**Abstract**

✓ A simulation experiment of a new quench protection method using ARSL was conducted. The method is that a current of a quenching sub-coil is quickly decreased by transferring its current to the other sub-coils of a magnet composed of multiple sub-coils.
✓ Effectiveness of the new method was investigated by a simulation experiment using small scale test coils wound of YBCO tapes.
✓ It was shown that the method can suppress hot-spot temperature and increase quench detection voltage to protect an HTS magnet from quench damage.

**Quench protection procedure of ARSL method**

✓ Magnetic fields vertical to wide face of wires of Sub-coils (SC’s) 1 and 8 are larger than those of SC’s 2-7.
✓ The critical currents $I_{c}$ of SC’s 1 and 8 is smaller than those of SC’s 2-7.

**Sequence of ARSL method**

**Simulation Experiment**

✓ Quench is started by heater and detected monitoring resistive voltage $V_s$ exceeding quench detection threshold voltage $V_q$.
✓ A current of the YBCO test coil $I_t$ is controlled by a controllable power supply (Fig. 4(a)) according to the same pattern of current during quench protection sequence of the model coil (Fig. 3).

A simulation experiment of a new quench protection method using ARSL was conducted. The method is that a current of a quenching sub-coil is quickly decreased by transferring its current to the other sub-coils of a magnet composed of multiple sub-coils. Effectiveness of the new method was investigated by a simulation experiment using small scale test coils wound of YBCO tapes. It was shown that the method can suppress hot-spot temperature and increase quench detection voltage to protect an HTS magnet from quench damage.

**Case Study-Model Magnet**

- **SPECIFICATIONS OF MODEL MAGNET OF CASE-STUDY**
  - **Wire**
    - Type: YBCO tape
    - Width: 4.0 mm
    - Thickness: 0.115 mm (Cu layer 50 µm thick)
  - **Critical Current**
    - $\geq 145$ A (at 77.3 K, self field)
  - **Insulation layer thickness**
    - 25 µm

- **Composed magnet**
  - Number of sub coils: 8
  - Height: 98.4 mm
  - Withstand voltage: 1.9 kV
- **Sub-coil**
  - Type: Double pancake-coil
  - E.D.: 3.0 mm
  - Number of turn: 1300

- **Inductances**
  - Compound magnet (Lc): 98.98 H
  - Sub coil (Ls): 1.88 H
  - Coil combined of Sub-coils 2-7 (La): 58.66 H

**Simulation Experiment Procedure**

- **Current detection signal**
  - Quench detection
  - Sensitivity to current

Thermal environment of the wires in the model magnet can be simulated by the test coils. The hot-spot characteristics can be investigated by the experiment using the test coils.
**Assumptions of local defect (A quench is triggered by a defect)**

All sub-coils have the same size of defects

The same size means:
- Lengths of the defects \( L_d \) are the same.
- All defects have the same deterioration factor \( \eta \).

\[
\eta = \frac{I_c - I_{Re}}{I_c}
\]

\( I_c \): Critical current of no defect area
\( I_{Re} \): Current at which a resistive zone start to spread at the defect area

(* When \( I_c \) increases, \( I_{Re} \) increases.)

Values of \( I_{Re} \) of SC’s 2 and 7 are 14% higher than that of SC’s 1 and 8, because \( I_c \) of SC’s 2 and 7 is higher than that of SC’s 2 and 7.

**Simulation Experimental Results**

**Behaviors of SC’s 1 and 8**

- **Without ARSL**
  - Quench was not triggered in SC’s 2 and 7.
  - (See Fig. 8)

- **With ARSL**
  - Hot spot temperature \( T_{HS} \) of SC’s 2 and 7 to which the current was transferred from SC’s 1 and 8

  - To check the possibility that SC 2 and or 7 is quenched by the transferred current, when SC 1 or 8 is quenched at the current \( I_0 \),

  - Applying \( I_0 \) to the test coil, the wire was heated until \( T_{HS} \) became \( I_{Re} \) at \( I_0 \) \( (T_{HS}) \) is 82.6 K at \( I_{Re} = 1.14 \times 140 \) A, See Fig. 7).

- After that, the quench sequence started by putting the current to the test coil following to the current pattern of SC’s 2 - 7 (Fig. 3).

**Concluding Remarks**

- Experiment is conducted by making small scale test pancake-coils wound with YBCO wires to simulate quench behaviors by putting the same pattern of currents calculated for the model magnet to the test coil.

- Experimental results show that the quench protection performance of the method with ARSL is much improved.

- In this study, the ARSL quench protection method is effective to suppress the hot-spot temperature and decrease the peak voltage during quench protection sequence, while increasing quench detection voltage to safely protect a magnet from quench damages.

In the case without ASRL, \( \eta \) should be larger than 14 s to keep the peak terminal voltage \( Vq \) of the model magnet below the withstand voltage 1 kV for the operating current of 140 A. However, the magnet is damaged even with sensitive quench detection of \( Vq = 8 \) mV.

By use of ARSL method, the model magnet can be protected from the quench damages for much higher values of \( Vq = 0.17 \) mV for \( \alpha = 0.5 \), and \( Vq \) is suppressed to 460 V well below 1 kV, while SC’s 2 - 7 are not quenched by the transferred current.

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