Strain response of superconducting magnets during excitation and quench training based on polymer-FBG and cryogenic strain gauge measurements

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Background

Intense magnetic field and current of superconducting magnet can induce intense and nonuniform strain in coils that may initiate the quench during operation, it is essential to study that mechanical behavior of superconducting coil and support structure is the magnet is energized. Currently, the conventional resistance strain gauge (RSG) and optical fiber Bragg gratings (FBGs) were usually used to investigate strain induced by Lorentz force or cooling, or detect a quenching for a LTS or HTS. Unfortunately, FBGs with hard package or bare FBGs both have very fragile mechanical performance at cryogenic temperature, so it’s necessary to improve mechanical property of FBGs at cryogenic environment, then, to develop the double strain measurement system (FBGs + RSG) monitoring the strain of the on-line superconducting magnets.

Objective

This paper presents an approach to monitoring the strain response of two different LTS magnets during excitation and quench training using home-made polymer-FBGs which can enhance mechanical properties of FBGs at cryogenic environment(4.2K). For the purpose of comparisons to monitor their electromagnetic strains, the steady-state strains of the superconducting magnets were also evaluated by means of a FEM.

Results

- The superconducting magnet is charged from 0A to 30A until the coils (superconducting Nb3Sn/Cu) are superseeded, and the central magnetic field of 1.23T was achieved.
- The strain increases to a value of about 1510με with the transport current reaches to 30A until a quench occurs.
- The strain results of Polymer-FBGs agree well with conventional RSG, and the histories of the strain and applied current are almost synchronous.

Conclusion

- We studied the strain response of two superconducting magnets with different LTS materials and configurations based on homemade polymer-FBGs and conventional RSG strain measurement methods during excitation and quench, and numerical analysis of the strain fields was also carried out in the two LTS magnets based on FEM.
- These measurements show that polymer-FBGs strain sensors embedded within the magnet structure exhibit better stability and reproducibility at cryogenic environment(4.2K) and intense magnetic field, and also reveal more attraction like smaller size, immunity to electromagnetic interferences, non-circuits compensation and sensing performance of internal strain measurements.
- The quench feature can be also detected with observations of abrupt strain pulse when a quench occurs based on polymer-FBGs and conventional RSG measure methods, and the abrupt strain pulse was detected by polymer-FBGs was earlier than conventional RSG, and exerts better reliability and stability than conventional RSG during quench occurs.

Strain measurement methods

- Resistance strain gauges (RSG): FFGQ21, series, 4mm × 2.7mm. (1210, KYOWA produced) with 100ohm compensation bridge circuit. It’s a conventional type of superconducting magnet.
- Polymer optical fiber Bragg gratings (Polymer-FBGs): processes of homogeneous polymer-FBGs, interrogation system (Optical System200), wire strain sensor fabrication with communication protocol IEEE802.35-4, and maximum transmission rate 200Kbps in x-axis was used to connect the resistive strain gauge (FBG).
- Polymer-FBGs were attached on a copper plate, then, a current was applied to the copper plate at different constant temperatures.
- Wave length shift of the polymer-FBGs versus applied strain.
- Polymer-FBGs with polyimide coating can enhance mechanical properties at cryogenic environment(4.2K). The wavelength shift showed good linear dependence on the applied strain, and the strain sensitivity of the polymer-FBGs is temperature independent.
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Two different LTS magnets

- NbTi/Cu racetrack superconducting magnet:
  - Magnet structure and locations of sensors
  - Magnet real structure
  - Maximum central magnetic field is 1.2T, MM01, MM01 and MM01 are load, temperature sensor and strain sensor, respectively.
- Hybrid superconducting solenoid (NbTi/Cu+Nb3Sn/Cu):
  - Magnet structure and locations of sensors
  - Magnet real structure
  - Four distributed polymer-FBGs labeled SM01, SM02, SM03, SM04 were attached on the surface of NbTi/Cu solenoid to detect hoop strain of the central Nb3Sn/Cu solenoid.

Polymer-FBGs

- RSG
- Polymer-FBGs
- ... current
- I(A)

Temperature (K)
- 103K
- 123K
- 143K
- 163K
- 183K
- 203K
- 223K
- 243K
- 263K
- 283K
- 303K

Wavelength shift (pm)
- 0
- 100
- 200
- 300
- 400

Strain (microstrain)
- 0
- 100
- 200
- 300
- 400
- 500

Polymer-FBGs

- NbTi/Cu racetrack superconducting magnet
- Hybrid superconducting solenoid (NbTi/Cu+Nb3Sn/Cu)
- RSG