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INDISPENSABLE ROLE OF FBG SENSORS AND ITS DEVELOPMENTS IN ELECTRICAL POWER SYSTEMS.

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Abstract –Fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by creating a periodic variation in the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. The FBG system, consist of excimer laser, mask aligner, optical spectrum analyzer and tunable laser source was utilized to fabricate the fiber gratings. FBG is developed to measure the tension, temperature, strain, ice monitoring, relative error of the load and sag of the overhead power transmission line and real long term online monitoring of temperature, strain, ice on the overhead transmission lines is very important to insure the power grid safe during the ice disaster. To solve the electromagnetic interference, a tension sensor based on Fiber Bragg Grating is developed to measure the tension of the power transmission line. Finally functions and applications of prospects of FBG sensors represented.

Keywords: Fiber Bragg Grating; temperature measurement; strain measurement; ice monitoring; Temperature, Strain, Transmission power line.

1. INTRODUCTION

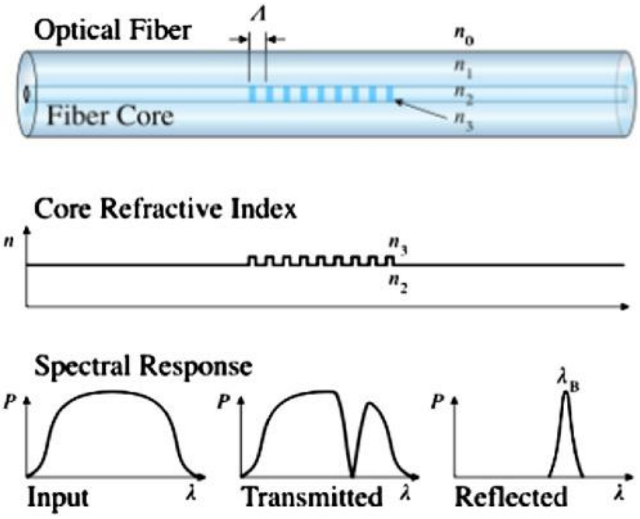
In-fiber Bragg grating (FBG) sensor technology has become one of the most rapidly progressing sensing topics of this decade in the field of optical fiber sensors. FBG sensors are currently emerging from the laboratory to find practical applications. Rapid progress has been made in both sensor system developments and applications in recent years. Electric power infrastructure built on a large scale. Power plants are forcing power utilities to look for new strategies in planning and operation of overhead lines. The security of the power grid operation has been paid more attention by public. Power cable system is one of the most important components of the grid. Some failures happen in system, the electric insulation drops significantly, and the temperature at fault points rises. Temperature and strain online monitoring of power cable can further guarantee the grid operating safety. Main parameters are the temperature of the conductor and the mechanical stress of the wire. They determine the Existing reserves in transmission capacity limited by the maximum allowed temperature of the metals and the critical
sag and thus ground clearance. Up to now operation of overhead lines is asking for safety margins for the temperature which is usually evaluated through almost obsolete calculation procedures and assumptions. Icing of high voltage transmission lines poses a great threat to the safety of the power grid. The accidents caused by icing, such as line disconnection, tower failure and flash over, occurred in many countries. Monitoring of the icing is very important to prevent
the disasters, and many power companies have pay attention to this. Many cameras or monitors are installed on the high voltage transmission lines, which can transfer the images of ice from remote area to the power stations. Based on above, that online monitoring system should apply FBG to simultaneous measurement of the temperature, ice and strain of power cable.

2. GENERAL OVERVIEW

Existing temperature and force monitoring techniq ues. For phase conductors are based either on mec hanical or on optical fiber systems. The former h ave limited lifetime and reliability. Fiber systems so far, use Raman scattering where the ratio of i ntensity of the Stokes and anti-Stokes line of the Scattered spectrum is proportional to the temperature. The Fiber Bragg Grating (FBG) sensors are proved to be a good candidate for long term monitoring of power equipment. Because the tension of the Aluminum Conductor Steel Reinforced (ACSR) is a function of the ice load, the tension of the ACSR can be treated as a warning parameter for the safety of the overhead power lines. An ACSR tension sensor, in which the FBG is adopted as the sensing element, is developed for the icing monitoring. It was imperative to evaluate the performance of fiber Bragg grating sensor system after successfully for study to check the flexibility. There are two major aspects considered for verification of fiber Bragg grating sensor system, which are; First aspect is that the fiber Bragg grating sensor system work in a technical sense, i.e., data can be produced stored and transferred. The main purpose of this study was to check the usability of the fiber Bragg grating system for measure the tension, temperature, strain, ice monitoring and sag of the Overhead power transmission line.

2.1 FIBRE BRAGG GRATING – PRINCIPLE

One of the most commonly used and broadly deployed optical sensors is the fiber Bragg grating (FBG), which reflects a wavelength of light that shifts in response to variations in temperature and/or strain. FBGs are constructed by using holographic interference or a phase mask to expose a short length of photosensitive fiber to a periodic distribution of light intensity. The refractive index of the fiber is permanently altered according to the intensity of light it is exposed to. The resulting periodic variation in the refractive index is called a fiber Bragg grating. When a broad-spectrum light beam is sent to an FBG, reflections from each segment of alternating refractive index interfere constructively only for a specific wavelength of light, called the Bragg wavelength, described in equation (1). This effectively causes the FBG to reflect a specific frequency of light while transmitting all others. Fiber Bragg Gratings are made by creating a periodic variation in the refractive index of an optical fiber. This can be realized by irradiation of the fiber with intense UV laser light. Light Travelling down such a fiber will be partially reflected at the index variations but only for a small range of wavelengths, where constructive interference occurs, the light will be reflected .



A Fiber Bragg Grating structure, with refractive index Profile and spectral response

The maximum wavelength of the reflected light is the so-called Bragg wavelength:

$\lambda B = 2 \cdot \Lambda \cdot nefF$

Where Λ is the grating's period and neff is the effective refractive index. From the equation (1) it can be deduced that λB is affected by any variation of the grating caused by external influences: Strain on the fiber causes changes in both parameters via the elasto-optic effect while temperature altersneff via the thermo optic effect. A fiber Bragg grating is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. A Fiber Bragg Grating structure, with refractive index profile and spectral response, is shown in Fig As well as being sensitive to strain; the Bragg wavelength is also sensitive to temperature. This means that fiber Bragg gratings can be used as sensing elements in optical fiber Sensors. In a FBG sensor, the relative shift in the

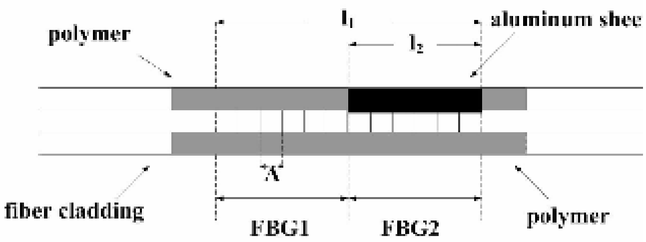
Bragg wavelength, due to a change in strain and a change in temperature is approximately given by,

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\Delta\varepsilon + (\alpha + \xi)\Delta T$$

Where P e is the strain optic coefficient, α is the thermal expansion coefficient of the optical fiber, ξ is the thermo-optic Coefficient. Equation (1) indicates that the temperature influence should be eliminated in the strain sensor. Therefore, a temperature Compensate FBG is added, it is glued at the fixture part where Strain variation is nearly zero.

2.2. FBG SENSOR DESIGN:

The FBG Sensor has response to both strain and temperature And the effects on reflected waves, which are made by temperature and strain, have the cross-sensitivity. For these reasons, they should be discriminated in order to improve the measurement precision.



Structure of FBG with stuck aluminum sheet

Under a certain stress, make the FBG2 (11:12 ≈ 2:1) paste to the aluminum sheet firmly. After the strain given off, the FBG1's deformation recovers, and its central reflected wavelength is unchanging. However, the period Λ of FBG2 has been changed for the existing prestrain. This alternation makes the central reflected wavelength of FBG2 change. Moreover, using the polymers with good thermal conductivity and ductility to package the grating which is after prestrain, it is convenient to paste up the measured cable. By using given parameters, such as the sensitivities of temperature and strain, the cross-sensitivity of FBG reflected wave, can be eliminated through detecting the side-play amount of these reflected wavelengths. The side-play amount of wavelength caused by temperature and strain is

$$\Delta\lambda_B = K_\varepsilon \Delta\varepsilon + K_T \Delta T$$

Where KT and Kε is the temperature sensitivity and strain sensitivity of FBG, IT and Iε is the temperature variation and strain variation of FBG respectively. According to above equation the IλBi (i=1,2) of two FBG can be solved by

$$\begin{pmatrix}\Delta\lambda_{B1}\\ \Delta\lambda_{B2}\end{pmatrix} = \begin{pmatrix}K_{\varepsilon 1} & K_{T1}\\ K_{\varepsilon 2} & K_{T2}\end{pmatrix}\begin{pmatrix}\Delta\varepsilon\\ \Delta T\end{pmatrix}$$

And then the information about the temperature a nd strain will be got.

2.3 MAIN ADVANTAGES OF FBG SYSTEMS

It is very important to that the only connection between the sensors on the structure and the interrogation equipment is a fiber optic cable. This means that no electric signal or power has to be provided to the monitored System. The device under test is completely passive, doesn't need to be shielded against Electromagnetic noise can be operated in harsh environment, at high temperature, submerged, etc.

● FBG sensors can be embedded and multiplexed on a single
fiber for multi-point measurements.

● Cabling is much easier and “cleaner” for FBG sensors than
for electric sensors: every strain gauge must be connected with
a multi-wire cable, vs. a single fiber for several optic sensors.

● FBG sensors are immune to problem linked to
Environmental effect such as corrosion, oxidation, and aging that afflict conventional sensors, leading to easier and faster installation and bonding procedure.

2.3.1. Features of FBG Systems:

· High resolution

· Insensitive to temperature variations (900°).
· Insensitive to corrosion, vibrations and EM fields
· No calibration required
· Ideal for harsh on-site conditions
· Suitable for extreme pressure conditions
· Extended temperature range
· High chemical resistance
· Applicable in deep water
· Long lifetime

3. APPLICATIONS IN ELECTRICAL EN GINEERING

Fiber Bragg grating (FBG) sensor technology has become one of the most rapidly progressing sensing topics of this decade in the field of optical fiber sensors. FBG sensors are currently emerging from the laboratory to find practical applications. Rapid progress has been made in both sensor system developments and applications in Power systems.

a) Strain & temperature measurement, structural health monitoring.

b) Airship (electrical insulation, lightning safe).

c)Strain and vibration sensors in Power generators 4 FBG strain sensors at the edges of stator winding Vector sum of 4 strain signals yields time characteristics of both bending amplitude and direction.

d) Measurement and monitoring cooling air flow Distribution along stator of Power Generator

e)Railway overhead contact lines, Railway pantographs (electrical insulation) line and Interface Monitoring on High Voltage Railway Voltage in this FBG strain sensors embedded directly in high voltage current collector CC: Monitoring defects of contact line by their impacts on CC.

f) Monitoring on Railway Overhead Contact Line (OCL) "Temperature Monitoring of Overhead Contact Line Systems -A Cost Cutting and Power Management Tool for Future Rail Lines Test at high speed line Main Sensor interrogation FBG temperature sensors directly on high voltage OCL.

g) Gas Turbine Temperature & vibration monitoring Generation Type II FBG temperature sensors (silica based) are installed in turbine vanes, which are not necessarily in a radial configuration. An overall temperature measurement in the combustion chamber is very difficult due to the extreme temperatures. To investigate these phenomena, a total of 60 FBG temperature sensors was installed in the exhaust path of a 200 MVA gas turbine in a power station in Finland. They are operating at about 600 °C for more than 8 month now.

h) Rotor Blade load monitoring if Wind turbine Bending load monitoring of blades in world's largest wind turbine E112 (4,5 MW, blade length 53 m) 6 FBG strain sensor pads used on opposite positions of wind blade.

3.1 POWER LINE TEMPERATURE MONITORING

To avoid the installation of a new cable, the presented system uses the correlation between the conductor temperature and temperature of the jumper cable bridging two sections of a line at a tension tower. Instead of replacing a whole cable length, only a short jumper cable housing a sensor fiber is used. Contrary to the Raman based fiber system, the sensor is realised as a Fiber Bragg Grating (FBG) using the thermo optic effect to measure temperature. One end of the jumper cable is entering a separator where the sensor fiber is spliced to an ordinary fiber leading down the tower for further data transmission; the other end is connected to the phase conductor as usual.

Power cable fault mechanism:

The cable’s main body, when it is laid a straight-line, the distribution of thermal field is basically uniform, when it is laid a bending-line, insulation layer that is just on the bending part becomes deformed so that density and insulation strength of insulation layer change. The electric field and thermal field deforms as well. All these variations lead to insulation layer unevenly heated. When the insulativity falls off the faults are generated finally. To the cable joint, as the contact resistance increasing, the temperature rises along with it. The deeling insulativity is caused by the high temperature in a long time. And the energy transmitted to the two sides of wire is equal.

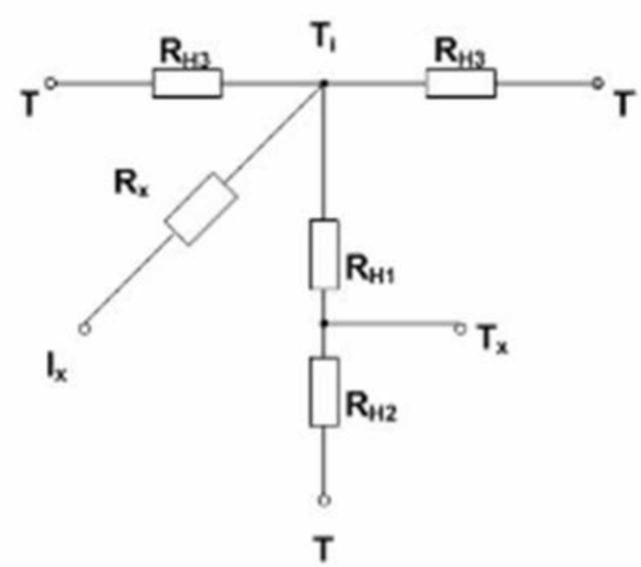


Figure 3.1: The electro thermal hybrid network of cable joint.

Ti – Temparature of joint
T **-** Environment temperature of electrical trench
Tx – Temparature of measurement point
Rx – Contact resistance of joint
Ix – Cable current measured by current transformer
RH3 – Thermo resistance converted cable two sides into joint
RH1 – Thermo resistance joint to the measurement point
RH2 – Equivalent Thermo resistance from measurement point
to environment temperature.

According to the hybrid network the relationship among the resistance, current and temperature can be defined as

$$R_x = K\frac{I_{X0}^2(T_x - T)}{I_x^2(T_{x0} - T_0)}R_0$$

Where Ix0, Tx0, T0, R0 are the intial measured values, K is the coefficient of rate correction. From the above equation, Rx is directly proportional to (Tx-T), that is, the variation of temperature could reflect whether the operation of the cable joint is normal. Based on the analysis of the mechanism of the power cable fault, lots of online sensor systems have been designed to monitor the power cable.By adding st rain sensors, also using FBG technology, and a small weather station, mounted on the tower, a complete power line monitoring system has been realized. International Wire & Cable Symposium 50 Proceedings of the 55th IWCS/Focus .The signals from the FBG sensors can be either processed in a small unit mounted to the tower or transported to another location by an optical underground cable. In both cases, one processing unit can handle signals from several locations. Before presenting the individual components of the system, a short explanation of the principles of Fiber Bragg Gratings will be given.

3.1.1 Jumper Cable with Sensor

The FBG sensor used for the temperature measurements consists of the FBG itself protected by a 1.5 mm diameter stainless steel tube sealed at both ends. The outgoing fiber is protected by an ordinary plastic tube. The length of the steel tube housing depends on the jumper cable length and ranges from 1.5 m to 3 m. To use the sensor efficiently it has to be placed into the core of the jumper cable which is generally of the same type as the phase conductor. In case of the presented system, the phase conductor was a steel/aluminum design with a steel cross section of 39.5 mm2 and an aluminum cross section of 243.1 mm^2.

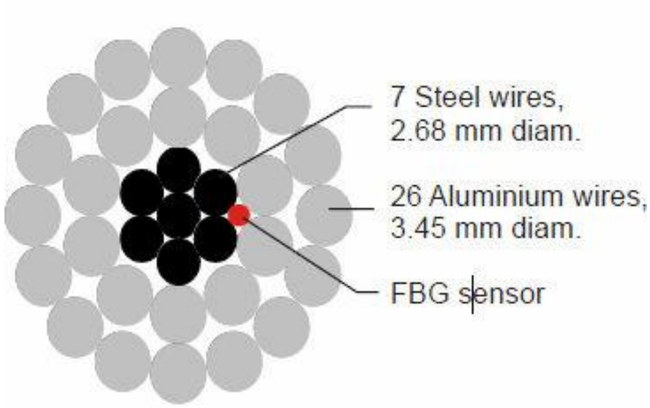


Figure 3.4.Cross section of jumper cable including FBG sensor

3.2 STRAIN MEASUREMENT

3.2.1. Structure of the Tension Sensor

The sensor consists of two sections of the same shape, and the two sections are fit together with the bolts to fasten the ACSR (the bolts are not shown in Fig. The FBG is glued at the thinnest part, in the middle of the sensor, which is designed to gain a smaller tension resolution. In order to be applied in harsh environment, the FBG is prepackaged with metal shim.

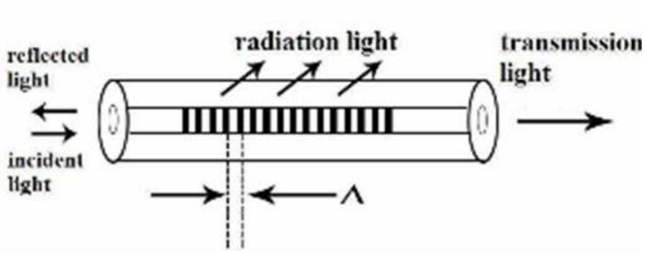


Figure 3.2.1 Structure of FBG sensor

When the force is applied to the ACSR, the strain of the FBG varies. Base on the principle of the FBG and the structure analysis, the Bragg wavelength shift in FBG is linear with the tension of the ACSR, thus the tension can be monitored by measuring the Bragg wavelength shift of the FBG reflective there have been many advances in the methods used to perform strain measurements. The three most prevalent technologies today are electrical foil gages, electrical vibrating wire, and fiber Bragg grating (FBG) optical sensors. For most standard strain sensing applications, electrical sensing has been and will continue to be the best and most effective solution. However, optical sensors can offer an important alternative in traditionally challenging applications.

Strain sensor

The sensor for strain, as already mentioned, is also using FBG sensor technology but is specifically adapted to its main task: Strain measurement. It comes in a rectangular shaped housing and is attached to a clevis strap.

Data processing and control unit

In order to use the FBG sensors for a monitoring system controlled by an ordinary PC, their wavelength coded optical signals have to be converted into a data stream. Two steps are necessary: First an optical to electrical conversion and finally an A/D conversion. The outgoing data is transferred to a PC via a serial RS232 interface. The whole μ-processor controlled unit fits into a 19” rack for indoor use or can be delivered in a robust case for outdoor use. The monitoring software runs on any PC and can be adopted to the actual situation or needs. With the data from the weather station sent to the computer, the power line operator gets a comprehensive set of Information to manage his lines.

3.2.2. FBG based Temperature and Strain online monitoring

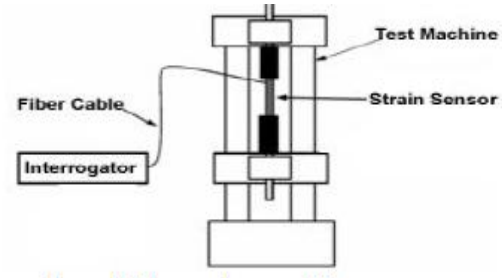
This system uses the Samsung S3C44BOX microprocessor which has the abundant on-chip recourses, as the control core of the data acquisition and storage. The wave length demodulation uses the Fabry-Perot (F-P) filter produced by the Micron Optics. Its free spectral range is 43nm, the wavelength gap is 0.2nm, and the insertion loss is 1.3db. Below fig presents the broad band light sent by the 980nm pump laser passes through the coupler A, isolator A, coupler B and optical switch successively. The optical switch controls the branch section. The microprocessor applies a saw-tooth driving voltage to the piezoelectric ceramic of F-p filter through D/A converter. When the scanning wavelength of the filter matches with the grating reflected wavelength, it allows the grating reflected signal to pass the filter. Afterwards, the optical signal power (OSP) is magnified by a length of erbium-doped optical fiber at first, passes through the coupler A, isolator A, and coupler B to arrive at the photoelectric detector (PD); then the OSP is converted by PD into the electric signal, which is collected by the microprocessor through channel1. At the same time, the saw-tooth driving signal is collected by channel 2. The F-P driving voltage of corresponding channel 2 can be gotten while the signal in channel1 maximizing. Then by solving the linear relation between the F-P driving voltage and side-play amount of wavelength, demodulating to the FBG sensor can be done.

3.3 ICE MONITORING OF LINE

Ice monitoring on the overhead transmission lines is very important to insure the power grid safe during the ice disaster. To solve the electromagnetic interference, a tension sensor based on Fiber Bragg

Grating is developed to measure the tension of the power transmission line.

LABORARY TEST: Because the strain of the FBG in the sensor is different with the strain of the conductor, calibration of the sensor developed should be carried on before the installing. A 1×7 steel wire strand is used as the test power line. The calibration is carried out on a High Force Electromechanical Testing Machine (CMT4000). The steel wire strand with a developed FBG sensor attached is vertically clamped by the testing machine. An elongation gauge is also attached to the strand to measure the elongation under different tensions applied to the ground conductor. In the tests, the force applied to the ground conductor is first increased to a certain level with an increment of 1kN, and then decreased to zero with a decrement of 1kN. The Bragg wavelength was monitored and measured with an FBG interrogator during the cycle of loading and unloading. The measured sensitivity of the sensor is 0.2286pm/N.



Schematic diagram of the test equipment

The span of the 1×7 steel wire strand is 10.55m, and the tension sensor is installed closed to one terminal, the weights suspended on the strand are used to simulate the ice load. The weights are divided into five groups and each group has the same number of weights. The weights are loaded on the steel wire strand group by group until all loaded, and after the weights are unload the weights group by group until no-load. There is a six minutes interval between each loading (unloading) step. The Bragg wavelength is monitored and measured with an FBG interrogator during the cycle of loading and unloading. The measured Bragg wavelength of the FBG which is used as the strain sensing element.

4. CONCLUSION

A power line monitoring system based on FBG sensor implemented in the jumper is a highly accurate, reliable and cost-efficient system. The advantages of this monitoring system, its ease of installation, the short power outage time for assembly. The FBG sensor system converts the measured signal into the shift of resonant wavelength which is convenient to the gratings multiplexing; the equipment volume is reduced by applying the embedded technique. This variation cuts down the cost, makes the information sharing become more easily, and the application can reduce the incidence of power cable faults. The FBG sensor did perform quite consistently and functioning well and useful for the practical field application of strain/ temperature measurements of a power line conductor. The relative error of the load and sag, measured by the developed FBG sensing system and a tension sensor of ACSR used in transmission line ice monitoring.

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