Optimization of cable vibration response signal in cable force analysis of cable-stayed bridge

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Abstract. In the cable force detection of the cable bridge, the frequency method is the most suitable and most commonly used method. And in the application of the frequency method, the core issue is the pickup of the natural frequency. In the practice of the general frequency method, the natural frequency is often picked up by collecting the vibration response signal of the bridge cable, and then analyzing the spectrum to pick up the natural frequency. This method can be applied to most cables. However, for some cables with unsatisfactory acquisition signals, the periodicity of the signal on the spectrogram will not be obvious. At this time, further cepstrum analysis of the cable signal can better analyze the spectral period of the cable vibration response signal in order to obtain a more accurate natural frequency and calculate a more accurate cable force value.

1. Introduction
As one of the main load-bearing members of the cable-stayed bridge, due to slight changes in strain and stress, it will cause large displacements and lead to structural damage and insufficient bearing capacity of the cable-stayed cable. Therefore, the health status of the cable being monitored is especially important. The state stipulates that for medium and large cable-stayed bridges, cable force testing shall be conducted once a year. In the practice of cable force detection of cable-stayed bridges, many studies have focused on the analysis of cable boundary conditions (fixed connection, shock absorbers, couplings, etc.), cable properties (sag, bending stiffness, etc.) on the influence of the formula and the derivation of the vibration equation (catenary equation, parabolic equation), and there is not much research on the further processing of the vibration response signal of the cable collected on the bridge. In signal processing, cepstrum analysis is a common method. The main advantage of cepstrum analysis is that it analyzes periodic and complex signals to separate the signal components of the signals coupled at different frequencies. This feature makes the method can be used in gear failure detection. In the cable force detection of cable-stayed bridges, picking up the natural frequency of the cable is the most important part. According to the vibration response characteristics of the object, the periodicity of the cable vibration response signal is resolved, which becomes the analysis of the cable vibration response signal. The core issue of cepstrum analysis is a method specifically used to analyze signal periodicity.

2. Cepstrum analysis
In the processing of cable vibration signals of cable-stayed bridges, the most commonly used method is to perform a fast Fourier transform on the acquired original time-history curve to obtain the power spectrum of the signal. The difference of the equidistant peaks appearing on the signal power spectrum, the average value is the natural frequency of the cable. When the periodicity of the power spectrum
obtained after the fast Fourier transform of the original time history curve is not obvious, the cepstrum analysis will be used. Cepstrum analysis is the result of further processing the power of the signal. There are two types of cepstrum processing: real cepstrum method (which can be used for bridge cable force analysis) and complex cepstrum method (usually used for language and image signal processing). In the real cepstrum processing of bridge cable signals, we usually use amplitude cepstrum. The biggest advantage of cepstrum is that it can simplify complex spectrum images. The principle of this advantage is that cepstrum converts the family of sideband spectral lines on the original spectrogram into a single spectral line to facilitate observation and picking of peaks. After the cepstrum processing, the unit of the abscissa of the obtained image is time, and the reciprocal of the average value of the time difference between the approximately equidistant peaks appearing in the image is the natural frequency of the cable. For a bridge cable structure, the entire cable can be regarded as a system. The cepstrum is to convert the convolutional system response signal into a superimposed signal, thereby separating them in phase. The calculation process of cepstrum is as follows:

\[
Y(t) = x(t) \ast y(t) \quad \Rightarrow \quad Y(f) = X(f) \ast H(f) \\
S_r(f) = S_x(f) \ast H(f)^2 \\
C_x(t) = C_x(t) + C_n(t) \\
\ln S_r(f) = \ln S_x(f) + \ln H(f)^2
\]

In the flow figure: \(x(t)\) is the system input; \(y(t)=x(t) \ast h(t)\), \(h(t)\) is the system's impulse response function. Finally, \(C_x(t)\) is transformed into \(\ln S_x(f)\) after FFT transformation, and then \(S_x(f)\) is obtained through exponential operation; \(C_n(t)\) is transformed into \(\ln H(f)^2\) after FFT transformation, and \(H(f)^2\) is obtained after exponential operation. After the signal is decomposed by this process, the components of the signal can be identified.

3. Test verification
This study is based on the MATLAB platform to analyze the data. First, the data of the cable vibration acceleration response signal collected in the bridge is derived, resampled using MATLAB, and then the spectrum chart is drawn, and then the signal is subjected to cepstrum analysis to form new image. In this study, at first, it compared the spectrum image and the cepstrum image of a cable with great sampling data, and then it compared the natural frequency we picked to verify the feasibility of the cepstrum analysis on the cable force analysis. Then it analyzed the two cables with non-periodic spectrum images, compared the spectrum image and the cepstrum image to verify the advantages of the cepstrum in analyzing the cable signal. At last it compared the calculated cable force of the two cables, the cable force measured in 2016, and the bridge cable force to verify the reliability of the data.
According to the comparison of the above figures, the natural frequency of the cable is 0.8482 hz using the peak picking method, and in Figure 3, the average time interval represented by the peak is 1.18 s, and the unit of the abscissa after the cepstrum is seconds. Its reciprocal of the interval represents the natural frequency of the cable, so the natural frequency of the cable is found to be 0.8475 hz, and the error of the fundamental frequency calculated by the two methods does not exceed 1%, which can fully meet the engineering test requirements.
In Figure 4 and Figure 6, the frequency spectrum of the vibration response signal of the cable is not ideal and does not have a good periodicity, and the image is analyzed by the cepstrum of Figure 5 and Figure 7 to find The obtained fundamental frequencies are 0.82883hz and 1.76471hz respectively. The calculated cable force values and the cable force values are compared as follows:

| Chart1. Calculation of cable force and analysis of cable force of two cables |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cable force calculated by cepstrum (hz) | Monitoring cable Force in 2016 (kN) | Bridge force (kN) | Calculated cable Force in 2019 (kN) | Relative cable deviation in 2016 (%) | Relative bridge force deviation (%) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1 | 0.82883 | 2528 | 2461 | 2567 | 1.53 | 4.30 |
| 2 | 1.76471 | 3780 | 3681 | 3789 | 0.25 | 2.94 |
Through the comparison and analysis of the data in the above table, it is found that the error between the cable force calculated by the fundamental frequency picked up by the cepstrum method and the cable force data measured in 2016 is mostly less than 5%, and all are less than 10%. The comparison error of cable force at bridge time is also less than 10%. These data fully show the feasibility of cepstrum method when dealing with spectrum signals with insignificant periodicity, and also verify the reliability of these cables.

4. Conclusion
This study proposes a supplementary processing method for calculating the cable force by the frequency method in the cable force detection method of cable-stayed bridges. Aiming at the problem that part of the cable signal spectrum in the actual detection process does not have good periodicity, it is proposed to use the cepstrum method to process the signal to obtain the fundamental frequency. This study introduces the calculation process of the cepstrum, introduces why the cepstrum can separate the signals of different frequencies through the formula, and also applies the cepstrum method to the processing of the inclined cable acceleration response signal through the MATLAB platform. Using MATLAB to draw an image intuitively reflects the superiority of the cepstrum method in analyzing the signal period. The case analysis proves that the cepstrum method can optimally pick up the cable vibration response signal, which is convenient for analysis. By comparing the cable force detection value of different years with the bridge cable force value, it is proved that the cepstrum method can be used as a supplement to the frequency method to calculate the cable force.

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