Big Data Fast Analysis Method of Random Stress Spectrum for Crane Equipment

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Abstract. With the increase of service time, the random stress spectrum of crane equipment causes cumulative damage. Cumulative damage induced crack initiation is one of the important failure modes of crane equipment. Through the rapid analysis of the random stress spectrum obtained in real time by the structural health monitoring system of lifting equipment, the cumulative damage of the structure can be analyzed and the remaining life of the structure can be predicted. In this paper, based on the traditional rain flow counting method, the big data fast analysis method of random stress spectrum is studied by adopting stack data structure. The program of fast rain flow counting method based on stack structure with two parameters is compiled. The fast rain flow counting method based on stack structure is used to analyze and calculate the big data of stress monitoring collected by the structural health monitoring system of metallurgical crane, and the stress amplitude-mean-frequency matrix of the hot spot area of fatigue damage of the main girder is obtained, which lays an important foundation for the health status diagnosis of metallurgical crane equipment.

1. 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. Cumulative damage induced crack initiation is one of the 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 remarkable progress in monitoring, collecting and processing a lot of data (stress Spectrum, acceleration, environment and operational Data), which can provide users with a large number of equipment operation and maintenance information. The data collected from structural health monitoring systems are of the “big data” according to their variety, volume, value, velocity and veracity [4-5].

It is helpful to identify the fatigue damage or failure of crane equipment during operation through the big data of structural stress monitoring. According to the calculation of big data of structural stress monitoring, although rainflow counting method is widely used because it is in accordance with fatigue damage law, it has not been reported in the online data analysis system of SHM of crane equipment.
The main work of this paper includes: (1) The algorithm of rainflow counting method is modified, and the fast analysis of random stress spectrum big data is realized. (2) The fast rain flow counting method based on stack structure is used to analyze and calculate the random stress spectrum big data collected by the SHM system of metallurgical crane, which lays an important foundation for the health status diagnosis of metallurgical crane equipment.

2. Big data acquisition of random stress spectrum

Structural health monitoring (SHM) has become a more and more feasible option to estimate the structural health status of crane equipment. As shown in Figure 1, the typical crane equipment SHM system 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.

With the development of advanced sensing technology, more and more SHM systems are widely used. The SHM systems can collect a large amount of raw data. At present, the trend brings the demand of rapid analysis and processing of large capacity data. For example, 600 GB acoustic emission monitoring data were stored during 1 year for wind turbine. Random stress spectrum monitoring data of metallurgical crane reach 12G/day. More references about big monitoring data for SHM system can be found in Cai [6].

![Figure 1 SHM System for metallurgical crane](image)

3. Fast processing method for random monitoring 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), different from the traditional double counting method, the new method only needs one time.

(2) The random stress monitoring big data to be analyzed and the result to be saved are stored separately, which avoids repeated shifts of data and greatly improves the counting efficiency.

Figure 2 Schematic diagram of improved rainflow counting method (only one rainflow counting is needed)

The rainflow matrix RFM and the residual RES are empty at the beginning. The algorithm works with a stack of four points, which is initialized with the first four points of random stress spectrum $s = [s_1, s_2, s_3, s_4]$. Next the following counting rule will apply.

If $\min(s_1, s_4) \leq \min(s_2, s_3)$ and $\max(s_2, s_3) \leq \max(s_1, s_4)$, then the pair $(s_2, s_3)$ is a cycle. Its amplitude is

$$S_a = \frac{|s_2 - s_3|}{2}$$  \hspace{1cm} (1)

Its mean value is

$$S_m = \frac{(s_2 + s_3)}{2}$$  \hspace{1cm} (2)

If this is the case, we store the cycle in the matrix $\text{RFM}(s_2, s_3) = \text{RFM}(s_2, s_3)+1$ and remove both points from the stack.

(1) if $r = 0$, then $[s_1=s_4, s_2=s_4, s_3=z_k, s_4=z_k+1]$, and $k = k+2$;

(2) if $r = 1$, then $[s_1=\text{RES}_r, s_2=s_1, s_3=s_4, s_4=z_k]$, $k = k+1$, and $r = 0$;

(3) if $r \geq 2$, then $[s_1=\text{RES}_{r-1}, s_2=\text{RES}_r, s_3=s_1, s_4=s_4]$, and $r = r-2$;

Then The counting rule is recycled. If the counting condition is not fulfilled, then

(4) $r = r + 1$, $\text{RES}_r = s_1$, $[s_1=s_2, s_2=s_1, s_3=s_3, s_4=s_4, s_4=z_k]$, and $k = k+1$.

4. Engineering application

4.1. Location of monitoring points for metallurgical cranes

Selecting a metallurgical crane as monitoring object, the distribution of monitoring locations is shown in Figure 3.
4.2. Random Stress Spectrum Monitoring Based on Fiber Bragg Grating Sensor

The good features 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 3 Location of monitoring points for metallurgical cranes

Figure 4 Principle Diagram of Fiber Bragg Grating Sensor

The continuous broadband light emitted by the light source is transmitted through the transmission fiber, which is coupled with the grating, and selectively reflects back to the corresponding narrow-band light and returns along the original transmission fiber; the rest of the broadband light is transmitted directly.

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.
4.3. Real-time analysis results of random stress spectrum big data
Based on the above-mentioned method for random monitoring stress spectrum, as shown in Figure 6 (a) and (b), the histogram of stress amplitude distribution (stress amplitude $S_a$ in X-axis and frequency in Y-axis) and two-dimensional ($S_a$, $S_m$) rain flow matrix (stress amplitude $S_a$ and stress mean $S_m$ in XY plane and frequency in Z-axis) are obtained respectively.
Figure 6 Histogram of stress amplitude distribution. (Sa, Sm) rain flow matrix
Based on the two-dimensional (Sa, Sm) rain flow matrix data and the corresponding mechanical model, the fatigue damage degree and residual life of lifting equipment monitoring area can be analyzed conveniently and rapidly.

5. Conclusion
The improved big monitoring data analysis method and arithmetic of crane equipment stress is studied. The program of quick rainflow counting method with two parameters is researched by adopting stack data structure.

The fast rain flow counting method based on stack structure is used to analyze and calculate the big data of stress monitoring collected by the structural health monitoring system of metallurgical crane, and the stress amplitude-mean-frequency matrix of the hot spot area of fatigue damage of the main girder is obtained, which lays an necessary foundation for the health status diagnosis of metallurgical crane equipment.

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