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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 BasedVMDAndRobusticaSeparation 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.,WithVMDThe algorithm decomposes the preprocessed signal.;And then useRo-busticaAlgorithm 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$_{Fixed\text{-}P}$OinticaThe 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 requirements observation signal number and source signal number sameNeed to measurement internal combustion engine more a channel of Vibration SignalIn actual engineering test in by cost and installation conditions of LimitOften can only "with is less of sensor and difficult to determine source signal of numberThe methods in actual engineering application in by limit.LaterAnd have scholars put forward the internal combustion engine vibration signal of single-channel separation methods.$_{DU}$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 SignalBut experience modal decomposition methods lack of strict of mathematical derivedThe endpoint effect and modal aliasing problem will serious influence vibration signal of Separation Effect[11-13].At presentIn cylinder head vibration signal inCombustion signal composition and piston knock signal components are happened in the insertion nearIn time domain and frequency domain on the aliasing seriousOn the separation and recognition has been is research of hot and difficult.

1. VMDAndRobustICAAlgorithm of Basic Principle

1.1 VMDBasic Principle

Variational Mode Decomposition Algorithm[14]Is a kind of signal decomposition algorithmThe non-recursive of

decomposition ModeCan very well on multi-component signal the decomposition.Assume that will a signal by variational mode decomposition algorithm decompositionKA variational modal componentThe its corresponding of constraint Variational Problem

FastI CA The algorithm is a widely used independent component analysis algorithm.[15],Subsequently Zarzoso Wait.[16]Scholars proposed better robustness and faster convergence speed.Robustica Algorithm, RobusticaThe algorithm is an iterative algorithm based on kurtosis and optimal step size.,Passing a group of Signals RobusticaAfter the algorithm processing,You can g*et al*l the independent signal components.

1.2 VMD-robusticaCalculation process of Method

The VMD- robustica Method Available from singleIndependent source signals recovered from Channel mixed signals,The calculation process is as shown in Figure1.Shown.First useVMDThe algorithm decomposes the collected single channel signal.,Then the decomposed narrowband modal components and the collected single channel signals form a new signal group.,And then useRobustica Decoupling of the Algorithm,Combination, mode, state, Function Method(Combinedmodefunction·CMF)The components with higher similarity in time domain and frequency domain are combined.[17],Combined with Spectrum Analysis,Continuous Wavelet Transform(Continuouswavelet 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 isWP10-240Four-stroke Water-cooled inline Internal Combustion Engine,Ignition sequence is1-5-3-6-2-4.Test BenchWP10-240Internal Combustion Engine·GermanySiemens1pl6AC Motor,Drag-down console and Its Control accessories.In the course of the experiment,ToWP10-240Diesel Engine No.6.Cylinder as the research object,WithLc0158tCylinder Head, single-channel, vibration signal measurement,Use, cylinder, pressure transmission, sensorKistler7013cAnd single channel Charge Amplifier5018a1000Collecting cylinder pressure signal of Internal Combustion Engine,WithSM-12-100Magnetic-electric sensor collects the signal of TDC,In the reverse drag test,Position the accelerometer in the Section6.Cylinder piston tap,Measurement of piston percussion Vibration Signals,Test Measurement System as shown in Fig.2.Shown,Test conditions such as table1.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 allVMD-robusticaMethod of internal combustion engine in1000r/minVibration Signal of Cylinder Head under no-load conditionSeparation and Identification,Then the internal combustion engine at rated speed

Cylinder Pressure$_{PC}$And cylinder head vibration acceleration signalAAs 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 ComponentsNeed to the collection of the cylinder head vibration signal to reduce the trend and sliding average and pretreatmentAfter pretreatment after the signal as shown in Figure4Shown in.

First of the pre-treatment after the single-channel cylinder head vibration signal the variational Mode DecompositionIn the variational mode decomposition beforeNeed to by observe the contrast all modal of center frequency to determine best of modal numberKValueBy calculation get the results such as table2Shown in.

From table2Can be seen inWhen modal numberKTake8An arcaneHave two variational modal component of center frequency respectively5014HzAnd5594Hz,Apart closeSo can think that there. DecompositionSo best modal numberKShould be take7.

Will pretreatment after of Cylinder Head vibration signal after variational Mode Decomposition processing after can get7/A variational modal componentBecause of

By the figure5In the calculation results the analysis result shows thatComponentIC1And componentIC2In time-domain waveform on the compare the similarAnd further to analysis its spectrum after foundThey in frequency domain also compare the similarSo the combination modal function method will componentIC1And componentIC2CombinationCMF12SCMF12=SIC1+SIC2ComponentsCMF12The Time-Domain Waveform,Spectrum and Time-Frequency figure as shown in Figure6Shown in.At the same timeBy analysis found componentIC3May for piston knock SignalOnFFTAnalysis and continuous wavelet Time-Frequency AnalysisResults As shown in Figure7/Shown in.

From figure6InComponentsCMF12Time-Domain Waveform of amplitude in140°CAAnd380°CAAbout change is bigAccording to internal combustion engine of prior knowledgeInternal combustion engine the ignition of the order1-5-3-6-2-4,The first5, Cylinder and the first6, Cylinder of angry angle respectively in140°CAAnd380°CAAboutTwo cylinder work interval240°CA,At the same time from spectrum the can seeComponentsCMF12Of frequency components main concentration in4350Hz,Combined with cylinder pressure and cylinder head vibration of coherent function(Figure8),In the frequency composition nearCylinder Pressure and cylinder head vibration of coherence is very goodCylinder Pressure Change main by In-cylinder caused by CombustionBy cylinder pressure can calculation the combustion Signal[18]Here the main of separation get of component the qualitative judgmentAnd further to combined with Time-Frequency figure6cWe can know thatIn4350HzNear140°CAAnd380°CAAbout of frequency energy value is bigAnd in380°CAAbout of frequency energy value to greater140°CAAbout of frequency energy valueThis is because measurement of is the first6, Cylinder of Cylinder Head Vibration SignalThe first5, Cylinder is the first6, Cylinder of adjacent CylinderCombustion of vibration signal will transfer to the first6, CylinderBut to than the first

6, Cylinder caused by burning of Cylinder Head vibration signal smallSo can judgment ComponentsCMF12For combustion Signal.

According to figure7/We can know thatComponentIC3The Time-Domain Waveform of amplitude in380°CAAbout change is bigAt the same time in140°CAAbout also have certain of changeAnd componentIC3Of frequency components main concentration in1150Hz,According to the cylinder pressure and cylinder head vibration of coherent function(Figure8),In the frequency composition nearCylinder Pressure and cylinder head vibration of coherence badAt the same time by figure7cCan seeIn1150HzNear380°CAAbout of frequency energy value very bigAnd in140°CAAbout also have certain of Frequency EnergyInternal combustion engine the ignition of the order1-5-3-6-2-4,And piston cylinder wall of time consistentWill motored test measured of piston knock Vibration Signal Spectrum and ComponentIC3Of spectrum contrastAs shown in figure9Shown inCan found piston knock Vibration Spectrum and ComponentIC3Of spectrum Basic AgreementSo can judgment componentIC3Main for piston knock Signal.But in2000Hz

NearPiston knock vibration spectrum is bigThis may is because in motored test in Internal Combustion Engine of other moving parts of vibration causedAnd stay in-depth study.

3.2Internal combustion engine in2100r/min, 25%Load Conditions under cylinder head vibration signal of separation and Recognition

Internal combustion engine in2100r/min, 25%Load Conditions under of a work cycle of Cylinder Pressure and cylinder head vibration signal as shown in Figure10Shown in.

The collection of the single-channel cylinder head vibration signal to reduce the trend and sliding average and pretreatmentThen of the pre-treatment after the signal the decompositionBy observe the contrast all modal of center frequency after foundWhen modal numberKTake11An arcaneHave two modal of Center

Frequency4018HzAnd4720Hz,Apart close and appear the. DecompositionSo best of modal number of take10.

Will by variational mode decomposition algorithm calculation get10A variational modal component and pretreatment after of Cylinder Head vibration signal of a new of signal GroupWithRobustICAAlgorithm extraction its Independent ComponentThe get of each independent component the analysisWith Combination Modal Function

Method Will time domain and frequency domain similarity is high component the combination.By points analysis after found componentIC1And group of component

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

Burn signal and piston knock SignalThe 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.ComponentIC1And ComponentsCMF23The Time-Domain Waveform, FFTAndCwt**Figure 1.**11Tutu12.

Slave chart11Can know,ComponentIC1The Time Domain Waveform380°CAGreat changes,AfterFFTAfter spectrum analysis, it is found that the frequency is mainly concentrated in4250Hz,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 is1-5-3-6-2-4,No6.The firing angle of the cylinder is380°CAOffice,It is consistent with the energy amplitude of the Time-Frequency map at this position.,So can determine the componentIC1For combustion Signals.

According to chart12Can know,Combined ComponentCmf23The frequency components mainly focus on1500Hz,FromCwtYou can see in the Time-Frequency Diagram380°CAThe energy amplitude at140°CAEnergy amplitude,Ignition sequence with Internal Combustion Engine1-5-3-6-2-4Corresponding,Namely5.Number cylinder and6.The firing angle of the cylinder is140°CAAnd380°CAOffice,Its working interval is240°CA,And further, the frequency spectrum and the combined components of the vibration signal of the pistonCmf23The spectrum is compared,Slave chart14.You can see,Frequency Spectrum and combined components of vibration signals of piston percussionCmf23The spectrum is basically consistent,So Combination component can be judgedCmf23Mainly for the Piston tap Signal.But the vibration signal spectrum of the piston500HzAnd2500HzThere 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.

4Conclusion

(1)By test measurement of single-channel cylinder head vibration signal afterWithVMDAlgorithm, RobustICAAlgorithm and combination Modal Function MethodAnd 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 Engine1000r/minNo-load conditions underCombustion signal and piston knock signal of frequency components were concentrated in4350HzAnd1150Hz·In2100r/Min·25%Under load conditions,The frequency components of the combustion signal and the piston percussion signal are concentrated in4250HzAnd1500Hz.It can be seen that the frequency components of the combustion signal are concentrated in4300HzNearby,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 higher frequency,Large impact force,Which leads to a higher frequency of piston tapping signals.

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