Research on Wind Turbine Blade Monitoring Based on FBG Strain Sensors

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Abstract: As an clean renewable energy source wind energy is highly regarded by various countries in the world. Wind turbine blade is one of the most important components in wind turbine. It is the key component for receiving wind energy. As turbine size steps up and the size of modern turbine blade increases, condition monitoring and maintenance of blades become more important. Strain detection is one of the most effective methods to monitor blade condition. Sensitivity for EMC and lightning and zero drift of conventional strain gauges bring a lot of trouble. In this paper, a fibre Bragg grating sensor system is used for blade monitoring. The system overcomes the shortcomings. It is dainty, reliable, convenient to multiplex and so on.

Keyword: Bragg grating; wind turbine blade; monitoring system

1 Introduction

As clean renewable energy wind energy sources have gained much attention since the mid-20th 70. Compared to other renewable energy sources wind energy is unique due to the maturity of the technology, good infrastructure and relative cost advantages, so wind power business has made great strides.

Wind turbine blades are ones of the most important parts in wind generator. They are the key components of wind generator to receive wind energy. With the increase of unit capacity of wind turbines and the increase in blade size, condition Monitoring and maintenance for them becomes more critical. A new generation of wind power will reach 5 MW and higher offshore. Blades are up to 90-130m. If wind turbine blade gets failure, replacing it will be an expensive and time consuming operation. Condition monitoring and maintenance offers the chance to avoid such failures.

Wind turbine blades can become damaged by moisture absorption, fatigue, wind gusts or lightening strikes. Aerodynamic loads and loads due to changing gravity moments cause fatigue damage of the blades. Aerodynamic interaction between different turbines can cause unpredictable and excessive loads on the blades. These loads accelerate fatigue damage of the blade. Various techniques including strain, vibration and acoustic can detect damage in composite blades. The most promising methods are Bragg grating techniques. Bragg grating sensors are not sensitive for EMC and lightning. They are also considered to be accurate, reliable and stable. In this paper, a Bragg grating sensor is used for blade condition monitoring. The methods are all based on measuring the strain response of the blade.

2 Principle of operation of FBG sensors

When light is made to pass through the grating, at a particular wavelength, called the Bragg wavelength, the light reflected by the varying zones of refractive indices will be in phase and amplified.

The Bragg wavelength is expressed as

$$\lambda_B = 2n_{eff}\Lambda \tag{1}$$

where λ_B is the Bragg wavelength; n_{eff} is the effective refractive index of the FBG and Λ is the grating period. When strain is induced in an FBG or temperature is changed, the grating period Λ and the effective refractive index of the FBG n_{eff} are also affected. As a result, the Bragg wavelength is shifted as $\Delta\lambda_B$. The strain or temperature in measured points is gained by monitoring the Bragg wavelength. While stain and temperature are changed simultaneously, the effective Bragg wavelength shift $\Delta\lambda_B$ due to strain and temperature are expressed as:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-p_e)\varepsilon + (\alpha+\varsigma)\Delta T \tag{2}$$

where p_e is the effective photo-elastic constant of the fiber core material, ε is the longitudinal strain on the FBG, α is the thermal expansion, ς is the thermo-optic coefficient, ΔT is the change in temperature experienced at the FBG location.

For strain measurements, effects of temperature on the Bragg wavelength has to be compensated.

3 FBG strain sensor

Sense signals of FBG strain sensor use amplitude modulation. The wavelength signals include temperature information and strain information. How to separate temperature information from strain information is the key point in FBG strain sense technique. The main programs resolving temperature-strain cross-sensitivity problem include: dual-wavelength method, dual-parameter method, temperature compensation method, special performance fiber Bragg grating method. Dual- wavelength method is difficult to demodulate and costs more. Dual-parameter method has complex structure and loses the advantage of amplitude modulation. In this paper, the reference grating is used for temperature compensation. It is placed in the same temperature field as the sensing grating but don't sense strain. Temperature effects on the strain measurement are eliminated by subtraction of the effective Bragg wavelength shift due to strain and temperature.

Signal demodulator is another key issue to research practical FBG sensor. Common demodulation is divided into four categories: filter demodulation, interference demodulation, tunable light source demodulation and dispersion. Considering the stability, accuracy, cost and other issues, in this paper, the demodulation method is used for measurement of static and dynamic strain. Fig.1 shows the proposed sensor system.

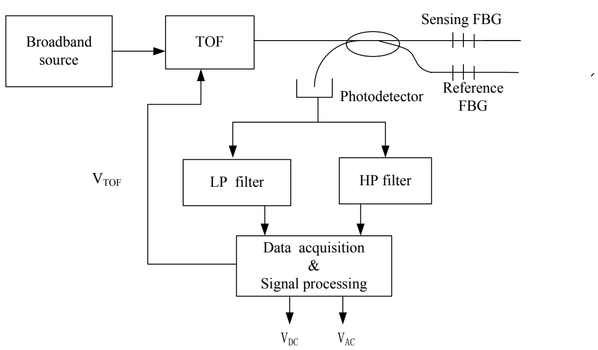

Figure 1 FBG sensor system

The system consists of a broad-band source and tunable optical filter (TOF), a fiber coupler, a sensing FBG, a reference FBG and photodetector. The reference FBG is isolated from strain effect and used as a reference to minimize the effect of temperature. Signal from the photodetector is processed to give two outputs, one (V_{DC}) is for static measurement, the other (V_{AC}) for dynamic measurement.

4 Installation of FBG sensors

According to structure of practical turbine blades, blade models are built using three-dimensional modeling software (Pro/E). Dynamic characteristic and static characteristic are analyzed by finite element method. Based on analytic result sensing points and status parameters are defined. Then installation sites, number and distribution of FBG sensor are determined. The FBG strain sensors are arranged in two ways. The first method is that sensors are installed on the key points easy to overload or damage (see Fig.2); the second method is that sensors are embedded into the entire blade material.

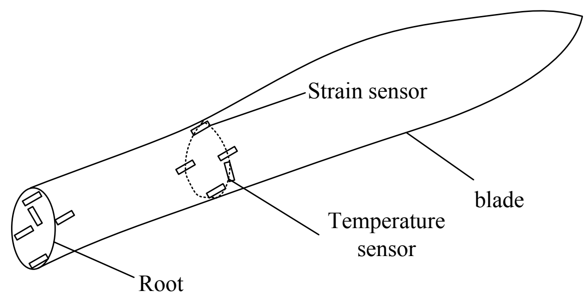

Figure 2 Strain sensor configuration in wind turbine blade

5 Wind turbine blade monitoring system

A wind turbine blade monitoring system is made up of four components (see Fig.3):

Sensor subsystem. The sensor subsystem senses the characteristics of blades and outputs electric or optical signals. It is the foundation of monitoring system.

Data collection, transmission, processing subsystem. Data collection, transmission, processing subsystem consists of hardware and software. The hardware includes transmission cable and A/D conversion card. Software system stores digital signal in the computer. Data collection software platform uses LabVIEW. The data collected is stored data management subsystem. Data col-

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lection subsystem is the bridge linking sensor subsystem and data management subsystem.

Fault diagnosis subsystem. Fault diagnosis subsystem **c**onsists of damage recognition software, model updating software, structure safety assessment software and warning devices. In this system, damage recognition software is running at the beginning. If the damage is found, model updating software and structure safety assessment software are running. If abnormity is found, the alarm is sent from warning devices. Damage recognition software is developed using the calculation analysis software (MATLAB) platform. Model updating software and structure safety assessment software use the structure analysis software (ANSYS). Damage recognition is based on structure response information. The structure response information is collected by data collection subsystem and is stored in data management subsystem. The result of damage recognition, model updating and structure safety assessment are stored in data management subsystem as structural history data.

Data management subsystem. The core of data management subsystem is database. Database manages structural information, geometric information, monitoring information, analytic result and so on. It is the core of wind turbine blade monitoring system. It is responsible for data management of wind turbine blade monitoring system.

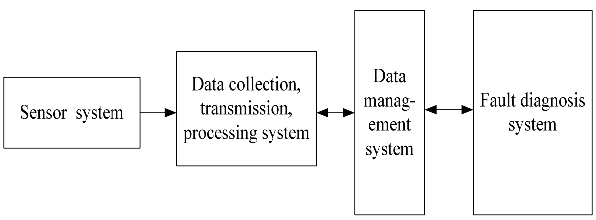

Figure 3 Wind turbine blade monitoring system

6 Conclusion

Wind turbine blades are the most important parts in wind generator. Real-time monitoring blade may find fault in time, maintain them and reduce the cost ultimately. FBG strain sensors can work in the environment with moisture absorption, fatigue, wind gusts and lightening strikes. They are not sensitive for EMC and lightning. They are also considered to be accurate, reliable and stable. Monitoring wind turbine blade using FBG strain sensors has vast potential for future development. In this paper, how to monitor wind turbine blade using FBG strain sensors is researched.

(1) Designing the structure of FBG strain sensor. Temperature-strain cross-sensitivity problem is resolved using the reference FBG. In this system static and dynamic strain is measured simultaneously.

(2) Researching the installation mode. Based on load analytic result installation sites, number and distribution of FBG sensor are determined. The FBG strain sensors are arranged in two ways. The first method is that sensors are installed on the key points easy to overload or damage; the second method is that sensors are embedded into the entire blade material.

(3) Describing the structure of wind turbine blade monitoring system. It consists of sensor subsystem, data collection, transmission, processing subsystem, fault diagnosis subsystem and data management subsystem. Various subsystems work in coordination with each other and finish monitoring assignment.

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