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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 andTeagerOn the basis of energy operator demodulation,HanningA New Fault Diagnosis Method for Rolling Bearings Based on window interpolation and fast Fourier transform. Firstly, the Minimum Entropy Deconvolution is used to denoise the bearing fault signal.TeagerAfter de-noising, the fault vibration signal is demodulated by energy operator.TeagerDemodulation spectrum; andHanningFinally, 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 thatTeagerCompared 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;TeagerEnergy 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.HilbertTransformation is

Commonly used signal demodulation methods can be used for the demodulation of bearing signals, but there are some limitations.[1.], Literature [2-3] Proposed an iteration-basedHilbert

Fault Diagnosis Method of Rolling Bearing Based on transformation.TeagerEnergy Operator

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

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

Fault type. Literature [5-6] Splitting empirical patternsTea ★ - GEREnergy Operator demodulation method, usingTeagerEnergy 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

The fault diagnosis of moving bearing and gearbox has achieved good results. Literature [10] YesMedThe Application of Fault Feature Extraction in Rolling Bearing is analyzed in detail. Literature [11] WillTeager

Energy Operator andMedIn the fault diagnosis of rolling bearing,MedNoise reduction pretreatment of vibration signal, and then through TeagerEnergy Operator to obtain envelope spectrum, effective

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 - GERThe 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_I(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 isF_0Single Frequency Signal at sampling frequencyF_SSampling and getting discrete-time signals Type,AFor amplitude;φFor the initial phase.Sungai SignalX(N)OfTeagerEnergy OperatorPSIDefined[17] =2 piF_0/F_S

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.TeagerNeng

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.TeagerThe 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 [J [18] Yes.2.Methods were compared in detail. WithHilbertCompared with the transformation,Tea

GEREnergy operator has the advantages of small computation and high demodulation accuracy.TeagerThe 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_IFor window function coefficients and meet constraints: I-1.I-1. ÅA_I=1.Å$(-1)^I A_I$=0 I=0I=0

Computable2 ~ 5.The maximum sidelobe attenuation Window Function Coefficient1.. By table1.You know,HanningWindow Yes2.Maximum sidelobe Attenuation

Table1. Maximum sidelobe attenuation Window Function Coefficient Coefficients of msdw

Coefficient	2.-Msdw	3.-Msdw	4.-Msdw	5.-Msdw
$^A0$	0.5	0.375	0.312 5	0.273 437 5
$^A1.$	0.5	0.500	0.468 75	0.437 5.
$A_{2.}$		0.125	0.187 5	0.218 75
$A_{3.}$			0.031 25	0.062 5.
$^A4.$				0.007 812 5

Window for maximum sidelobe attenuation window Interpolation FFT Method. Figure1.ShownI Take2.,3.,4.,5.Window Length and sampling frequency64Frequency 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 [13-14Interpolation based on the maximum sidelobe attenuation windowFFTFrequency Estimation of the method is described in detail, compared with other classical

FFTCompared 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 isNOfHanningWindowW(N)Add the signal

=0 1N-1.

$K_0=F_0/F_{\text{Wang Yi}}F_{\text{Wang Yi}}=F_S/N$

However, due to Asynchronous Sampling and other reasons, inK_0Often not an integer, so the precise frequency of the signalF_0Can be expressed

Type,LPeak frequencyK_0The spectral line number corresponding to the maximum sampling amplitude is a positive integer;QFrequency Deviation, whose range is-0.5 0<0.5.

Visible, get the exact frequencyF_0The key is to find the frequency deviationQ. There are many methods to solveQValue, literature [13.This paper introduces a simple method of Three-line interpolation.

Peak frequencyK_0Nearby3.Amplitude solution of root Discrete SpectrumQ. LingL-1ForLLeft line,L 1ForLRight spectral line

SeekQAfter, according to the formula (9.) The exact frequency of the signalF_0.

4. Bearing Fault Diagnosis Method

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

MedMethods The vibration signals were pre-processed for noise reduction; ② Calculating Bearing Vibration SignalsTeagerOutput of Energy Operator;③Okay.TeagerNeng

The output of the scalar operator is fast Fourier transform.TeagerDemodulation Spectrum;④Spectral addition of DemodulationHanningWindow, then OKL,L

1.,L-1; ⑤ Calculation of frequency deviation based on three spectral line amplitude interpolationQ;6.Get the corrected bearing fault characteristic frequency value and judge the fault type. Detailed Process Diagram2..

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 SKFDeep groove ball rolling bearings with joint diameterD_P=

39.039 8mm, Rolling Element diameterD_B=7.940 04mm, ScrollNumber of entitiesZ= 9, Contact angleBeta= 0 °. Motor load is0 ~ 0 ~ 2.2 kWThe rotational speed is about1 720 ~ 1 797 r/min, Sampling frequency is12 kHz.

5.1 Fault Diagnosis of Bearing Inner and Outer Rings

Bearing Inner Ring fault point diameter0.177 8mm, Fault depth0.279 4mmMotor Speed1 797 r/min. Calculation bearing inner ring fault of by frequency (. Ball passing frequency inner raceBPFI)162.185 973Hz. Select data segment2 049 ~

072In1 024A sampling points the analysis figure3Shown in for Inner Ring fault signal. From figure3In can significantly see bearing inner ring fault signal has periodic impact characteristics.

In order to improve the bearing fault frequency characteristics frequency recognition accuracy calculationMEDProcessing after the bearing inner ring signalTeagerEnergy

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

InterpolationFFTMethods of solution fm 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.

4The,TeagerEnergy operator only can remove the inner ring fault characteristics frequencyFBPFI= 164.062 5Hz(And and theory calculation value have is big

Error) its frequency doubling not obvious. The figure3SignalMEDNoise reduction pretreatment reference literature [8-10Natural 20] Select appropriate

MEDParameters (filter order numberL = natural 20Maximum cycle iterative numberM = 30Iterative ErrorE = 0.01). Figure5Shown in forMEDFilter after the inner ring signal demodulation spectrum. And figure3Compared 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 024And2 048. Introduced root mean square error (Root mean square errorRMSE) Index evaluation algorithm effectiveness reflect correction results of precision.RMSEDefined as follows:

(16) In,NRepresentative sample number,F_{CI}Is each sampleCorrection fault characteristics frequency value,F_JSaid Calculation of theory frequency

Value. Table2, Table3Shown in respectively100A sample and50A sample in point of failure diameter0.177 8mm, Motor speed1 721 ~ 1 797 r/minOfRMSESimulation results.

Table 2 100A sampleRMSE(Inner Ring0.177 8mm)

Tab.2 RMSE. 100 samples(IR 0.177 8mm)

Speed (R/min)	1 797	1 772	1 748	1 721
Not correction	1.876 527	4.132 871	5.419 789	2.982 938
Correction	0.586 248 8	0.644 447 6	0.698 912 1	0.681 935 6

Table3 50A sampleRMSE(Inner Ring0.177 8mm)

Bearing outer ring select fault point diameter0.177 8mm, Fault depth is0.279 4mm, The point of failure is located6.Clock direction.

Same as the outer ring analysis method, table4.Table5.Shown100Sample and50Sample diameter at fault point0.177 8mmMotor Speed is1 725 ~ 1 796 r/minOfRMSESimulation results.

Table 4 100SampleRMSE(Outer Ring0.177 8mm)

Tab.4 RMSE of 100 samples(Or 0.177 8mm)

Speed (R/min)	1 796	1 773	1 750	1 725
Uncorrected	1.835 531	0.461 367	0.912 797	2.406 453
Correction	0.478 059	0.403 902	0.433 565	0.498 889

Table 5 50SampleRMSE(Outer Ring0.177 8mm)

Tab.5 RMSE of 50 samples(Or 0.177 8mm)

Speed (R/min)	1 796	1 773	1 750	1 725
Uncorrected	1.835 531	0.461 367	0.912 797	2.406 453
Correction	0.397 366	0.374 909	0.336 528	0.478 578

By table4.Table5.Compared with other motor speed,1 773 r/minUncorrected and corrected

This is because the characteristic frequency value is uncorrected in this state105.468 75HzAnd theoretical calculation of characteristic frequency value105.930 11HzVery close. In this state, after correction

OfRMSEThe value has not decreased significantly. For most cases, the spectrum-correctedRMSEValue effect is better.

5.2 Window Effect

Window Function selection and windowed InterpolationFFTAccuracy has a greater impact. Analysis Using windowed InterpolationFFTBearing Fault Diagnosis

Influence of time-lapse Window Function on Bearing Characteristic Frequency Accuracy7., Figure8Shown in for respectively Selection2 ~ 5TheMSDWThe bearing internal and external circle

Line and window InterpolationFFTMethodsRMSEValue Curve (Data Length are1 024) Can see,RMSEValue with the window function items

6. Conclusion

(1) AccordingTeagerEnergy Operator and fault Rolling Bearing Vibration Signal of characteristics calculation vibration signalTeagerEnergy Operator

Output and on its 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 interpolationFFTMethods 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 characteristics frequency of recognition accuracy performance on is better than traditionalTeagerEnergy Operator demodulation methods.

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