Abstract
The crane is an important industrial equipment. With rapid economic development and urgent industry needs in our country, the crane tends to be large-scale, high parameters and high risk. Therefore, it is of great concern to us that how to maintain the safety of the crane. The paper develops a set of health monitoring and diagnosis system for the crane based on bragg grating sensors. In the system, the fiber grating strain sensors are emplaced in key parts of the crane. Through collecting and analyzing of the strain signals, we can real-time understand the safety condition of the crane. Compared with the original strain measurement technology, The system makes the data collection more reliable, safe and convenient. In addition, the theory of fatigue cumulative damage is applied in analyzing the strain monitoring data, which can make us to timely know the structural damage. The system can realize long term strain monitoring and reduce the risk of accidents of the crane greatly.

Keywords Structural Health Monitoring; Bragg Grating Sensors; Strain; Crane

1. Introduction
The crane is the "backbone" of the main industrial sectors, widely used in metallurgy, chemical industry, power, ports, construction, manufacturing and other fields. And it is the important infrastructure of our national economy. With rapid economic development and urgent industry needs in our country, the crane tends to be large-scale, high parameters, high risk, more complex and functional diversification. At present, the main method for guaranteeing the crane safety is regular inspection. While inspecting, the crane must stop working, the technical means include visual inspection, sensory judgment, magnetic particle inspection, etc[1]. Conventional methods and instruments are relatively backward ,the working intensity of the inspectors is huge but low efficient. For large-scale crane, the inspection work usually accompany with the danger. In addition, inspection is often static, inspection results can not reflect the operation condition of the crane. To improve the safety level of the crane and enhance the safety supervision of the crane, structural health monitoring technology is gradually applied in the crane. Structural health monitoring technology generally refers to non-destructive testing technique, which monitor the structural data information and diagnosis the structural safety. The structural health performance indicators reflect the structural health condition. the status data of full life-cycle structure gives a strong support to the crane design[2].

2. Design of Structural Health Monitoring Hardware System
Structural health monitoring system for the crane is an integrated monitoring system,
which can monitor the deformation, strain, deflection, vibration of the key parts of the crane through applying new optic fiber grating sensing technology. The Structural health monitoring system for the crane consists of the hardware system and software system.

2.1 Structural Health Monitoring Hardware System

Structural health monitoring hardware system for the crane includes fiber grating sensing subsystem, signal demodulation subsystem and remote data transfer subsystem.

2.1.1 Fiber Grating Sensing Subsystem

The system uses the fiber grating strain sensor with the temperature self-compensation. The sensor is designed for monitoring the strain of the crane steel box girder. Owing to using the unique temperature compensation technique and the strain sensitizing technique, the sensor has higher measurement resolution and accuracy, excellent temperature compensation capability \(^3\). Its technical performance parameters are shown in Table 1.

Table 1. The performance parameters of the fiber grating strain sensor

<table>
<thead>
<tr>
<th>Project</th>
<th>Unit</th>
<th>Parameter values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>με</td>
<td>± 1500</td>
</tr>
<tr>
<td>Coefficient of strain measurement</td>
<td>με/pm</td>
<td>0.96</td>
</tr>
</tbody>
</table>

2.1.2 Signal Demodulation Subsystem

Considering the characteristics of the crane, we have designed and developed a new health monitoring demodulator which can be applied in dynamic data signal acquisition and different types of sensors signal demodulation, for example, fiber grating temperature sensors, strain sensors, pressure sensors, displacement sensors etc. And the demodulator also can be used for high-speed fiber-optic acceleration sensor signal demodulation and data acquisition. The demodulation device uses scanning laser and parallel spectroscopy detection techniques. Compared to the traditional ASE + tunable filter technology, light output power efficiency is up to 85%, light output power increased by 100 times, power consumption decreased by 50 %, the effective light source service life increased by 10 years. The performance indicators of the demodulator are shown in Table 2.

Table 2. the performance indicators of the demodulator

<table>
<thead>
<tr>
<th>Project</th>
<th>Unit</th>
<th>Parameter values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring points per channel</td>
<td>pcs</td>
<td>40 ;</td>
</tr>
<tr>
<td>Wavelength accuracy</td>
<td>pm</td>
<td>Typical values at room temperature±1</td>
</tr>
<tr>
<td>Dynamic detection range</td>
<td>dB</td>
<td>Output optical signal power : 0 ~ -20dB detected the input optical signal power up to -70dB</td>
</tr>
<tr>
<td>Strain resolution</td>
<td>με</td>
<td>0.1</td>
</tr>
</tbody>
</table>

2.1.3 Remote Data Transmission Subsystem

Remote data transfer subsystem employs GPRS DTU integrated ARM9 high-performance industrial embedded processor, real-time operating software system platform, large memory, built-in proprietary TCP / IP protocol stack. The subsystem is high-speed, reliable, data terminal always online. The virtual private network of multi-protocol conversion can ensure robustness and reliability of network data transmission.
by using multi-carrier collision avoidance listening technology. AES 128-bit data encryption algorithms can ensure data security.

2.2 Design of Structural Health Monitoring Software System

Structural health monitoring software system consists of sensor module, date processing and transmission module, data remote analysis and diagnosis module etc. The system can realize real-time monitoring for the crane, also data storage and date query. Combining relevant theory, the system provide structural damage identification, damage diagnosis and damage early warning. Design of Software system is shown in Figure 1.

![Figure 1. Health monitoring and diagnosis software system of the crane](image)

Considering the functional requirements of health monitoring system of the crane, the software system employs advanced C / S structure to realize real-time stress calculation, display, alarm and forms a friendly interactive environment.

2.3 Damage Diagnosis Algorithm

Fatigue process is usually considered as damage accumulation process. While the accumulative damage reach the limit value, the structure will happen fracture. Fatigue liner accumulation damage theory, which is put forward by Mr. M.A.Minor in 1945, is adopted in health monitoring and diagnosis of the crane.

The calculation steps of the accumulative damage are as follows:
- Step1: changing the strain data into the stress data;
- Step2: calculating the stress spectrum of the measured spot by the “rain-flow” method;
- Step3: according to liner accumulation damage theory, calculating the fatigue accumulation damage degree \( D \) during the \( T \) period of time, the formula is as follows:

\[
D = \frac{T f_e}{A} E S^m
\]

Among \( A \), \( m \) are material parameters determined by \( S-N \) curve, \( S \) is the stress range, \( f_e \) is the average number, \( E \) is the expectation value.

3. Health monitoring system application test

This system has been mounted on the 300 tons gantry crane in Nanjing Jinling shipyard, the crane hoisting 55m in height, 71m in span.
3.1 Sensor Installation location

Eighteen fiber Bragg grating strain sensor were installed in the different location of the crane. Among six sensors were installed on the upper surface of the main beam, four sensors on the lower surface. Two sensors were installed on the soft leg, six sensors on the hard leg. The sensors installation locations are shown in figure 2.

![Figure 2. Schematic diagram of sensor installation locations](image)

3.2 Comparison of the experiment data

In order to verify the reliability and accuracy of the health monitoring system, the health monitoring results were compared with the results of the TDS-530 digital static strain gauge (Made in Tokyo). We choose two kinds of sensors of the same type, which were installed on the East in 1/2 of the crane beam. When the crane lifts the equipment weighing about 50t, and taking about 100 seconds. The experiment results of the different type of sensors were expressed in figure 3,4.

![Figure 3. The experiment result of the fiber grating sensor](image)
In the above figure, transverse axis represents the time range of the crane in operation, vertical axis represents the strain value. From the above results, we considered that the experiment results of fiber grating strain sensor and the traditional strain sensor have much consistency in the data.

4. Conclusions

Based on Bragg Grating Sensors, structural health monitoring system for the crane were developed. The paper briefly introduced the composition of the structural health monitoring system, and experiment processing and results. Through the experiment results, we can make a conclusion that the structural health monitoring system for the crane is reliable and accurate, and can be applied in long-time safety monitoring and damage diagnosis of the crane.

5. Acknowledgement

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References

