An algorithm of eliminating spike of the measured excavator load spectrum signal based on peak-valley extraction

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Abstract. The spike of the original measured load spectrum signal has great influence on the fatigue life prediction, so it must be identified and eliminated accurately. According to the variation law of the strain and force signals collected by the excavator load spectrum test, and the characteristics of the spikes contained therein, a spike elimination algorithm based on "peak-valley extraction" was proposed. In this algorithm, the spikes of digital signal is discriminated and corrected according to the changing trend of signal. The results of both the simulation test and the industrial example show that, the algorithm based on "peak-valley extraction" can accurately distinguish the spike from the normal signal. The principle of the algorithm is clear, the computational complexity is low, and the result is true and reliable, which lays a data foundation for the subsequent fatigue life prediction and fatigue reliability evaluation.

1. Introduction

The fatigue reliability evaluation of the structure of the excavator working device cannot be separated from the real load spectrum. The load spectrum is prepared by strain, force and other types of signals through steps such as rain flow counting. If the original measured signals contain spikes, the load spectrum obtained from these original signals and the fatigue damage obtained from the load spectrum will cause errors. This will cause deviations in subsequent fatigue life prediction and fatigue reliability evaluation [1]. Therefore, the spikes of the measured signals must be accurately removed. Signal preprocessing generally includes: zero drift removal, noise reduction, singular value removal, etc. In the Literature [2], the combination of amplitude threshold method and gradient threshold method achieved some certain effect when removing the abnormal signals in the measured torque signal of the loader drive system. However, the threshold values of the threshold detection method refers to the overall data distribution, while the spike is essentially the mutation of the change trend of the measured digital signal, which refers to the local data, Therefore, this kind of method cannot effectively deal with the measured digital signals with changeable trends [3], especially when dealing with the signal that can only be measured once, it will produce a large error [4]. In the Literature [4], a new method of removing singular value based on the variation rate was proposed for truck mounted concrete pump strain signals. The effect of the algorithm will be worse when eliminating consecutive singular values in the strain signal; In the Literature [5], the information entropy and BP neural network were introduced into detecting the singularity in the damage stress wave signal of pile foundation. The results show that the singularity can be detected effectively for the known singularity type and the measured signal with enough samples.
In the excavator load spectrum test, the signals collected synchronously can be divided into displacement, oil pressure, force and strain signals. With the change of the attitude of the working device and the working condition, the intensity of these signals’ change is not the same. In the subsequent preparation of the load spectrum, it is not only required to effectively remove the singular value of different types of signals, but also required to retain the true larger amplitude of the signal, and the signal length of each channel should not be changed. In order to meet the above requirements, this paper studies the singular value removal algorithm suitable for various signals in the excavator load spectrum test based on the changes and singular value characteristics of the various types of signal. This method is versatile and easy to use the programming implementation, and can effectively locate and modify the singular values, which lays the foundation for subsequent compilation of load spectrum and fatigue reliability assessment, and has good engineering application prospects.

2. Spike elimination algorithm based on "peak-valley extraction"

2.1. "Peak-valley extraction" model

![figure1](image)

**Figure 1.** Flow chart of "peak-valley extraction" model.

"Peak-valley extraction" is a method of data compression that is, deleting non-peak or valley points in the signal and only retaining the peak and valley points in the signal as useful signals [6]. The basic idea is that if the value of a data point is larger than the value of its two points before and after, or smaller than the value of its two points before and after, the data point is retained, otherwise it is deleted. The flow chart of "peak-valley extraction" is shown in Figure 1. The input *xydata* has two
columns, where, the first column `xydata(:, 1)` is the sampling time, and the second column `xydata(:, 2)` is the sampling value corresponding to each sampling time. The output is `xydata2`, where, the first column `xydata2(:, 1)` is the sampling time corresponding to the peak-valley value, and the second column `xydata2(:, 2)` is the peak valley value.

2.2. Algorithm of eliminating spike based on "peak-valley extraction"

The load spectrum test signal usually has a higher sampling frequency. Compared with the characteristics of instantaneous generation and disappearance of the spike, the trend of normal signal has continuity (mainly from the influence of inertia and damping of complex mechanical system). Even the normal signal with rapid change trend and great fluctuation still has continuity compared with the spike. In essence, the spike is a sudden change of the trend of the measured signal, and the gradient of the measured signal can reflect the change trend. Therefore, this paper proposes a spike elimination algorithm based on "peak-valley extraction" of the gradient of the measured signal: First, the gradient of the measured signal is calculated; second, the gradient signal is compressed by the peak-valley extraction algorithm. Since the spike changes much faster than the normal signal, after "peak - valley extraction", the spike as the inflection point will be retained. At this time, the difference between the spike and the normal signal is very obvious, that is, the spike and the two points before and after generally have only one sampling interval, and sometimes they are also considered to be within three sampling intervals [2]. In addition, using the characteristics of the discreteness of spike and the continuity of normal signal, the spike signal can be distinguished well from the normal signal that changes rapidly.

```
L = length(Y1)
for u = 1:L
    if dY1(u-1) <= 3 * sampling_interval
        Y2(u) = Y1(u)
    end
end
```

Figure 2. Flow chart of elimination algorithm for spike based on "peak - valley extraction".

The flow chart of elimination algorithm for spike based on "peak - valley extraction" is shown in Figure 2. Where, `xydata2`, the signal after peak - valley extraction of the gradient of the original signal, is the input to this part of the program. Let the first column `xydata2(:, 1)`, the peak and valley sampling time, is `Y1`, and the second column `xydata2(:, 2)`, the peak and valley value, is `Y2`.

Then the `diff` of `Y1` was calculated, and the result was kept in `dY1`. Next, each element in `dY1` was traversed, and if `dY1(u-1)` is less than or equal to 3 times sampling interval, `Y2(u)` was determined as spike, and the serial number of `Y2(u)` in the original data was recorded. These found serial numbers make up the array `Q`. Finally, the data points with serial number of `Q` in the original data were
eliminated, and the eliminated points were supplemented with the algorithm of linear interpolation to get \( xydata3 \), which is the final signal with spike eliminated.

3. Simulation text: typical signal characterized by large amplitude and large gradient

In order to verify the effectiveness of the proposed method, a typical signal with large amplitude and large gradient is constructed. As shown in Figure 3, among them, the amplitude and corresponding gradient of spikes at \( a, b \) and \( c \) are smaller, while the spikes at \( d \) are continuous and more than 3, and the amplitude and gradient of spikes at \( e \) are larger. Obviously, the amplitude threshold method can't recognize these spikes. From the gradient curve, only the spikes at \( d \) and \( e \) may be identified by gradient threshold method.

In contrast, the spike elimination algorithm proposed in this paper was used to process the above signal. The comparison result is shown in Figure 4. It can be seen that this method has higher spike elimination efficiency and accuracy.

![Figure 3. A piece of artificial typical signal characterized by large amplitude and large gradient.](image)

4. Industrial example: load spectrum signal of hydraulic excavator working device

4.1. Load spectrum test of excavator during dynamic excavation

The XE215G medium sized hydraulic excavator was selected as test prototype. The signals need to be collected, the data acquisition equipment, and the detailed test scheme of the load spectrum test were described in [7]. The test system is shown in Figure 5. The test was carried out under four typical medium, namely loose soil, primary soil, clay with small stones, and heavy clay or dense hard soil with large rocks. The field test is shown in Figure 6. According to Nyquist sampling law and excavator test experience [8], the sampling frequency is 20 Hz.
Displacement sensor
Oil pressure in the large and small cavity of the Boom Cylinder, Stick Cylinder and Bucket Cylinder

DEWE-43 data collector
DEWE-2601 dynamic strain indicator
Pressure Sensor
Displacement sensor
3D Pin-shaft force sensor
Tension force sensor
Strain gauge

Oil pressure in the large and small cavity of the Boom Cylinder, Stick Cylinder and Bucket Cylinder
Telescopic amount of the Boom Cylinder, Stick Cylinder and Bucket Cylinder
Hinge joint force of the bucket and stick
Link rod force
Rocking bar force
Strain values of the large stress measuring points on the boom and stick

Figure 5. Schematic diagram of dynamic test system.

Figure 6. Test fields for: (a) Category I: Loose soil; (b) Category II: Primary soil; (c) Category III: Clay with small stones; (d) Category IV: Heavy clay or dense hard soil with large rocks.

4.2. Characteristics of load spectrum test signal of excavator under actual working condition
Taking the signals collected under the medium of heavy clay or dense hard soil with large stones as an example, the characteristics of the signals were analyzed.

Figure 7. Measured signal (left rocker force) of medium sized excavator test prototype in medium of Category IV: heavy clay or dense hard soil with large rocks, and (b)–(e) are the enlarged views of position 1 ~ position 4.
Among all the collected signals, the force and strain signals are sensitive to external load change and vibration interference, so the spike is most likely to appear. The signals of strain or force in the process of dynamic excavation also have the following characteristics: The external load varies greatly in the four stages of one operation cycle (digging section, lifting section, unloading section and returning section), so the effective signal itself has the characteristics of large amplitude and large gradient, and the spike presents the phenomenon that small spike and large spike appear in one signal at the same time. In the digging section, the inhomogeneity of the medium will cause the normal mutation of the effective signal. As shown in Figure 7, several suspected spikes in Figure 7(a) were locally amplified for observation, as shown in Figure 7(b) to Figure 7(e), where positions 1 and 3 belong to spike, while positions 2 and 4 are normal load mutations caused by the inhomogeneity of the medium. It can be seen that threshold detection method is difficult to distinguish such cases. These real load signals with higher peak value have great influence on the fatigue damage of structures, and are also the important basis for extreme load inference in the load spectrum compilation. Therefore, they cannot be easily removed as spike signals. How to distinguish the normal signals with faster change trend caused by the uneven medium and the spikes is a key problem.

4.3. Results of spike elimination based on "peak-valley extraction"
The algorithm was programmed in MATLAB, and the spike of the signal shown in Figure 4 was eliminated. The result is shown in Figure 8.

It can be seen from Figure 8 that the spike elimination algorithm based on "peak-valley extraction" keeps the normal large amplitude at positions 2, 4 and 5, while eliminating the spikes at positions 1 and 3. It can be seen that this spike elimination algorithm has a better resolution to the spike and the normal signal in industrial example.

![Figure 8](image-url)

**Figure 8.** Comparison of before and after spikes were eliminated of the signal shown in Figure 6, and (b)~(f) corresponding to postion 1~5.
5. Conclusions
The spike elimination algorithm based on "peak-valley extraction" is proposed, which has been applied to a piece of typical artificial simulation signals with large amplitude and large gradient and achieved good results.

The load spectrum test of excavator during dynamic excavation was carried out, and the characteristics of the collected strain and force signals under the actual working condition were analyzed. The spike elimination algorithm based on "peak-valley extraction" was applied to eliminate the spike of the variable signal. The results show that the distinction between the spike and the normal signal is obvious, and the normal signal was not eliminated by mistake. It lays the data foundation for the subsequent fatigue life prediction and fatigue reliability evaluation.

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References
[1] Liu H O, Zhang G X, Xi J Q, Zhang H Y and Xu Y 2017 Dynamic load spectrum signal denoising of tracked vehicle transmission Journal of Jilin University (Engineering and Technology Edition) 47 42-49
[2] Wang H J, Wang J X and Wang N X 2012 Combined Application of Amplitude Threshold and Gradient Threshold on Abnormal Load Omitting Journal of Vibration, Measurement & Diagnosis 32 387-391+512
[3] Yan C L, Duan Y Q, Liu Y and Liu K G 2012 Elimination Algorithm for the Spike of the Measured Digital Signal Based on the Racetrack Method Transactions of the Chinese Society for Agricultural Machinery 43 230-234
[4] Wu Y X, Hu F and Hua G J 2011 Method of Removing Singular Values in Calculation of Fatigue Damage for Truck Mounted Concrete Pump Journal of Zhengzhou University (Engineering Science) 32 92-95+100
[5] Li J D and Kang W X 2017 The intelligent detection of singularity in signal based on information entropy and BP neural network Journal of Mudanjiang Normal University (JCR Science Edition) 04 1 5+43
[6] Lu P M 1999 Anti-Fatigue Design for Large Complex Structures (Xi’an: Shaanxi Science & Technology Press) pp 6-30
[7] Xiang Q Y, Lu P M, Wang B H and Xue L 2018 Research on characteristics of actual hinge joint load of hydraulic excavator working device Journal of Mechanical Strength 40 1063-70
[8] Yin Y, Grondin G Y, Obaia K H and Elwi A E 2007 Fatigue Life Prediction of Heavy Mining Equipment. Part 1: Fatigue Load Assessment and Crack Growth Rate Tests Journal of Constructional Steel Research 63 1494-1505