Separation of vibration signals of internal combustion engine cylinder head based on Variational Mode Decomposition and robust Independent Component Analysis

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Abstract: Summary: It is difficult to separate combustion signal and piston knock signal from cylinder head vibration signal in time-frequency domain. Use Based VMD And Robustica Separation of independent source signals. Vibration Signal Measurement of single-channel Cylinder Head of Internal Combustion Engine. First of all, the measured signals are preprocessed by eliminating trend terms and moving average. With VMD The algorithm decomposes the preprocessed signal.; And then use Ro-bustica Algorithm to extract independent components, The components with high similarity in time domain and frequency domain are combined with the combined modal function method.; Combined with Spectrum Analysis, Continuous Wavelet Transform, The results of separation are identified and verified by the coherence function method and the backward drag test. The results show that: Under different test conditions, This method can effectively separate combustion signal and piston knock signal from cylinder head vibration signal.

Keywords: Internal Combustion Engine; Cylinder Head Vibration; Variational Mode Decomposition; Combined Mode Function Method; Robust Independent Component Analysis

Wait [8] Based on the combustion pressure excitation signal and Valve Seat-drop excitation signal are separated from the cylinder head vibration signal by the algorithm. Han chunyang and others [9] Separation of combustion signals and piston impacting cylinder signals from mixed vibration signals of Internal Combustion Engines by multi-channel blind minimum mean square error and reduced Blind Source Method. But Blind Source Separation Methods require observation signal number and source signal number same, Need to measurement internal combustion engine more a channel of Vibration Signal. In actual engineering test in by cost and installation conditions of Limit Of then can only "with is less of sensor and difficult to determine source signal of number, The methods in actual engineering application in by limit. Later And have scholars put forward the internal combustion engine vibration signal of single-channel separation methods [10]. Such, [10] Use experience Mode Decomposition and independent component analysis phase combined with the methods from internal combustion engine single-channel body vibration signal in separation recognition the combustion signal and piston knock Signal But experience modal decomposition methods lack of strict of mathematical derived. The endpoint effect and modal aliasing problem will serious influence vibration signal of Separation Effect. [11-13]. At present In cylinder head vibration signal in Combustion signal composition and piston knock signal components are happened in the insertion near In time domain and frequency domain on the aliasing serious. On the separation and recognition has been is research of hot and difficult.

1. VMD And Robustic Algorithm of Basic Principle

1.1 VMD Basic Principle

Variational Mode Decomposition Algorithm [14] is a kind of signal decomposition algorithm. The non-recursive of

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decomposition. Mode Can very well on multi-component signal the decomposition. Assume that will a signal by variational mode decomposition algorithm decomposition KA variational modal component The its corresponding constraint Variational Problem.

FastICA The algorithm is a widely used independent component analysis algorithm. Subsequently, Zarzoso Wait. Scholars proposed better robustness and faster convergence speed. Robustica Algorithm, Robustica The algorithm is an iterative algorithm based on kurtosis and optimal step size., Passing a group of Signals Robustica After the algorithm processing, You can get all the independent signal components.

1.2 VMD-robustica Calculation process of Method

The VMD- robustica Method Available from single Independent source signals recovered from Channel mixed signals. The calculation process is as shown in Figure 1. Shown. First use VMD The algorithm decomposes the collected single channel signal. Then the decomposed narrow band modal components and the collected single channel signals form a new signal group. And then use Robustica Decoupling of the Algorithm, Combination, mode, state, Function Method (Combined mode function CMF) The components with higher similarity in time domain and frequency domain are combined. Combined with Spectrum Analysis, Continuous Wavelet Transform/Continuous Wavelet Transform/CWT The independent source signals are identified by the coherence function method and the backward drag test., Where the coherence function is defined.

2. Internal Combustion Engine Test

Test object is WP10-240 Four-stroke Water-cooled inline Internal Combustion Engine. Ignition sequence is 1-5-3-6-2-4. Test Bench WP10-240 Internal Combustion Engine Germany Siemens Ip6f AC Motor, Drag-down console and its Control accessories. In the course of the experiment, To WP10-240 Diesel Engine No. 6 Cylinder as the research object, With LC0158 Cylinder Head, single-channel, vibration signal measurement, Use, cylinder, pressure transmission, sensor Kistler 7013c And single channel Charge Amplifier 5018a1000 Collecting cylinder pressure signal of Internal Combustion Engine, With SM-12-100 Magnetic-electric sensor collects the signal of TDC, In the reverse drag test, Position the accelerometer in the Section 6. Cylinder piston tap, Measurement of piston percussion Vibration Signals, Test Measurement System as shown in Fig. 2. Shown, Test conditions such as table 1. Shown.

3. Separation and recognition of vibration signals of Cylinder Head

At low speed, The vibration excitation signals of internal combustion engines are relatively easy to be separated., High Speed and High Load, The internal combustion engine vibration excitation source signal will contain more other interference components. First of all VMD-robustica Method of internal combustion engine in 1000r/min Vibration Signal of Cylinder Head under no load condition Separation and Identification, Then the internal combustion engine at rated speed

Cylinder Pressure: And cylinder head vibration acceleration signal As shown in Fig. 3. Shown.

In order to separate vibration signals of Cylinder Head better, Reduce in measurement signal of process in the random error Components Need to the collection of the cylinder head vibration signal to reduce the trend and sliding average and pretreatment After pretreatment after the signal as shown in Figure 4 Shown in.

First of the pre-treatment after the single-channel cylinder head vibration signal the variational Mode Decomposition In the variational mode decomposition before Need to by observe the contrast all modal of center frequency to determine best of modal number K Value By calculation get the results such as table 2 Shown in.

From table 2 Can be seen in When modal number K Take 8 An arcane Have two variational modal component of center frequency respectively 5014 Hz And 5594 Hz. Apart close So can think that there. Decomposition So best modal number K Should be take 7.

Will pretreatment after of Cylinder Head vibration signal after variational Mode Decomposition processing after can get 7/A variational modal component Because of
By the figure5 in the calculation results the analysis result shows that ComponentIC1 and componentIC2 in time-domain waveform on the compare the similar so the combination modal function method will componentIC1 and componentIC2 combination CMF12SCMF12 = SIC1 + SIC2 Components CMF12. The Time-Domain Waveform, Spectrum and Time-Frequency figure as shown in Figure6 Shown in. At the same time By analysis found componentIC3 May for piston knock Signal On FFT Analysis and continuous wavelet Time-Frequency Analysis Results As shown in Figure7 Shown in.

From figure6 in Components CMF12 Time-Domain Waveform of amplitude in 140°C A And 380°C A About change is big According to internal combustion engine of prior knowledge Internal combustion engine the ignition of the order 1-5-3-6-2-4, The first 5, Cylinder and the first 6, Cylinder of angry angle respectively in 140°C A And 380°C A About Two cylinder work interval 240°C A, At the same time from spectrum the can see Components CMF12 Of frequency components main concentration in 4350 Hz, Combined with cylinder pressure and cylinder head vibration of coherent function (Figure8 ), In the frequency composition near Cylinder Pressure and cylinder head vibration of coherence is very good Cylinder Pressure Change main by In-cylinder caused by Combustion By cylinder pressure can calculation the combustion Signal [18]. Here the main of separation get of component the qualitative judgment And further to combined with Time-Frequency figure6c we can know that In 4350 Hz Near 140°C A And 380°C A About of frequency energy value is big and in 380°C A About of frequency energy value to greater 140°C A About of frequency energy value This is because measurement of is the first 6, Cylinder of Cylinder Head Vibration Signal The first 5, Cylinder is the first 6, Cylinder of adjacent Cylinder Combustion of vibration signal will transfer to the first 6, Cylinder But to than the first

6, Cylinder caused by burning of Cylinder Head vibration signal small So can judgment Components CMF12 For combustion Signal.

According to figure7 We can know that ComponentIC3 The Time-Domain Waveform of amplitude in 380°C A About change is big At the same time in 140°C A About also have certain of change And componentIC3 Of frequency components main concentration in 1150 Hz According to the cylinder pressure and cylinder head vibration of coherent function (Figure8 ), In the frequency composition near Cylinder Pressure and cylinder head vibration of coherence bad At the same time by figure7c can see In 1150 Hz Near 380°C A About of frequency energy value very big And in 140°C A About also have certain of Frequency Energy Internal combustion engine the ignition of the order 1-5-3-6-2-4, And piston cylinder wall of time consistent Will motored test measured of piston knock Vibration Signal Spectrum and ComponentIC3 Of spectrum contrast As shown in figure9 Shown in Can found piston knock Vibration Spectrum and ComponentIC3 Of spectrum Basic Agreement So can judgment componentIC3 Main for piston knock Signal. But in 2000 Hz

Near Piston knock vibration spectrum is big This may is because in motored test in Internal Combustion Engine of other moving parts of vibration caused And stay in depth study.

3.2 Internal combustion engine in 2100 r/min, 25% Load Conditions under cylinder head vibration signal of separation and Recognition

Internal combustion engine in 2100 r/min, 25% Load Conditions under of a work cycle of Cylinder Pressure and cylinder head vibration signal as shown in Figure10 Shown in.

The collection of the single-channel cylinder head vibration signal to reduce the trend and sliding average and pretreatment Then of the pre-treatment after the signal the decomposition By observe the contrast all modal of center frequency after found When modal number KTake11 An arcane Have two modal of Center Frequency 4018 Hz And 4720 Hz, Apart close and appear the. Decomposition So best of modal number of take 10.

Will by variational mode decomposition algorithm calculation get10A variational modal component and pretreatment after of Cylinder Head vibration signal of a new of signal Group With Robust ICA Algorithm extraction its Independent Component The get of each independent component the analysis With Combination Modal Function
Method Will time domain and frequency domain similarity is high component the combination. By points analysis after found component IC1 And group of component

CMF23/SCMF23=SIC2+SIC3/May for internal combustion engine of burning

Burn signal and piston knock Signal! The following combination Spectrum Analysis, Continuous Wavelet
Time-Frequency Analysis, Coherent Function Method, Down condition under the piston knock signal and internal combustion engine of prior knowledge of separation get the results the further recognition. Component IC1 And Components CMF23 The Time-Domain Waveform, FFT And CWT

Figure 1.11 Tutu12.

Slave chart 11 Can know, Component IC1 The Time Domain Waveform 380°CAGreat changes, After FFT After spectrum analysis, it is found that the frequency is mainly concentrated in 4250Hz, Yutu13. Can know, The correlation between cylinder pressure and cylinder head vibration is good near the frequency component. Cylinder pressure changes mainly caused by In-cylinder Combustion, The combustion order of the internal combustion engine is 1-5-3-6-2-4, No. 6. The firing angle of the cylinder is 380°CA Office, It is consistent with the energy amplitude of the Time-Frequency map at this position. So can determine the component IC1 For combustion Signals.

According to chart 12 Can know, Combined Component Cmf23 The frequency components mainly focus on 1500Hz, From Cwt You can see in the Time-Frequency Diagram 380°CATA The energy amplitude at 140°C A Energy amplitude, Ignition sequence with Internal Combustion Engine 1-5-3-6-2-4 Corresponding, Namely 5. Number cylinder and 6. The firing angle of the cylinder is 140°C A And 380°C A Office, Its working interval is 240°C A, And further, the frequency spectrum and the combined components of the vibration signal of the piston Cmf23 The spectrum is compared, Slave chart 14. You can see, Frequency Spectrum and combined components of vibration signals of piston percussion Cmf23 The spectrum is basically consistent, So Combination component can be judged Cmf23 Mainly for the Piston tap Signal. But the vibration signal spectrum of the piston 500Hz And 2500Hz There are other frequency components nearby. This may be due to the movement of other parts in the reverse drag condition. There's still room for further study.

4 Conclusion

(1) By test measurement of single-channel cylinder head vibration signal after With VMD Algorithm, RobustICA Algorithm and combination Modal Function Method And combined with Spectrum Analysis, Continuous Wavelet Time-Frequency Analysis, Coherent function method and motored test accurate effective to separation recognition the internal combustion engine of combustion signal and piston knock Signal.

(2) In Internal Combustion Engine 1000r/min No-load conditions under Combustion signal and piston knock signal of frequency components were concentrated in 4350Hz And 1150Hz In 2100r/Min 25% Under load conditions, The frequency components of the combustion signal and the piston percussion signal are concentrated in 4250Hz And 1500Hz. It can be seen that the frequency components of the combustion signal are concentrated in 4300Hz Nearby, This is mainly due to the high frequency oscillation in the combustion stage of the internal combustion engine. But the frequency of the piston tapping signal varies in different working conditions. The main reason is that the internal combustion engine has a higher speed and a larger load, Piston hits cylinder wall at high frequency, Large impact force, Which leads to a higher frequency of piston tapping signals.

References

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