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Big Data Analysis Method of Random Stress Spectrum for Crane Equipment

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Abstract*—Fatigue damage is one of the most important failure modes of crane equipment. It is an important means to judge the fatigue damage of crane equipment structure by analyzing the random stress spectrum big data collected by the structural health monitoring system of crane equipment. Rain flow counting method is the main method for big data analysis of random stress spectrum, but it has not been applied in the on-line data analysis of crane equipment structural health monitoring system. In this paper, the big data analysis method of random stress spectrum of crane equipment is studied. The arithmetic of rain flow counting method is improved. The program of fast rain flow counting method with two parameters is compiled. The online real-time analysis of big data of random stress spectrum is realized. In this paper, the proposed method is used to analyze and calculate the random stress spectrum big data collected by the structural health monitoring system of metallurgical crane, and the effective stress amplitude-frequency histogram of the hot spot area of fatigue damage of the main girder is obtained, which lays an important foundation for the subsequent analysis of fatigue damage and health status of crane equipment.

Keywords—big data analysis method, random stress spectrum, crane equipment

I. INTRODUCTION

Crane equipment is widely used in port, metallurgy, shipbuilding, construction and other industries. It is one of the most important equipment in industrial production. Fatigue damage is one of the most important failure modes of crane equipment. Fatigue damage failure has great potential danger. When the key structure of crane equipment reaches or approaches its fatigue life, the key structure may suddenly fracture, causing heavy casualties. According to statistics, in the field of modern industry, more than 80% of structural failure is caused by fatigue damage [1] failure.

In recent years, structural health monitoring (SHM) [2-3] of crane equipment has made continuous progress in measuring, processing, collecting and storing large amounts of data (stress Spectrum, acceleration, environment and operational Data), which can provide valuable information for owners and managers to control and manage the integrity of its structure. The data sets acquired from SHM systems are undoubtedly of the "big data" type due to their sheer volume, complexity and diversity [4-5].

It is helpful to identify the fatigue damage or failure of crane equipment during operation through the correlation analysis of monitoring big data. According to the analysis of monitoring big data of random stress spectrum monitoring, rainflow counting method is widely used because it is in accordance with fatigue damage law, but it has not been applied in the on-line data analysis of structural health monitoring system of crane equipment.

The main work of this paper includes: (1) The algorithm of rain flow counting method is improved, and the fast analysis of random stress spectrum big data is realized. (2) The proposed method is used to analyze and calculate the random stress spectrum big data collected by the structural health monitoring system of metallurgical crane, which lays an important foundation for the subsequent analysis of fatigue damage and health status of crane equipment.

II. BIG DATA ACQUISITION OF RANDOM STRESS SPECTRUM

Structural health monitoring (SHM) has become a more and more feasible option to evaluate the health status of crane equipment structure. The typical crane equipment structure health monitoring system shown in Figure 1 realizes the health monitoring of metallurgical crane structure by real-time monitoring the stress state in the hot spot area of structure based on advanced fiber Bragg grating (FBG) sensors.

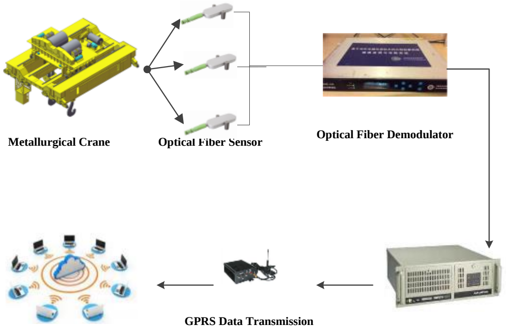


FIGURE I. STRUCTURAL HEALTH MONITORING SYSTEM FOR CRANE EQUIPMENT

With the rapid progress of smart sensor technology and decreasing cost of online monitoring, more and more SHM systems are widely used. The SHM systems can collect a large amount of raw data. This current trend brought new challenges for the capacity of traditional data process and analysis approaches. For example, 300 GB acoustic data were collected during 6 months for wind turbine monitoring. Random stress spectrum monitoring data of metallurgical crane reach 12G/day. monitoring. Some good literature about big data analytics for structural health monitoring can be found in Cai [6].

III. Fast Processing Method for Big Data of Random Stress Spectrum

Rainfall flow counting method was first proposed by Matsuishi and Endo [7]. The cyclic counting results obtained by this method have a clear mechanical meaning and well characterize the cyclic stress-strain characteristics of materials.

The process of rainflow counting pretreatment for big data of random stress spectrum mainly includes:

(1) Data compression: Exclude the continuous equivalent data points in the random stress spectrum and keep only one of them.

(2) Peak and Valley Value Processing: Guarantee that the stress spectrum data point is the peak or valley value.

As shown in Figure 2 (a), the random stress spectrum is first rotated clockwise by 90 degrees, and the data flow from top to bottom along the roof like raindrops, so it is called rainflow method [8-10].

As shown in Figure 2, (1) When truncation and docking are performed at the maximum peak (or valley), all the final cycle counts can be achieved with only one rain flow count. (2) The random stress spectrum big data to be processed and the result data to be saved are stored separately, which avoids repeated shifts of data and greatly improves the counting efficiency.

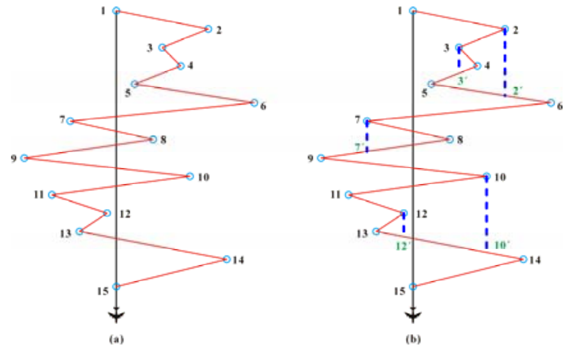


FIGURE II. SCHEMATIC DIAGRAM OF IMPROVED RAIN FLOW COUNTING METHOD (ONLY ONE RAIN FLOW COUNTING IS NEEDED)

A. *Extraction of Random Stress Spectrum Cycle*

During the extraction cycle, the sequence of random stress spectrum and the sequence of counting results are stored separately. Let A store the random stress spectrum sequence. Let B stores the counting result sequence, the specific process of extraction cycle is as follows:

(1) Read the first data point in A into B, Let m= 3, n = 1;

(2) Four points of B(n-1), A(m-1), A(m), A(m+1) are used to determine the rain flow counts. Calculate the difference between adjacent points:

$$\begin{aligned} Y_1 &= \left|A(m-1)-B(n-1)\right| \\ Y_2 &= \left|A(m)-A(m-1)\right| \\ Y_3 &= \left|A(m+1)-A(m)\right| \end{aligned} \tag{1}$$

(3) If Y_1-$Y_2 \geqslant 0$ and Y_3-$Y_2 \geqslant 0$, a cycle is taken out. Its amplitude is:

$$S_a = \frac{\left|A(m)-A(m-1)\right|}{2} \tag{2}$$

its mean value is:

$$S_m = \frac{\left[A(m)+A(m-1)\right]}{2} \tag{3}$$

and let m=m+2. Otherwise, the A(m-1) data point is read into B, let n=n+1 and m=m+1.

(4) Judging the position of B in A, if it is neither the last point nor the next point of the last point, then turn to step (2). if it is the last point, read the last two points in A into B and make n = n + 1; if it is the next point in the last point, read the last point in A into B.

(5) If there are three data point in B, take out a cycle, Its amplitude is

$$S_a = \frac{\left|B(n)-B(n-1)\right|}{2} \tag{4}$$

its mean value is

$$S_a = \frac{\left|B(n)-B(n-1)\right|}{2} \tag{5}$$

and count finished. On the contrary, read all points in B into A, empty B, and turn to step (1), Restart until the count is completed.

B. *Statistical Method for Big Data of Random Stress Spectrum*

The two-dimensional matrix (Sa, Sm) of the amplitude (Sa) and mean (Sm) of the stress cycle in the whole random stress spectrum big data is obtained by using the two-parameter rainflow cycle counting method to process the random stress spectrum big data. Stress amplitude (Sa) is the most important factor affecting fatigue damage. So the statistical results of stress amplitude (Sa) need to be paid more attention.

Determining the Maximum Samax and Minimum Samin of Stress Amplitude Sa, then the classification process is carried out. Assuming that it is divided into N levels, the formula for calculating group spacing H is as follows:

$$H = \frac{\left(S_{a\max} - S_{a\min}\right)}{N} \tag{6}$$

Where N is usually 8, 16 and 24.

Obviously, the upper and lower limits of each level can be expressed as:

$$\begin{cases} H_{i\,bot} = S_{a\min} + (i-1) \times H \\ H_{i\,top} = S_{a\min} + i \times H \end{cases} \tag{7}$$

Where i=1, 2,…,N.

According to the formulas (6) and (7), the stress amplitude Sa and mean Sm were analyzed statistically. The histogram of stress amplitude (Sa) distribution and two-dimensional (Sa, Sm) rain flow matrix of random stress spectrum can be obtained.

IV. Engineering Application

A. Location of Monitoring Points for Metallurgical Cranes

Selecting a metallurgical crane as monitoring object, the location distribution of monitoring points is shown in Figure 3.

FIGURE III. LOCATION OF MONITORING POINTS FOR METALLURGICAL CRANES

B. Random Stress Spectrum Monitoring Based on Fiber Bragg Grating Sensor

The characteristics of fiber Bragg grating (FBG) sensor make it one of the best choices for long-term monitoring of crane equipment. Its basic principle is shown in Figure 4.

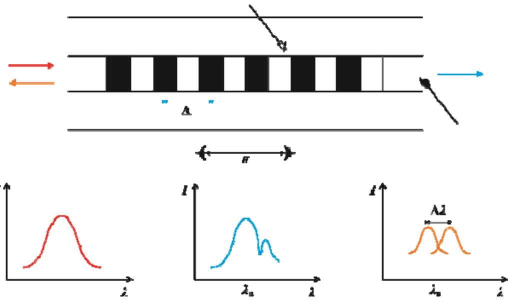


FIGURE IV. PRINCIPLE DIAGRAM OF FIBER BRAGG GRATING SENSOR

Fiber Bragg Grating Sensor (FBG) has many advantages, such as high measurement accuracy, large capacity, simple wiring and easy installation, small interference from complex external environment, small zero drift, good reliability and long service life. It is especially suitable for long-term monitoring of crane equipment.

The random stress spectrum big data based on FBG sensors are shown in Figure 5.

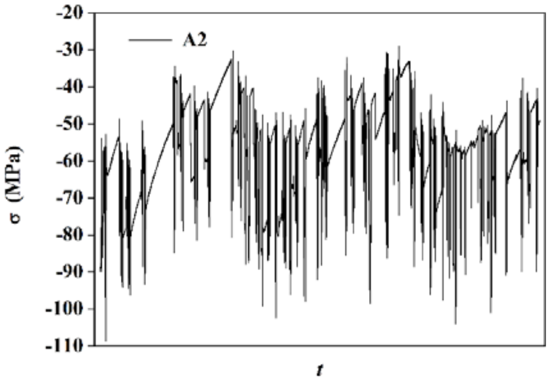
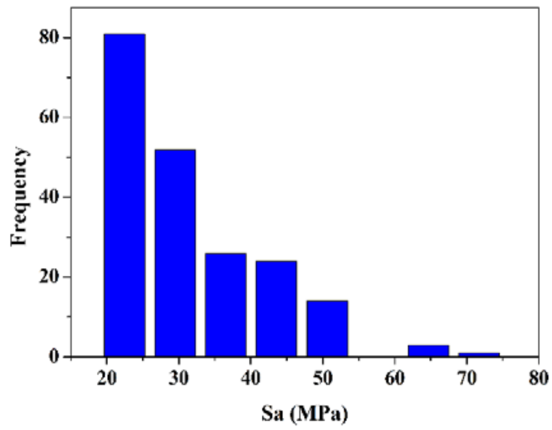


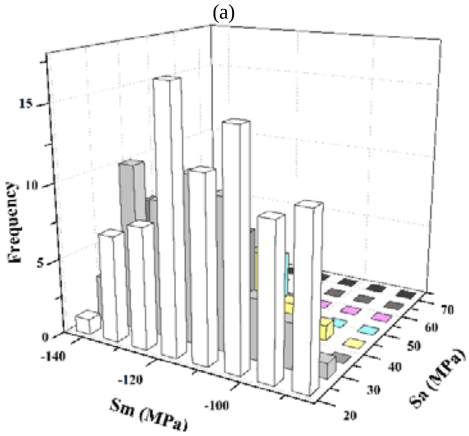
FIGURE V. RANDOM STRESS SPECTRUM BIG DATA OF A2

C. Real-Time Analysis Results of Random Stress Spectrum Big Data

Based on the above-mentioned big data analysis method of random stress spectrum, as shown in Figure 6 (a) and (b), the histogram of stress amplitude distribution (stress amplitude Sa in X-axis and frequency in Y-axis) and two-dimensional (Sa, Sm) rain flow matrix (stress amplitude Sa and stress mean Sm in XY plane and frequency in Z-axis) are obtained respectively.



(a)



(b)

FIGURE VI. (A) HISTOGRAM OF STRESS AMPLITUDE DISTRIBUTION, (B) (SA, SM) RAIN FLOW MATRIX

Based on the two-dimensional (Sa, Sm) rain flow matrix data and the corresponding mechanical model, the fatigue damage and health status of crane equipment can be analyzed conveniently and rapidly.

V. CONCLUSION

The big data analysis method of random stress spectrum of crane equipment is studied. The arithmetic of rain flow counting method is improved. The program of fast rain flow counting method with two parameters is compiled through data compression, peak and valley value processing, cyclic extraction and other steps. The online real-time analysis of big data of random stress spectrum is realized.

The proposed method is used to analyze and calculate the random stress spectrum big data collected by the structural health monitoring system of metallurgical crane, and the effective stress amplitude-frequency histogram of the hot spot area of fatigue damage of the main girder is obtained, which lays an important foundation for the subsequent analysis of fatigue damage and health status of crane equipment.

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