

Advances in Vibration and Noise Reduction of Hybrid Transmission

Chen Feng, Yan Ren, Shi Haohao and Zhou Yidan

School of Mechanical Engineering, Nantong University, 226019 Nantong, China

Abstract. The vibration and noise problems of hybrid transmission during operation will affect the comfort of HEV. The research on the vibration and noise reduction of hybrid transmission can provide technical support for NVH performance improvement. This paper describes the detection and identification of noise sources, gear modification, optimization of boxes' natural frequency and increasing damping for vibration and noise reduction in hybrid transmission. Finally, the directions of development are analysed for vibration and noise reduction technology of hybrid transmission.

1 Introduction

As people's new requirements for energy saving and environmental protection, green energy-saving cars came into being. HEV (Hybrid Electric Vehicles) with low fuel consumption, low pollution, high energy efficiency and good performance and other advantages, has gradually become the mainstream of energy-saving vehicles. We can see its market share become higher and higher. Hybrid transmission is a key component of HEV, and has the advantages of compact structure, high efficiency, adaptability and the function of the power shunt. But the hybrid transmission in the work process has vibration and noise issues that will affect vehicle performance and driving comfort. Therefore, it is particularly important to take effective measures to control its vibration and noise to improve the NVH (Noise, Vibration and Harshness) control of HEV. At present, there are some researches on the detection and identification of the noise source in hybrid transmission, the vibration and noise reduction by improving transmission components and parts, and the vibration and noise reduction technology of hybrid transmission with damping. It's of great importance to take efforts to optimize transmission structure and damping for NVH performance of hybrid transmission. In order to enhance HEV competitiveness in the automotive market, the study for improving the driving comfort of hybrid transmission is significant.

2 Vibration and noise reduction technology of hybrid transmission

Hybrid transmission is made up by the box, planetary gear, reducer and other structures. The vibration of

planetary gears, bearings, shafts and boxes and other components during operation cause noise. Among them, gear meshing noise in the planetary gear mechanism is the main noise source of the hybrid transmission. The part of the noise is transmitted to the box in the form of air-borne sound and the other part is transmitted to the box as solid sound through the shaft and the bearing system, resulting in radiation noise from the box. If the gear meshing frequency coincides with or is close to the natural frequency of the box, resonance will be caused. Many researches have been done for the vibration and noise reduction of hybrid transmission, which mainly focused on the detection and identification of noise sources, optimizing the hybrid transmission structure and changing the damping for the vibration and noise reduction of the hybrid transmission.

2.1 Detection and identification of transmission noise source

Accurate detection and identification of hybrid transmission noise source is the premise to solve the vibration and noise problems of the hybrid transmission. The detection and identification of hybrid transmission noise source is the use of vibration and noise hardware test system for vibration and sound pressure signal acquisition, then uses software analysis system to analyse the signal identification collected, and ultimately determines the noise source characteristics and location. Hybrid transmission vibration and noise test system is showed in Figure 1. The current mainstream hardware test system consists of Danish B & K series microphones (measure noise), acceleration sensors (measure vibrations) or microphone probes (measure noise), and LMS SCADAS data acquisition systems in Belgium.

Table 1. Several identification methods of hybrid transmission noise source

Noise source identification method	Theory	Application
Time domain analysis	According to the corresponding time characteristics for each part of noise source or noise source, the main noise source is identified by time-domain average and correlation analysis.	Suit for the stationary signal identification of periodic components.
Frequency domain analysis	Judging by the narrow-band filtering method, the main noise source is identified through spectrum analysis, rotational machinery characterization and coherence analysis.	Be suitable for the analysis and recognition of smooth signal of rotating system.
Time-frequency analysis and wavelet analysis	On the basis of the varying frequency signals, the time-frequency analysis display range is automatically adjusted in the time domain window to accurately identify the main noise source.	Suit for non-stationary or transient signal analysis.
Surface vibration velocity measurement	Depending on different speeds of the parts surface caused by vibration, the main noise source is identified.	For noise mainly based by structural noise in on-site noise identification.
Sound intensity measurement	In accordance with the measurement of the components compared to the radiation power of the noise, the main noise source is recognized.	Apply to identify noise in poor acoustic measurement environment.

Test.Lab analysis system is commonly used software analysis system. How to use the appropriate noise source identification method to improve the efficiency and accuracy of vibration and sound pressure signal analysis is the focus of noise detection and identification technology study, after the noise signal of hybrid transmission detected by test system. Several main hybrid transmission noise source identification methods, principles and applications are listed in Table 1. As can be seen from table 1, different noise identification methods have their own scope of application. In actually, noise source identification method for hybrid transmission should be chose reasonably, which should be based on the measurement environment, signal stability and sound source frequency components and so on.

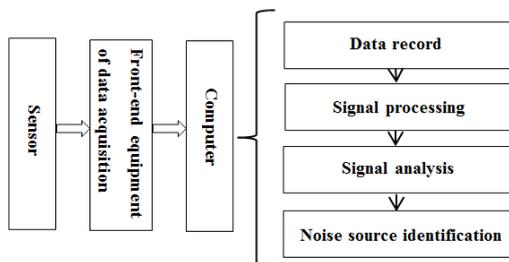


Figure 1. Vibration and noise test system flow

For a hybrid bus braking abnormal noise, Yu Feng et al [2] used morlet wavelet noise signal for time-frequency analysis of the test and compared the frequency to recognize the noise source. The experiment of vibration and noise reduction proves that the time-frequency analysis method is accurate and effective. Based on the relationship between single point vibration velocity and radiated sound energy of mechanical structure, Li Ji et al [3] detected single-point vibration velocity and vibration mode of structure surface for solution of transmission radial acoustic energy. The way can achieve a rapid detection of transmission scene noise

goal for noise mainly based by structural noise. For the extraction problem of fault signal in unsteady rotating machinery vibration noise signal, Zhu Maotao et al [4] used order analysis technology to identify the main noise source of a hybrid transmission and compared the time-frequency characteristics curve to real-time distribution of order noise source analysis to prove this frequency domain analysis method effective. Hybrid transmission noise source detection and identification technology is fairly mature technology. Current measuring instruments and identification technology can detect the noise source preferably. With further improvement of these technological accuracy, real-time and convenience (on-site testing) and reduction of the test equipment cost, the technology will be better and better applied.

2.2 The transmission structure optimization for vibration and noise reduction

There are many structures that can be chose for hybrid transmission optimization. Vibration and noise reduction by optimizing the structure is the most used technology. As gear modification and natural frequency optimization of the box are the most significant vibration and noise reduction method, they are the most widely used. A brief description is followed.

2.2.1 Gear modification

As the error of the manufacture and installation and the work load deformation, gears in hybrid transmission cause interference part. The gear modification is a method that trims gear interference part and eases the gear meshing stiffness changes to reduce meshing impact and load imbalance in distribution. Gear meshing contact is improved after modification. The purpose of reducing gear vibration noise can be achieved. Tooth direction and tooth profile modification can be used to optimize gears noise question, the two repair methods can be used alone

or in combination. Zeng Hong et al. [5] selected different modification quantities and modified curves to design gear modification, and determined the most reasonable modification scheme of gear vibration and noise reduction based on the contact stress after gear modification. Pan Haibo [6] analyzed the noise of transmission and found that the meshing noises of gearwheel had an important influence on the noise of whole box. He established a tooth profile model, which was coupled with a tooth crest and a tooth root modification curve. The modified transmission noise state had been improved by experimental verification. This tooth profile modification method is reliable. Pan Gongyu et al. [7] studied the vibration problem caused by poor gear meshing engagement in deep hybrid transmission and found that the gear noise of hybrid transmission had been improved, after the tooth was optimized by combining the method of tooth profile modification with the method of tooth direction modification. These studies show that adopting a proper modification method and modification parameters for gear modification can improve gear meshing and achieve vibration and noise reduction for a hybrid transmission.

2.2.2 The optimization of the box natural frequency

In general, optimizing the box natural frequency of the hybrid transmission requires optimizing the structural parameters of the box. It can reduce the natural vibration and noise radiation, and make box natural frequency stagger the natural frequency of other components and the excitation frequency of power components to avoid resonance among components. There are many studies for optimization of the box structural parameters, such as changing the geometry of the box structure, increasing the thickness of the box, designing some local protrusions or recesses to reduce the radiation area, and the addition of point mass or stiffeners and other ways. In these optimization methods, current researches mostly focus on adding stiffeners where the vibration response of the box is obvious, so as to improve the box rigidity, optimize the box natural frequency of the hybrid transmission and improve its anti-vibration ability. Pan Gongyu et al. [8] theoretically analyzed that the box of a hybrid transmission didn't generate resonance phenomenon, because the box natural frequency was staggered by the gear meshing frequency which corresponded to the fixed speed of the front wheel. The accuracy of theoretical analysis was verified through experiments. Hong Liang et al [9] added stiffener structure near the output shaft end of the hybrid transmission box to increase the box rigidity, and improved the dynamic characteristics. The study provides the basis that noise reduction of hybrid transmission box can be ameliorated by box natural frequency optimization. According to topology optimization result, Wang Haoran et al. [10] strengthened material on the parts of electric car transmission box that had an important influence on the strength improvement, thereby increased the box natural frequency. Modal analysis showed that the vibration and noise of the

optimized box was improved. The optimization of the box natural frequency is an effective measure to improve the resonance phenomenon and it's significant to control the radiation noise of the hybrid transmission.

2.3 Adding damping for vibration and noise reduction

Damping vibration and noise reduction of hybrid transmission achieves the purpose of vibration and noise reduction by dissipating the vibration energy transmitted along the mechanical structure (such as gears, shafts, etc.). It can weaken the natural vibration or resonance of the transmission. Different damping noise reduction methods are used in different structures or parts of the transmission, such as increasing damping ring on the gear end, adding damping plug into the teeth, forming a constrained damping structure in the box, and embedding high damping materials into the box body. These methods can increase hybrid transmission damping to improve the vibration absorption and noise reduction performance. In addition, transmission components made of high damping materials can also achieve vibration and noise reduction. For example, the noise of the transmission used high damping aluminum alloy is lower than that used ordinary aluminum alloy. Yu Yinghua et al [11] compared the vibration and noise of transmission when using foam aluminum damping plugs or ordinary cast iron damping plugs in the way of combining the theoretical analysis and experimental verification. The experimental result showed that the vibration reduction effect of foam aluminum damping plugs was better. Liu Yixiang et al. [12] attached the damping material to the outside of the upper transmission box body, poured damping material into the lower box body, added alloy damping ring on the gear spokes and stuck damping material inside the rim to reduce vibration and noise. After implementing a series of damping vibration and noise reduction measures, experimental verification indicated that structural vibration was weakened and radiation noise was reduced. These measures achieve a certain degree of vibration and noise reduction. At present, the researches on vibration and noise reduction of hybrid transmission by damping mainly focus on the application of damping alloy materials. There is little research on the vibration and noise reduction of transmission using other damping materials (such as composite materials), which needs further study.

3 Vibration and noise reduction technology trends for hybrid transmission

Automotive NVH control requirement is continuously improved. Hybrid transmission is one of main noise sources of HEV, the requirements of its vibration and noise reduction are also increasing. It will become the focus of research on NVH control for hybrid transmission that takes effective measures to improve the efficiency and effectiveness of hybrid vibration and noise reduction technology, which can improve the driving

comfort. The future development trend mainly has the following aspects.

3.1 Vibration and noise reduction design for overall hybrid transmission

In recent years, researchers have studied the vibration and noise reduction design of hybrid transmission components and obtained the theoretical reference for the design of component parameters. Transmission vibration and noise can be to some extent reduced with rational design parameters of gear teeth, pressure angle, the size of the spiral angle and the box shape, stiffness and other parts. However, in the development of the whole hybrid transmission, there is less research on how to avoid interaction between the parts and resonance. In the development of vehicle vibration and noise reduction performance, researchers plan and match the noise contribution of different systems, formulate the noise requirements of each system, and adjust the frequency range of each system to avoid resonance. At present, however, the vibration and noise reduction of each component is mostly independent when the hybrid transmission is developed. At the time of design, the modal frequency of each component is less concerned. The resonance when the modal frequencies are adjacent or similar is not adjusted yet. Therefore, it is necessary to strengthen the overall design research for hybrid transmission vibration and noise reduction. In the overall design phase, it's indispensable to develop standards to limit the noise of each component, and mark the various parts of the frequency through vibration and noise test and analysis to get the best solution for the overall vibration and noise reduction of hybrid transmission components. This way can reduce the impact of vibration and noise after the components are assembled into transmission, so as to decrease the changes of the components for vibration and noise reduction in the later period. Hybrid transmission vibration and noise can be actively and effectively controlled.

3.2 Vibration and noise reduction materials for hybrid transmission

With the continuous improvement of the requirements for vibration and noise control of hybrid transmission, its requirements of sound absorption and sound insulation for noise reduction materials are also getting higher and higher. Smaller internal damping metal materials, like copper, iron and steel, are used earlier. The alloy materials with larger damping value gradually are followed. Damping alloy not only has the advantages of solid, cheap and easy processing, but also can achieve the goal that noise is reduced by large damping materials. That means they meet the lightweight shell and reduce radiation noise requirements for hybrid lightweight at the same time, so light and good alloy materials (like Aluminum-magnesium alloy and alloy steel, etc.) have been more and more adopted. Fe-Mn-based damping alloy is applied to gear vibration and noise reduction because of its high strength and the damping property

increased with increasing amplitude. The Zn-Al damping alloy of grade ZA-27 is light in weight and strong in plasticity, and the noise of transmission box manufactured by it is lower than ordinary materials. Damping materials with different components have different characteristics for their own range of applications. The development trend of the research on damping materials is multidirectional. On the one hand, it is necessary to further explore the most optimal combination between the composition of the existing materials, the properties of the materials and the performance requirements for hybrid transmission, so as to achieve the maximum vibration and noise reduction. On the other hand, it's vital to develop a new composite damping material combined metal materials and polymer materials to meet the increasing shock absorption and sound absorption performance requirements of hybrid transmission.

3.3 Vibration and noise comprehensive test bench for hybrid transmission

Before the stereotype of the hybrid transmission, a large number of transmission vibration and noise bench test must be past. The hybrid transmission is placed in a virtual vehicle environment, and simulated its operating conditions to effectively evaluate its vibration and noise conditions in each operating conditions. By this way, it can verify whether hybrid transmission meets the vibration and noise design specifications. At present, the hybrid transmission test bench basically meets the vibration and noise test requirements of transmission under purely electric and traditional power and other operating conditions. However, the hybrid transmission test bench can't achieve the full analog of hybrid operating conditions (such as braking conditions and power switching state). The validity of the simulation test can't be guaranteed under full conditions for hybrid transmission vibration and noise bench test. It is necessary to develop hybrid test bench for vibration and noise of hybrid transmission to try to accurately and fully simulate the load and power drive under the actual driving conditions of the hybrid transmission. It can provide the basis for the validation of hybrid transmission noise design indicators and taking actions to reduce products noise. To improve the hybrid transmission vibration and noise test bench performance, for one thing, we need improve the performance of the hardware equipment to simulate the road conditions, such as the use of electric loading device instead of mechanical loading device to simulate to reduce the difficulty of test control and improve the level of automation, and then to achieve accurate simulation of information (such as hybrid transmission speed, resistance and torque, etc.). For another, we should improve the analog control system of full condition, particularly strengthen the control of the drive and loading devices to optimize control parameters for hybrid transmission working conditions. This method which accurately simulates its actual working conditions can make noise test results more reliable.

4 Conclusion

Hybrid transmission, as a key component of hybrid vehicle, has important effects on the NVH performance of HEV during operation. Nowadays, people continue to improve the NVH control requirements of the vehicle, transmission vibration and noise reduction should be given high priority. In recent years, the vibration and noise reduction of hybrid transmission has made its vibration and noise reduced by using testing system and identification technology to detect its noise source, gear modification, optimizing natural frequency of box and improving the damping of the box structure and so on. These researches accumulate many theoretical achievements and effectively reduce transmission vibration and noise. With the development of overall vibration and noise reduction design, damping materials, comprehensive test bench for hybrid transmission vibration and noise reduction, and the reduction of the equipment cost (such as transmission test benches and noise source measuring instruments), the hybrid transmission vibration and noise reduction technology will further develop economically and efficiently.

References

1. Jiří Tůma. Vehicle Transmission Noise and Vibration: Measurement, Signal Analysis, Signal Processing and Noise Reduction Measures[J]. *Gastroenterology*, 2014, 144(2):381-391.
2. Yu Yi, Xu Zhongming, Zhou Xiaolin, et al. Noise Recognition and Improvement of Hybrid Buses Based on Complex Morlet Wavelet[J]. *Journal of Mechanical Transmission*, 2013(7):88-90.
3. Li Ji, Wang Zhen, Zhao Fengqiang. Application of Surface Velocity Method in Gearbox Noise Detection[J]. *Journal of Vibration Engineering*, 2004, 17(1): 91-95.
4. Zhu Maotao, Xu Xiang. Idyllic. Analysis of Noise Source Order of Power Split Hybrid Transmission[J]. *Mechanical Design & Manufacture*, 2014(3): 220-223.
5. Zeng Hong, Wu Rilong. Study on Gear Shape Modification Technology of Electric Vehicle Gearbox[J]. *Auto Parts & Accessories*, 2014(4):34-36.
6. Pan Haibo. Research on the influence of tooth profile modification on the tooth surface vibration noise of automobile transmission[J]. *Mechanical Transmission*, 2016(11):176-180.
7. Pan Gongyu, Wang Xianmin, Li Dong, et al. Gearbox optimization and test verification of hybrid transmission[J]. *Journal of Henan University of Science and Technology*, 2016, 37(3):10-14.
8. Pan Gongyu, Liang Yanchun, Shen Dengfeng, et al. Dynamic Analysis of Power Split Hybrid Transmission Case[J]. *Mechanical Design & Manufacture*, 2014(11): 181-183.
9. Hong Liang, Liu Chengwu, Huang Key. Research on Modal Characteristics of a Two-speed Planetary Casing Shell of a Hybrid Commercial Vehicle[J]. *Electromechanical Technology*, 2016(1):61-63.
10. Wang Haoran, Fang Yuan, Zhang Tong. Vibration Analysis and Topology Optimization of Reducer for Electric Vehicles[J]. *Mechanical Transmission*, 2015(11):128-131.
11. Yu Yinghua, Yu Guojun, Xu Ping. Study on Vibration and Noise Reduction Performance of Foamed Aluminum Gear Damper[J]. *Manufacturing Technology & Machine Tool*, 2010(8):84-86.
12. Liu Yixiang, Guan Xiangyi. Experimental Study on Damping Vibration Reduction and Noise Reduction of Gear Transmission[J]. *Journal of Harbin University of Commerce: Natural Science Edition*, 2010(1):68-73.