Study of stress, strain in super-conducting magnet by Fiber-Bragg Grating

Feng Zun-An[a] ， QiuLiang Wang[a] ，Dai Feng [b], Huang Guojun[b]

[a]Institute of Electrical Engineering，CAS，Beijing 100080
[b]Institute of mechanics，CAS，Beijing 100080

Stress and strain are one of the sophisticated problems in superconducting magnet system. Although some simulation can be done to predict its performance, great concerns are taken about the real action. In this paper the performances of the Fiber Bragg Grating are investigated in liquid nitrogen temperature and are applied to measure the strain in the superconducting magnet. The experiment result agrees well with simulation result.

INTRODUCTION

Stress and strain are one of the sophisticated problems in superconducting magnet system. The prediction of stress and strain is very important for the magnet designers. Although some simulation can be done to predict its performance, great concerns are taken about the real action. Fiber optic sensors have been used extensively in measurement of strain, temperature, pressure, magnetic field and electrical current over the past years [1]. It has many advantages over conventional electrical strain gauges, such as the absence of electrical interference, high resolution and small size, especially the sensor signal is not influenced by disturbances on the signal lines from the location of the probe in the cryostat to the detector outside [2]. In this paper the performances of the Fiber Bragg Grating strain are investigated in liquid nitrogen temperature and are applied to measure the strain of superconducting magnet wound by Bi2223 tapes. The experiment result agrees well with simulation result.

THEORY OF FIBER BRAGG GRATING AND DEMARCATION EXPERIMENT

Fiber Bragg Grating (FBG) is a longitudinal periodic variation of the index of refraction in the core of an optical fiber. The spacing of the grating determined the wavelength of the reflected light. The Bragg Condition is the result of two requirements:

1. Energy Conservation: Frequency of incident radiation and reflected radiation is the same.
2. Momentum Conservation: Sum of incident wave vector and grating wave vector are equal to the wave vector of the scattered radiation (Figure 1).

$$K + k_i = k_f \tag{1}$$

The resulting Bragg Condition is: $\lambda_B = 2\Lambda n_{eff}$

(2)

The grating reflects the light at the Bragg wavelength (λ_B). λ_B is a function of the grating periodicity (Λ) and effective index (n_{eff}).Typically, λ_B= 1.5 mm, Λ = 0.5mm

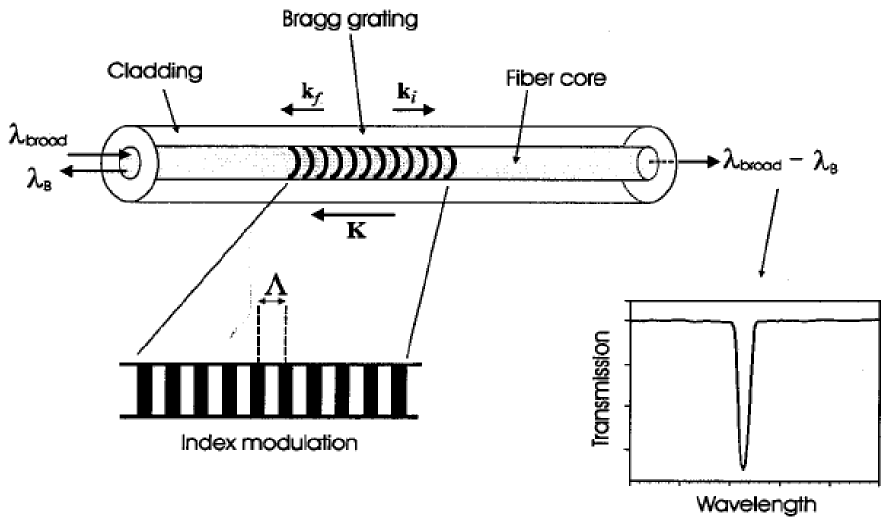

Figure 1 Fiber Bragg Grating

The shift of Bragg Wavelength can be expressed as following:

$$\Delta \lambda_B = 2nL(\{1-(n^2/2)[P12 - n(P11 + P12)]\}\, \varepsilon + [a + (dn/dT)/n]\ \Delta T \qquad (3)$$

Where:

ε : applied strain,
Pi,j :Pockel's coefficient of the stress-optic tensor,
n: Pisson's ratio,
a :coefficient of thermal expansion ,
ΔT :temperature change,
Δ $[P12 - n(P11 + P12)] \sim 0.22$,

If we keep the temperature constant, the displacement in Bragg Wavelength is approximately linear with respect to strain and temperature.During the experiment we change the strain of the beam by increasing the poise tied on the beam. Every time we increase a poise a $\Delta\lambda$ is got, at the same time the strain of the beam can been calculated by the follow function:

$$\varepsilon = \frac{M}{EI} \times \frac{Y}{2}$$
$$M = F \cdot L \qquad (4)$$
$$I = \frac{bY^3}{12}$$

Where, Y: the depth of the beam, b: the width of the beam, ε :strain, E=20 × $10^9 Pa$

Figure 2 shows the result of the experiment. The abscissa presents the $\mu\varepsilon$ of the beam, and the y-axis presents the wavelength that is reflected. Based the experiment we can get the $\mu\varepsilon$ - $\Delta\lambda$ function:

$$\mu\varepsilon = 0.48\Delta\lambda \tag{5}$$

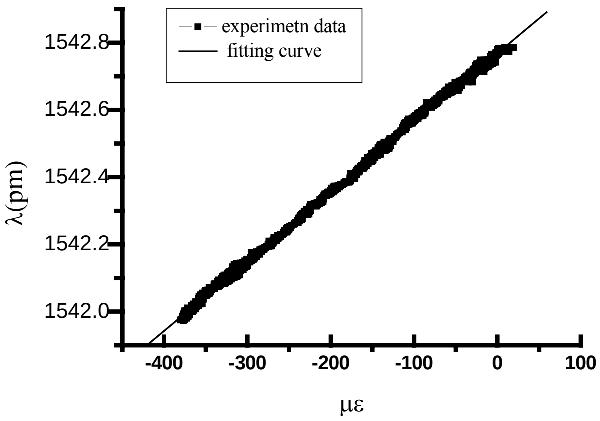

Figure 2: the relationship between wavelength and strain

Table 1: the simulation parameter

Parameter	Value	Error
A	1542.769	3.317E-4
B	0..00207	1.732E-6
R	0.9939	
SD	0.00934	
N	1744	
P	<0.0001	

MEASUREMENT OF THE REAL MAGNET STRAIN

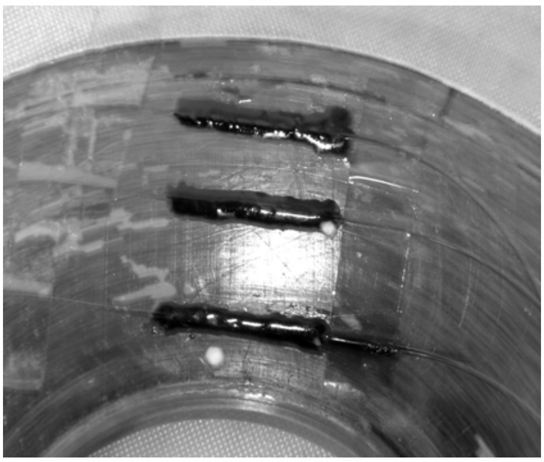

Figure 3: The FBG strain sensor stuck on the magnet

After the demarcation experiment was done, we use it in a superconducting magnet wound by Bi2223 tapes. The Fiber Bragg Gating sensor is stuck on the flank of the magnet (Figure 3). When the current is below 20 ampere, due to the small magnet and low magnetic field, the stress and strain are too small to be measured. We regard the strain of the magnet as the strain zero point when its operating current is 20 ampere. We measure the strain of the magnet at different operating current that is more than 20A ampere by FBG strain sensor. The result of the experiment is shown in Figure 5.

SIMULATION

The finite element method (FEM) is used to simulate the magnet strain. A model that is averaged all the mechanical property according to the proportion of every material of the magnet was conducted widely. This time we build a detail model for every material of the magnet. Because our magnet is axisymmetric, a planar model is build. The analysis coupled the magnetic field and structure. The couple analysis is that the input of one physics analysis depends on the results from another analysis. We chose sequentially coupled physics analyses method using the concept of a physics environment. The term physics environment applies to both a file we create which contains all operating parameters and characteristics for a particular physics analysis and to the file's contents.

The simulation parameter is presented in Table 1. The tapes and the resin are created respectively. The detail model is created (Figure 4). The average model regard the hole magnet as one material, and the mechanical property of it depends on the proportion of each material of the magnet. The mechanical property of each material of the detail model is attributed separately. So the detail model can simulate the magnet more accurately. The material property is nonlinear. The property of the tapes and the resin is plastic and elastic. The total strain components $\{\varepsilon_n\}$ are used to compute an equivalent total strain measure:

$$\varepsilon_e^t = \frac{1}{\sqrt{2}(1+v)}[\_\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2 + \frac{3}{2}(\varepsilon_{xy})^2 + \frac{3}{2}(\varepsilon_{yz})^2 + \frac{3}{2}(\varepsilon_{xz})^2]^{\frac{1}{2}} \quad (6)$$

ε_e^t is used with the input stress-strain curve to get an equivalent value of stress σ_e.

The elastic (linear) component of strain can then be computed:

$$\{\varepsilon_n^{el}\} = \frac{\sigma_e}{E\varepsilon_e^t}\{\varepsilon_n\} \quad (7)$$

And the “plastic” or nonlinear portion is therefore:

$$\{\varepsilon_n^{pl}\} = \{\varepsilon_n\} - \{\varepsilon_n^{el}) \quad (8)$$

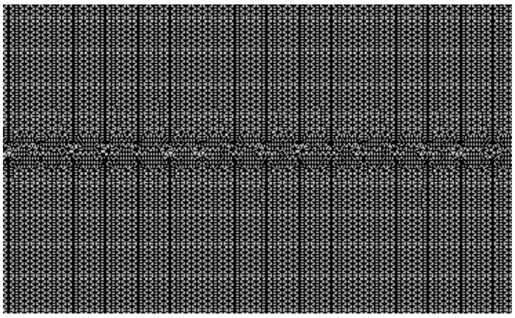

Figure 4: A part of the detail FEM model

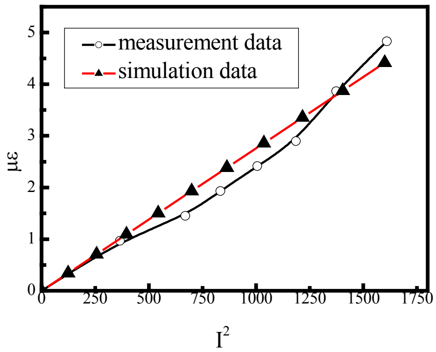

Figure 5: The experiment and simulation data

CONCLUSION

The FBG strain sensor is applied in measuring the superconducting magnet stain firstly. The simulation result well agrees with the measurement result.

ACKNOWLEDGMENT

This work is supported by the laboratory of the applied superconduct Institute of Electrical Engineering, CAS , and Institute of mechanics, CAS .

REFERENCES

[1]. R. O. Claus, K. D. Bennet , A.M. Vengsarkar and K. A. Murphy, Embedded Optical Fiber Sensors for Materials Evaluation ,Journal of Nondestructive Evaluation , (1989) 8

[2]. Johannes M. van Oort , Ronald M. Scanlan , Herman H. j. ten Kate , A Fiber-Optic Strain Measurement and Quench Location System for Use in Super-conducting Accelerator Dipole Magnets, IEEE TRANSACTIONS ON APPLOED SUPERCONDUCTIVITY, (1995) 5

[3]. K Osamura , M Sugano , A Nyilas , H S Shin, The tensile property of commercial Bi2223 tapes: a report on the international round-robin test , Supercond. Sci .Technol . (2002)15,888-893.