Study on quantitative diagnosis method of valve clearance based on cylinder head vibration signal of diesel engine

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Abstract

The vibration signal of cylinder head contains abundant performance information of diesel engine, and it is inseparable from injection advance angle and valve timing in time domain, so it is easy to separate the response signal of each exciting force from vibration signal. In this paper, the vibration signals of the exhaust valve closing were cut out by extract time interval sampling, and the energy information of feature frequency range was extracted by HHT transform, the corresponding relationship between valve clearance and energy information was established after normalization, so that it is realized to quantitatively diagnose the valve clearance.

Keywords: cylinder head vibration, diesel engine valve, extract time interval sampling, quantitative diagnosis

1 Introduction

There has to be vibration when diesel engine works, the vibration signal contains abundant performance information of the diesel engine. There are many vibration sources, and the moving parts are many and various shapes, thus the contribution of excitation forces to the body vibrations are inconsistent, so the diesel engine vibration is very complex with nonlinear and nonstationary characters [1-2]. The motion of the diesel engine is complex, and is a combination of rotary motion and reciprocating motion. The vibrations include combustion vibration, the opening and closing collisions of intake and exhaust valves, and the collisions produced by all mechanical moving parts, etc., so the online fault diagnosis on the diesel engine with vibration signal is very difficult.

There are many diagnosis methods on diesel engine valve with the vibration signal [3- 4], and those focus only on qualitative research on the state of the diesel engine valve, the engineering applications of valve clearance online quantitative monitoring present great difficulties, so this paper analyses the vibration mechanism of the engine valve. According to intercepting the vibration signal of the exhaust valve closing on time domain, extracting the feature energy information of the vibration signal with HHT transform, and normalization process, the correspondence between the valve clearance and the vibration information is researched, that lays the technical foundation for the online quantitative diagnosis on diesel engine valve clearance.

2 Valve vibration mechanism

The valve moves on plunger role, it can be simplified as single degree of freedom model [5-6]. Figure 1 shows a single degree of freedom dynamic model of the valve.

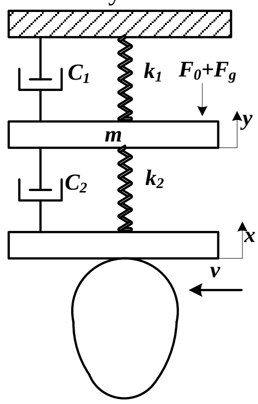

FIGURE 1 Valve train dynamic model of single degree of freedom

The differential equation of the valve motion can be described as

$$\frac{d^2y}{d\alpha^2}+\frac{c_1+c_2}{m\omega}\frac{dy}{d\alpha}+\frac{k_1+k_2}{m\alpha^2}y = \frac{c_2}{m\omega}\frac{dx}{d\alpha}+\frac{k_2}{m\omega^2}x-\frac{1}{m\omega^2}(F_0+F_g), \quad (1)$$

where m is the system quality equivalent, k_1 the valve spring stiffness, k_2 the system equivalent stiffness, c_1 the system external damping, c_2 the damping, F_0 the valve

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spring preload, F_g the force of gas on valve, α the cam angle, ω the cam angular velocity, y the valve lift, x the equivalent cam lift.

$$x(\alpha) = \zeta h(\alpha) - e\,, \tag{2}$$

where ζ is the rocker ratio, e the valve clearance, h the plunger lift and the function of cam angle.

The equation (1) meets the initial condition

$$\begin{cases} y\Big|_{\alpha=\alpha_0} = x(\alpha_0) \\ \dfrac{dy}{d\alpha}\Big|_{\alpha=\alpha_0} = \dfrac{dx}{d\alpha}\Big|_{\alpha=\alpha_0} \end{cases}, \tag{3}$$

α_0 is the valve opening angle, at this point the valve in upward force and the downward force exactly is in balance, α_0 can be seen as the following equation on α :

$$c_2\omega\frac{dx(\alpha)}{d\alpha} + k_2 x(\alpha) = F_0 + F_g(\alpha)\,, \tag{4}$$

The force balance of the valve in the open moment meets equation (4), the first item on the left is smaller damping force, if it is ignored, then:

$$e = \zeta h(\alpha_0) - \frac{F_0 + F_g}{k_2}\,, \tag{5}$$

According to the above formulas, when the valve clearance increases, the valve seating angle advances, seating speed and acceleration increase, these will inevitably lead seating impact energy to increase, it mean that there is a certain relationship between the valve clearance and vibration energy, therefore it is possible to quantitatively detect valve clearance with the valve seating energy.

3 HHT transform principle

The quantitative diagnosis on diesel engine valve clearance needs to extract the energy information on the characteristic frequency range, it can be realized by HHT transform.

On 1998, Norden E.Huang put forward a new nonlinear and non-stationary signal processing method, Hilbert - Huang transform (HHT). With empirical mode decomposition (referred to as EMD) method, the signal is decomposed into several intrinsic mode functions (referred to as IMF), and then for the IMFs, Hilbert transform is used to obtain the instantaneous frequency and amplitude, thus the time-frequency distribution of signal can be thus fully expressed.

For the real signal $x(t)$, According to HHT on each c_i, ignoring the residual r_n, $x(t)$ can be described as

$$\begin{aligned} x(t) &= \mathrm{Re}\sum_{i=1}^{n} a_i(t)^{j\Phi_i(t)} \\ &= \mathrm{Re}\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt} \end{aligned}, \tag{6}$$

$a_i(t)$ is the amplitude function, $\Phi(t)$ is the phase function , which are the analytic signal built by Hilbert transform on each intrinsic mode function.

$$H(\omega,t) = \mathrm{Re}\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt}\,. \tag{7}$$

The Hilbert marginal spectrum can be defined as

$$h(\omega) = \int_0^T H(\omega,t)dt\,. \tag{8}$$

T is the total length of signal.

4 Fault test of diesel engine valve

4.1 THE ARRANGENMENT OF MEASURING POINT

Experimental system is shown in Figure 2. Low frequency interference signal has lager amplitude in diesel engine vibration signal. In order to reduce the interference of other factors, improve the signal-to-noise ratio of the vibration signal, and reflect the true state of the diesel engine, the acceleration sensor is installed over the cylinder head to measure the vertical vibration signal.

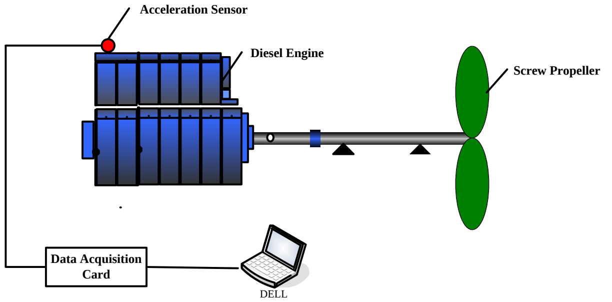


FIGURE 2 Sketch map of test system

4.2 EXTRACTION AND NONMALIZATION OF VIBRATION SIGNAL

The monitoring method on diesel engine state with the vibration signal needs to separate the vibration signals, there are differences among responses caused by the excitation sources of diesel engine in time phase, and it is easy to separate them on time domain. According to the working characteristics of diesel engine, in a work cycle, vibration signal contains valve characteristics in certain time period, so in the certain time period, vibration signal is intercepted to analyse.

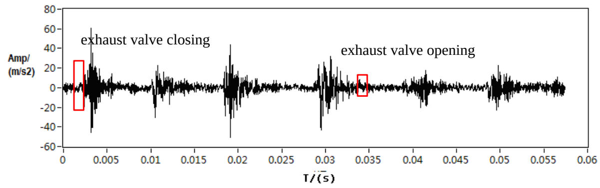
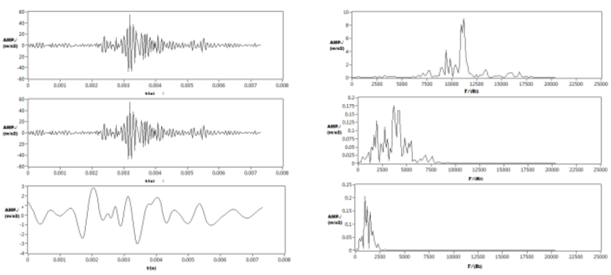


FIGURE 3 Cylinder head vibration of the 6# cylinder

Test was achieved on a certain diesel engine, and the vibration signal of 6# cylinder was extracted to analyse. The vibration signal of valve seating was used to diagnose the valve clearance. According to the valve timing of the diesel engine, the exhaust valve closed from 26° CA to 31° CA, as shown in Figure 3, the vibration signal of valve seating was intercepted with the extract time interval sampling, it contained the information of valve seating, and was decomposed by EMD, see Figure 4 a), and its Hilbert marginal spectrum as shown in Figure 4 b).



a) b)

FIGURE 4 IMFs and Spectrums of intercepted signals

According to the vibration characteristics of the diesel engine valve, the frequencies of valve seating signal mainly were above the 6 KHz. The frequencies of IMF0 were in this range by HHT, It meant the energy of valve seating signal was concentrated in the decomposition signal IMF0. As shown in Figure 4b, the frequencies of IMF0 were mainly 8000 HZ~14000 HZ, it indicated that the energy of valve seating was mainly concentrated in 8000 HZ~14000 HZ, This frequency band could be taken as characteristic frequencies at valve shutdown. When the speed of diesel engine was 1250 r/min, and the exhaust valve clearances were 0.3 mm, 0.4 mm, 0.7 mm and 1.0 mm, normalization was achieved with formula (9) and (10).

$$E = \left(\sum_{i=1}^{n} |E_i|^2 \right)^{1/2} . \tag{9}$$

The following equation gave an value for the normalized value η :

$$\eta = {E_i}/{E} \times 100\% . \tag{10}$$

In order to reduce the workload of test and calculation, the normalized values of 0.5 mm, 0.6 mm, 0.8 mm and 0.9 mm were achieved with interpolation, and the normalized curve of valve clearance was established, as shown in figure 5.

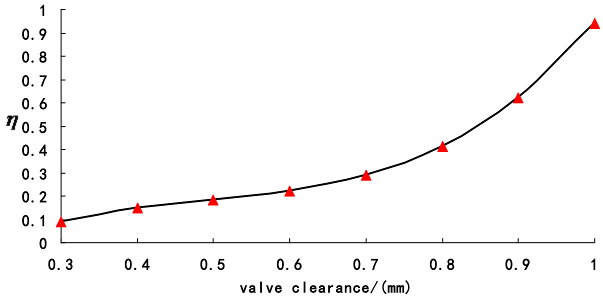


FIGURE 5 Normalization curve

4.3 EXPERIMENTAL VERIFICATION

In order to validate the method, at the speed of 1250r/min, setting valve clearances to 0.5 mm, 0.6 mm, 0.8 mm and 0.9 mm, test was completed. Table 1 shows the normalized data. Figure 6 shows the comparison between the test normalized curve and standard normalized curve, the error is less than 5%, it basically meets the requirement of engineering application.

TABLE 1 The comparison data of test

exhaust valve clearance (mm)	Standard normalized value (a)	Test normalized values (b)	Error c (%)
0.3	0.088	0.092	4.55
0.4	0.147	0.154	4.76
0.7	0.287	0.277	3.48
1.0	0.942	0.903	4.14

Where: $c = \frac{|a-b|}{a} \times 100\%$.

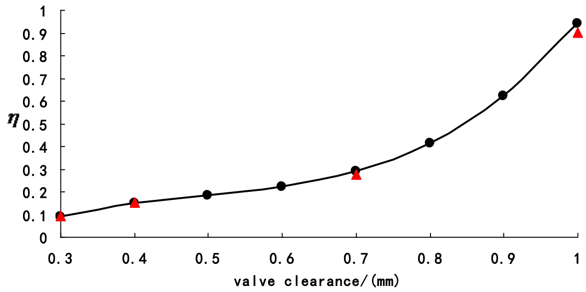


FIGURE 6 The comparison chart of test

5 Conclusions

Vibration signal of valve seating was cut out with extract time interval sampling, According to extracting the cylinder cover vibration information with HHT, and establishing the normalized standard curve, it can be achieved to quantitatively monitor valve clearance of diesel engine. The error is less than 5% that basically meets the requirement of engineering application.

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