Windowed interpolation Fast Fourier Transform in Rolling Bearings Application of Fault Diagnosis
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Abstract: In order to accurately identify the Fault Characteristic Frequency of rolling bearings, The Minimum Entropy Deconvolution and Teager Energy Operator demodulation, Hanning Fast Fourier transform. Firstly, the Minimum Entropy Deconvolution is used to denoise the bearing fault signal. Teager Energy Operator demodulation spectrum; and Hanning. Finally, the amplitude of the three discrete spectrum near the signal frequency points is interpolated to get the accurate fault characteristic frequency. The analysis results of bearing vibration signals show that compared with the Energy Operator demodulation method on the basis of less analysis points, the proposed method can still accurately identify the bearing Fault Characteristic Frequency in most cases.

Keywords: Rolling Bearing; Teager Energy Operator; Minimum Entropy Deconvolution; fault diagnosis; Interpolation

1. Introduction

The rolling bearing is one of the important parts of the rotating mechanism, and its running state directly affects the working state and service life of the Rotating Mechanism. Therefore, the rolling bearing fault diagnosis has important practical significance.

Frequency vibration is called the bearing fault characteristic frequency. When using the spectral analysis method to diagnose the bearing, the bearing fault type can be judged by checking whether the bearing vibration signal spectrum contains fault characteristic frequency. Research shows that in the fault diagnosis of rolling bearing, the vibration signal generated by the fault is in the background of strong noise, and often appear different.

Therefore, accurately extracting Fault Characteristic Frequency is the key to judge the bearing fault type. Hilbert Transformation is common used signal demodulation methods can be used for the demodulation of bearing signals, but there are some limitations. [4-5]. Literature [2-3] Proposed an iteration-based Hilbert Fault Diagnosis Method of Rolling Bearing Based on transformation. Teager Energy Operator

It is an algorithm which is used to analyze and track the energy of narrowband signals when studying nonlinear speech modeling. Hilbert Tokushi

It is suitable for detecting the impact components in the signal and is widely used in bearing fault diagnosis. Literature [4.] Utilization Teager Extraction of Bearing Fault Characteristic Frequency by Energy Operator


After demodulation and Analysis of the inherent mode function of single component, the fault types of bearings.
and gears can be effectively determined. Literature [7.] Lee

Teager Weak fault features of bearings are extracted by Energy Operator-enhanced cepstrum. In the background of strong noise, in order to effectively extract

Bearing Fault Characteristic Frequency, literature [8-9] Deconvolution of the Minimum Entropy (Minimum Entropy revolution,Med) Apply to roll


Extract bearing fault features.

Windowed interpolation Fast Fourier Transform (FFT (Fast Fourier trans - Form,FFT) Method was first used to improveFFTCalculation accuracy[12],

It is widely used in power harmonic analysis. Literature [13-14] Pairs based on the maximum sidelobe attenuation window (Maximum sidalobe decay window,Msdw) InterpolationFFTDid a lot of research

The method is simple and easy to realize.

In order to improve the recognition accuracy of fault frequency of Rolling Bearing, this paper, based on the characteristics of bearing fault signal, combined with Med And Tea - GERTThe advantages of energy operator DemodulationD. belegaWindowed Interpolation

Method, using the commonly used Msdw The demodulation signal is weighted and the spectrum is corrected.

2. Minimum Entropy Deconvolution

When a fault occurs in the rolling bearing, the collected signal can be Show By type (1.) It can be seen that the vibration signal of the fault bearingY(N)Fault bearing Impulse SignalU(N)Background noiseN(N)And pass pathH(N)The convolution result. When the bearing fault occurs, the output signal is affected by random noise, transmission path, etc.Y(N)The input signal is often not true.U(N)Characteristics. By literature [15] It is known that the maximum entropy, the largest kurtosis of the signal, and

MedThe core idea is to constructLOrder InverseFilterF(N), Enabling the output signalY(N)The inverse filter is restored Input SignalU(N)To highlight the impact pulse, that is MedThe methods for solving the problem mainly include objective function method and characteristic vector method[16].

From the above analysis, through the selection of reasonable filter parametersMedThe signal processing can reduce the interference of background noise and enhance the impact component of the signal. It is suitable for the filtering pretreatment of bearing vibration signal.

3. TeagerEnergy Operator Demodulation

Frequency isFsSingle Frequency Signal at sampling frequencyFsSampling and getting discrete-time signals Type,AFor amplitude;φFor the initial phase.Sungai SignalX(N)OfTeagerEnergy OperatorPSIDefined[17] = 2πF₀/Fs

By type (2.) As you can see,TeagerThe output of the energy operator is proportional to the square of the frequency and amplitude of the signal.TeaNeng

The output of the scalar operator is more sensitive to transient impact components. WithHilbertCompared with the transformation,TeagerThe calculation of energy operator is simple.

3. Sampling points, so it has a good time resolution.

Bearing work due to local damage (spalling, corrosion, crack, Vibration Signal has the characteristics of periodic impact.TeaNengThe energy operator has the advantages of enhancing the transient characteristics of the signal,

Therefore, it is suitable for detecting transient components of signals.

In practical engineering applicationHilbertTransform sumTeagerEnergy Operator is2.Demodulation method,
literature [18] Yes. 2. Methods were compared in detail. With Hilbert Compared with the transformation, the energy operator has the advantages of small computation and high demodulation accuracy. The energy operator is used for demodulation and Analysis of Bearing Vibration Signals.

4. Demodulation spectrum correction

The maximum sidelobe attenuation window is a cosine window with good sidelobe performance, which is expressed as follows:

Among them, INumber of items for Window Function $A_i$ For window function coefficients and meet constraints:

$$\sum_{i=1}^{I-1} A_i = 1, A_i(1) = 0, i = 0$$

Computable 2 ~ 5. The maximum sidelobe attenuation Window Function Coefficient $A_i$. By table 1. You know, Hanning Window Yes 2. Maximum sidelobe Attenuation

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>2.-Msdw</th>
<th>3.-Msdw</th>
<th>4.-Msdw</th>
<th>5.-Msdw</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_0$</td>
<td>0.5</td>
<td>0.375</td>
<td>0.3125</td>
<td>0.273</td>
</tr>
<tr>
<td>$A_1$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.46875</td>
<td>0.437</td>
</tr>
<tr>
<td>$A_2$</td>
<td>0.125</td>
<td>0.1875</td>
<td>0.218</td>
<td>0.218</td>
</tr>
<tr>
<td>$A_3$</td>
<td></td>
<td>0.03125</td>
<td>0.062</td>
<td>0.062</td>
</tr>
<tr>
<td>$A_4$</td>
<td></td>
<td>0.007</td>
<td>812.5</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Window for maximum sidelobe attenuation window Interpolation FFT Method. Figure 1. Shown 2, 3, 4, 5. Window Length and sampling frequency 64 Frequency response curve of window function. B Said, B equals the sampling frequency divided by the sampling point. Yutu1. As the number of terms increases, the sidelobe level decreases and the sidelobe fading rate increases. But, Msdw The width of the main lobe becomes wider as the number of items increases, thus reducing the frequency resolution.

Literature [13-14] Interpolation based on the maximum sidelobe attenuation window FFT. Frequency Estimation of the method is described in detail, compared with other classical FFT Compared with the interpolation method, this kind of algorithm has analytical solution, and does not need to calculate the one-dimensional transcendental equation, the interpolation formula is simpler and easier.

Implementation. Without losing generality, consideration (3.) The Single Frequency Signal shown, Length is NOF Hanning Window W(N) Add the signal

$$= \sum_{i=1}^{N} F_o$$

However, due to Asynchronous Sampling and other reasons, in $K_o$ Often not an integer, so the precise frequency of the signal $F_o$ Can be expressed

$$K_o F_o = F_s$$

Visible, get the exact frequency $F_o$ The key is to find the frequency deviation $Q$. There are many methods to solve $Q$ Value, literature [13]. This paper introduces a simple method of Three-line interpolation.

Peak frequency $K_o$ Nearby 3. Amplitude solution of root Discrete Spectrum Q, Ling L-1 For L Left line, L 1 For L Right spectral line

Seek $Q$ After, according to the formula (9.) The exact frequency of the signal $F_o$.

4. Bearing Fault Diagnosis Method

According to the previous analysis, based on Hanning window Interpolation FFT The bearing fault diagnosis method of the method includes the following main steps: 1. Utilization

Med Methods. The vibration signals were pre-processed for noise reduction; ② Calculating Bearing Vibration Signals Teager Output of Energy Operator; ③ Okay, Teager Neng
The output of the scalar operator is fast Fourier transform. TeagerDemodulation Spectrum; Spectral addition of Demodulation HanningWindow, then OKL, L

1, L-1; Calculation of frequency deviation based on three spectral line amplitude interpolation Q. 6. Get the corrected bearing fault characteristic frequency value and judge the fault type. Detailed Process Diagram 2.

5. Bearing fault diagnosis example

Example Analysis Data from the bearing failure simulation test bench of Case Western Reserve University bearing Research Center(19). Inner and outer race tests

Bearing is installed at the motor driver end6205-2rs JEM SKF Deep groove ball rolling bearings with joint diameter $D_r$ = 39.039 mm, Rolling Element diameter $D_E$ = 7.940 04mm, ScrollNumber of entitiesZ = 9, Contact angleBeta = 0 °. Motor load is $0 \sim 2.2$ kW The rotational speed is about 1720 ~ 1797 r/min, Sampling frequency is 12 kHz.

5.1 Fault Diagnosis of Bearing Inner and Outer Rings

Bearing Inner Ring fault point diameter0.177 8mm, Fault depth0.279 4mm Motor Speed1 797 r/min. Calculation bearing inner ring fault of by frequency (. Ball passing frequency inner raceBPF1) 162.185 973Hz. Select data segment 2 049 ~

0721n 024A sampling points the analysis figure 3 Shown in for Inner Ring fault signal. From figure 3 In can significantly see bearing inner ring fault signal has periodic impact characteristics.

In order to improve the bearing fault frequency characteristics frequency recognition accuracy calculation MED Processing after the bearing inner ring signal TeagerEnergy

Operator of output and on the instantaneousTeagerEnergy sequence the Fourier transform get demodulation spectrum. Then use and HanningWindow

InterpolationFFTMethods of solution fn the spectrum correction get correction after the bearing fault characteristics frequency see Figure6. By figure6The AfterMEDAnd spectrum correction after bearing inner ring fault characteristics frequency and frequency doubling of precision to effective improve and theory calculation value phase agreement.

4. The TeagerEnergy operator only can remove the inner ring fault characteristics frequencyFBPFI = 164.062 5Hz (And and theory calculation value have big error) its frequency doubling not obvious. The figure3SignalMEDNoise reduction pretreatment reference literature [8-10Natural 20] Select appropriate MEDParameters (filter order numberL = natural 20 Maximum cycle iterative numberM = 30 Iterative ErrorE = 0.01). Figure5 Shown in for MEDFilter after the inner ring signal demodulation spectrum. And figure3 Compared inner ring signal

MEDPretreatment after enhance the signal in impact components prominent the bearing inner ring fault characteristics frequency and its frequency doubling but its accuracy and theory calculation value still have certain error.

In order to verify this paper the proposed methods of common applicability to exclude human select factors and data sample and factors of influence respectively.

Take bearing inner ring fault diameter0.177 8mmOf random data sample100A and50A and respectively corresponding to each sample data length1 024 And 2 048. Introduced root mean square error (Root mean square error RMSE) Index evaluation algorithm effectiveness reflect correction results of precision RMSEDefined as follows:

(16) In, N Representative sample number, Fc, Is each sample Correction fault characteristics frequency value, Fc, Said Calculation of theory frequency

Value. Table2, Table3 Shown in respectively 100A sample and 50A sample in point of failure diameter 0.177 8mm, Motor speed 1 721 ~ 1 797 r/min OIRMSESimulation results.
Table 2 100A sampleRMSE(Inner Ring 0.1778 mm)

<table>
<thead>
<tr>
<th>Speed (R/min)</th>
<th>1797</th>
<th>1772</th>
<th>1748</th>
<th>1721</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not correction</td>
<td>1.876527</td>
<td>4.132871</td>
<td>5.419789</td>
<td>2.982938</td>
</tr>
<tr>
<td>Correction</td>
<td>0.5862488</td>
<td>0.6444476</td>
<td>0.6989121</td>
<td>0.6819356</td>
</tr>
</tbody>
</table>

Table 3 50A sampleRMSE(Inner Ring 0.1778 mm)

Bearing outer ring select fault point diameter 0.177 mm, Fault depth is 0.279 4 mm, The point of failure is located 6. Clock direction.

Same as the outer ring analysis method, table4. Table5. Shown 100 Sample and 50 Sample diameter at fault point 0.177 8 mm Motor Speed is 1 725 ~ 1 796 r/min. ORMSE Simulation results.

Table 4 100 Sample RMSE (Outer Ring 0.1778 mm)

<table>
<thead>
<tr>
<th>Speed (R/min)</th>
<th>1796</th>
<th>1773</th>
<th>1750</th>
<th>1725</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected</td>
<td>1.835531</td>
<td>0.461367</td>
<td>0.912797</td>
<td>2.406453</td>
</tr>
<tr>
<td>Correction</td>
<td>0.478059</td>
<td>0.403902</td>
<td>0.433565</td>
<td>0.498889</td>
</tr>
</tbody>
</table>

Table 5 50 Sample RMSE (Outer Ring 0.1778 mm)

<table>
<thead>
<tr>
<th>Speed (R/min)</th>
<th>1796</th>
<th>1773</th>
<th>1750</th>
<th>1725</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected</td>
<td>1.835531</td>
<td>0.461367</td>
<td>0.912797</td>
<td>2.406453</td>
</tr>
<tr>
<td>Correction</td>
<td>0.397366</td>
<td>0.374909</td>
<td>0.336528</td>
<td>0.478578</td>
</tr>
</tbody>
</table>

By table4. Table5. Compared with other Motor speed 1 773 r/min Uncorrected and corrected. This is because the characteristic frequency value is uncorrected in this state. 105.468 75 Hz. And theoretical calculation of characteristic frequency value 105.930 11 Hz. Very close. In this state, after correction ORMSE The value has not decreased significantly. For most cases, the spectrum-corrected RMSE Value effect is better.

5.2 Window Effect

Window Function selection and windowed Interpolation FFT Accuracy has a greater impact. Analysis Using windowed Interpolation FFT Bearing Fault Diagnosis

Influence of time-lapse Window Function on Bearing Characteristic Frequency Accuracy7., Figure8 Shown in for respectively Selection2 ~ 5 The MSDW The bearing internal and external circle

Line and window Interpolation FFT Methods RMSE Value Curve (Data Length are 1 024) Can see, RMSE Value with the window function items

6. Conclusion

(1) According Teager Energy Operator and fault Rolling Bearing Vibration Signal of characteristics calculation vibration signal Teager Energy Operator

Output and on the Fourier transform after get demodulation spectrum can effective recognition bearing of fault characteristics frequency but in most situation under recognition accuracy don't high and theory calculation value there deviation.

(2) This paper introduced of triple-spectrum-line interpolation FFT Methods The calculation accuracy high and easy to realize used of maximum sidelobe attenuation window for signal processing the most commonly used of a window function algorithm easy to programming very suitable for embedded system of application.
(3) Main lobe narrow of window function has is high frequency resolution on fault characteristics frequency correction have certain influence.

(4) The bearing internal and external circle diagnosis instance analysis willMED,TeagerEnergy Operator demodulation and window InterpolationFFTMethod Combined.

In most situation under select is less of analysis point can significantly improve Bearing situation under select is less of analysis point can significantly improve Bearing characteristics frequency of recognition accuracy performance on is better than traditionalTeagerEnergy Operator demodulation methods.

References
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