 mm
Inductance	11.4 mH	0.1 mH
Critical current	125 A	74 A
Total length	150 m	7 m
Inner diameter	100 mm	65 mm
Outer diameter	120 mm	100 mm

TABLE II
SPECIFICATIONS OF THE SOLENOID COILS

Parameters	Values	
	Primary coil	Secondary coil
Conductor type	Copper	
Turns	240 tums	470 tums
Inner diameter	52 mm	52 mm
Outer diameter	58 mm	65 mm
Height	115 mm	115 mm
Inductance	6.53 mH	28.26 mH

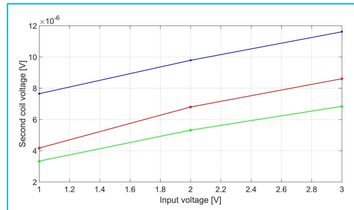


Figure shows the second coil voltage versus the input voltage of AC coil
- **Figure shows the experimental result whose variables are input voltage and separation distance.**
- **The second coil voltage is acquired when the quench is defined on the basis of IEC 61788-3 criterion in the field coil.**
- **As shown the results, measured second coil voltage is proportional to input voltage.**
- **Also, as close as two cooper coil, the second coil voltage is increased.**

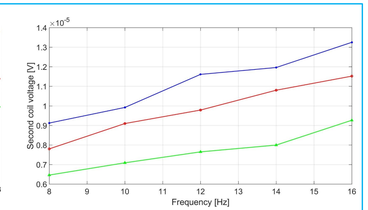


Figure shows the second coil voltage versus the input frequency of AC coil
- **Figure shows experimental result of second coil voltage by varying frequency when input voltage is 3 V.**
- **As shown the result, second coil voltage is increased as the frequency is increased.**
- **Because, inductive impedance is proportional to the frequency.**

4. Conclusion

- A quench detection method for high temperature superconducting rotating machine using magnetically coupled coils is presented to verify the feasibility of proposed system.
- Firstly, the quench detection test is performed using electromagnetically coupled coil to prevent the twist of signal wires for voltage tap.
- Secondly, the filter characteristic is verified using parallel RLC resonance filter to reduce the source noise which is generated by unpredictable industrial interference in the rotating machinery.
- As shown the simulation and experiment results, it is expected that the proposed system can be applied to HTS rotating machinery for active quench detection with noise reduction.

Presented at the 25th International Conference on Magnet Technology, 2017 Aug. 27 – Sep. 1, Amsterdam, The Netherlands; Program I.D. number: Po4.09