The Research on Sensor Optimal Layout on Detection Device for Automobile Seat Horizontal Drive Mechanism

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Abstract. The type of the sensor and the optimal placement of the installation location of the sensor are important factors in vibration signal acquisition on automobile seat horizontal drive mechanism (HDM) for quality grading. According to the characteristics of HDM, the actual installation condition and the attenuation characteristic of the vibration signal transmission, the type of sensor was selected reasonably. By means of finite element analysis method, the best placement of the sensors to mount on the fixture was analyzed aim to maximize the information reflecting the fault and be sensitivity to the direction of the vibration. The finite element simulation and experimental results show that the acceleration sensor can effectively detect the fault characteristic signal, which provides a basis for further quality grading for HDM.

1 Introduction

Horizontal drive mechanism (HDM) is an adjustment mechanism that converts the rotary motion of the drive motor into the linear motion of automobile seat glides back and forth in order to achieve suitable position. Since the worm gear tooth surface bumps or residue burrs in the processing, a small number of HDM will produce repetitive tapping noise during operation. When the defective portion size is small, the vibration energy is weak, the inspectors can not perceive directly even in a very quiet and semi-anechoic chamber. It makes the factory quality grading very difficult. Currently, most of the auto parts manufacturers determine the presence of percussion in HDM by means of the artificial methods using the sound signal. The company is trying on developing the online quality inspection system to solve the detection problem. Liu¹ and Wang² analyzed the sound signals of HDM with the anthropogenic breakdowns by Gabor time-frequency analysis and Hilbert envelope demodulation method to extract the percussive information. Although both of them obtained the defect feature information, they could not use directly in the detection systems because of two reasons: One is the sound signal detection needs higher environmental requirements. The other one is that the energy strength of the noise signal in the HDM with quality problems is weaker than the artificially generated breakdown's. To find the weak fault signal, the signal processing methods applied to analyze the collected signals to obtain frequency characteristics associated with the fault. Time-frequency signal processing methods such as wavelet denoising algorithm³⁻⁴ and feature extraction methods⁵⁻⁷ adopted to analyze the weak vibration signal for detecting weak source signals. Some scholars introduced nonlinear theory, such as the theory of chaos⁸⁻⁹, stochastic resonance¹⁰⁻¹² to identify weak signal frequency characteristics. All these methods were based on the premise that the analyzed signal contains the weak source signal. For small closed driving device such as HDM, the energy generated by the vibration signal is very weak. Such weak signal can be collected effectively or not is a question.

Compared with the general gear box, the horizontal drive mechanism gear box is too small to install the sensor directly. The sensor has to be installed on the fixture. For small closed driving device, the efficient acquisition of the weak signal depends on the optimal layout of the vibration sensor on the horizontal driver.

2 HDM weak vibration signal detection device

The vibration sensor is mounted directly on the gear box for the general gearbox. The vibration signal on gear box is strong. Compared with the general gear box, the horizontal drive mechanism is too small to install the sensor. It is shown in Fig. 1. The impulse vibration signal in the horizontal driver is weak. It is easy to be interference by and submergence in the noise signal. The effective transmission of weak vibration signal from HDM to the fixture is the premise on the HDM quality grading.

The structure of fixture to detect vibration from HDM mounted on the side of the HDM is symmetrical. Fixture connected to the base plate fixedly with bolts. The original fixtures contact with HDM by driving force. The improved fixture connected with HDM via preload, the mechanism shows in Fig.2. During the gearbox operation, the vibration

and impact generated by the worm and worm wheel travelled through the shaft and gearbox bearing to the surface of the gearbox. The vibration signal transmits to the jig. The sensor is installed on the jig.

Fig.1. Structure of HDM

Fig.2. HDM Fixture Installation Diagram

The energy of the vibration signal generated by HDM is very weak. It is need to choice the type and location of the sensor reasonably.

3 Selection of Horizontal Driver Vibration Sensor

The sensors for the vibration signal acquisition have non-contact laser displacement sensors, force sensors, acceleration sensors. As the non-contact laser displacement sensor is too large to the horizontal drive mechanism, and has to be installed in a distance of 5-10cm from the HDM. The vibration caused by the operation horizontal drive mechanism has interference on the vibration signals collected by laser displacement sensor. It is improper to use the displacement sensor to acquire the vibration signal of the HDM.

Excitation force is unchanged in the process of transmission. The signal collected by the force sensor is the deformation on the vibration fixture. The strength of the vibration fixture is large, and the force generated by the HDM is very weak. The force is seriously attenuated from the HDM to the fixture. So it is not suitable to use the force sensor to collect the vibration signal.

The signal collected by acceleration sensor is the acceleration of the measurement point. The mechanical model of the fixture to detect weak vibration signal shows in Fig.3. The vibration generated by internal excitation force in HDM, transferred to the jig through the spring and damping.

Fig.3. Vibration transferring model of the fixture

The differential equation of the system is shown in equation (1):

$$M\ddot{x} + c\dot{x} + kx = F_0 \sin(\omega t) \quad (1)$$

where $F_0 \sin(\omega t)$ is the excitation vibration source generated by HDM which is transmitted to the gearbox surface. M is the equivalent mass of the fixture. c is equivalent damping between fixture and base plate. k is equivalent stiffness between fixture and base plate.

The acceleration of motion equation can be obtained from equation (1) as equation (2). And we can get the acceleration amplitude in equation (3).

$$\ddot{x} = \frac{\omega^2 F_0 / M}{\sqrt{(\omega_0^2 - \omega^2)^2 + 4\left(\frac{c}{2M}\right)^2 \omega^2}} \sin(\omega t + \varphi) \quad (2)$$

$$D = \frac{F_0}{\sqrt{M^2(1 - (\frac{\omega_0}{\omega})^2)^2 + (\frac{c}{\omega})^2}} \quad (3)$$

From equation (3), we can see that the nearer the fault signal frequency is close to the natural frequency, the higher is the amplitude of the acceleration on the frequency corresponding to fault. The harmonic response of the fixture was analyzed as the bottom of the jig was fixed and the acceleration was set to 1 mm/s². The acceleration response relative to the original fixture increased by about 1000 times in the vicinity of 100 Hz where fault signal frequency located.

In the transmission path, the acceleration signal can well reproduce the characteristics of the fault vibration signal. At the same time acceleration sensor is small and can be installed directly on the fixture. The acceleration sensor is selected to acquire the vibration signal.

4 Position optimization for acceleration sensor on HDM

The finite element mesh model of the HDM vibration detection fixture was shown in Fig. 4.

Fig.4. Diagram of the Node Location Corresponding to the Measuring Points of HDM Detection Fixture

The node 1 to 6 in the finite element model were select as the location of the sensor. The characteristic frequency of the vibration signal caused by the fault HDM is around 100Hz. The vibration response of the 6 test point in the detection fixture was analyzed within 700 Hz.

(a) Harmonic Response of Node 1

(b) Harmonic Response of Node 2

(c) Harmonic Response of Node 3

(d) Harmonic Response of Node 4

(e) Harmonic Response of Node 5

(f) Harmonic Response of Node 6

Fig.5. Harmonic Response of Testing Point

The harmonic response values at 100Hz of each node are listed as follows:
Node 1:0.1379; Node 2:9.7146e-2; Node3:4.3514e-2;
Node 4:2.9727e-3; Node 5:2.1794e-3; Node 6:5.1378e-6.

We can conclude that:

(1) Comparing the harmonic response values of node 1 with node 5, we can know that when the sensor is at the same direction with the vibration propagation direction, the harmonic response value of node 1 is the largest one. The optimal location to install the sensor is at node 1, which is sensitivity to signal for effective vibration signal acquisition.

(2) Comparing the harmonic response values of node 6 with node 5, we can conclude that it is difficult to collect the vibration signal effectively when the direction of sensor is different from the vibration propagation direction. The sensor should be installed in the same direction with the vibration propagation direction.

5 Experiment

The vibration signal of the horizontal driver is sampled by the sensor on the test point optimization of the detection fixture. The vibration signal of the normal and innormal HDM with worm wheel fault are shown in Fig. 6. Compare Fig.6(a) with Fig.6(b), we can directly determine the quality grade of HDM through the amplitude of the time-domain vibration signal.

Fig.6. Vibration Signal of HDM with Worm Wheel Fault

6 Conclusions

The type of the sensor and the optimal placement of the installation location of the sensor are important factors in vibration signal acquisition. According to the characteristics of HDM, the acceleration sensor can effectively acquire the vibration signal including the fault information according to the actual installation condition and the attenuation characteristic of the vibration signal transmission. By means of finite element analysis method, we can optimize the best placement of the sensors with the goal of maximizing the information reflecting the fault and sensitivity to the direction of the vibration. On the base of installation conditions, the sensor shall be mounted on the top of the vibration detection fixture, in the same direction as the vibration propagation direction.

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