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Research Article

Analysis on the Noise for the Different Gearboxes of the Heavy Truck

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In order to locate the excessive noise caused by gearbox noise when a heavy vehicle is accelerating, the noise and vibration on the key parts of the gearbox were tested and analyzed, and the peak noise frequency of radiating from the subbox of gearbox was found, which is the same as the peak frequency of pass-by noise. Aiming at the larger gear noise of the gearbox subbox, the experiments of pass-by noise by the two ways of the different speed-ratio gearbox, and the transformation of vice-box with helical gear, the pass-by noise was reduced by 5.6 and 3.9 dB(A), and it was made to reach the less GB limit-value. Meanwhile, the effect of the different-ratio gearbox on the vehicle noise was analyzed. So, the methods provide a practical basis for the vehicle noise and the fault diagnosis of gearbox.

1. Introduction

The amount of vehicle noise is an important indicator on measuring the overall quality of vehicle, and reducing the pass-by noise is the key of vehicle noise control. Traditionally, when pass-by noise does not meet the state regulations, automotive design and testing personnel often take the sound insulation of the engine shielding [1, 2] or increase the noise elimination amount of muffler [3–5], and there are other ways to reduce the pass-by noise. These methods are used more and are feasible, but these are time consuming and also take large costs of investment, and production is also not easy to achieve. The noise control from the excitation source is one of the most active and radical measures. In the pass-by noise control, the noise problem of transmission system in the field of automotive NVH research has been very important and very difficult subject. The gearbox is the important automotive transmission parts, and the gearbox noise is the main noise sources of vehicle shown by the theoretical and experimental studies [6]. Not only does the noise of transmission system (such as the problem of transmission gear howling) affect the rides' comfort of the vehicle, but also the major design flaw of gearbox is reflected in some cases, and the life of the vehicle will be subject to a greater influence.

General fault diagnosis of gearbox is the bench test. However, the bench experiment is difficult to simulate the actual operating conditions of the vehicle, and the characteristics of different vibration and noise appear after loading. Due to the limitations of experimental data and accumulated experience, only Yanling et al. [7] studied that the transmission coefficient of unreasonable match caused the pass-by noise of cars to be out of limits. However, the study on the pass-by noise of heavy vehicles affected by the gearbox noise has been also rarely reported. In this study, due to the pass-by noise of a heavy-duty vehicle exceeding National Standards of GB1495-2002 in the company, the noise test system of DASP, microphone, and acceleration sensors, which are the Institute of Beijing Oriental vibration and noise, were used to test and analyse the vibration and noise of the whole heavy-duty vehicles. After determining the fault source of the gearbox, the reasons of howling noise for the entire driveline system were diagnosed and analyzed, and appropriate actions were taken;

ultimately the peak acceleration noise was controlled. Finally, the effects of different-ratio gearbox on the noise of transmission system were analyzed, and these provide some guidance for the noise control of the transmission system.

2. Test and Analysis on the Vibration and Noise of Gearbox

By the spectrum test of pass-by noise in heavy-duty vehicles, it was known that the time curve of pass-by noise in the 6-speed appeared to be the noise peak, and the peak-time curve increased 4.1 dB(A). The spectrum analysis of noise found that the peak frequency of 1380 Hz in the 1/3 octave was higher 11.4 dB(A) than that of the other frequencies. Therefore, the key of controlling the pass-by noise on the heavy-duty vehicle is to identify the noise source of the signal frequency 1380 Hz [8]. The peak of pass-by noise on the heavy-duty vehicle is only in the 6-speed, and it is not difficult to think of the relation of the noise peak and gearbox gear. Therefore, it is needed that the vibration and near-field noise for the key parts of the gearbox are carried out by the spectrum test.

2.1. Composition of Test System and Arrangement of Measuring Points. The experimental aim is to obtain the signals of vibration and noise on the gearbox when the gearbox is working in various gears, and then perform signal analysis and diagnosis. The pass-by noises were tested according to GB1495-2002. The heavy-duty vehicle is with a 12-speed gearbox, the rated speed is 2100 rpm, the into-line rotated-speed is 1050 rpm according to the GB1495-2002, the test of pass-by noise begins from the 4-speed, and tests continue to the 8-speed when the out-line rotated-speed is below the rated speed. Considering the characteristics of multiple noise sources in the experimental site of the vehicle, in order to accurately measure the noises of heavy-duty vehicle transmissions and weaken maximally the disturbing effect of other noise signals, the measurement methods of near sound field were used in noise test, the microphones were set on the closer measuring point of the gearbox to measure the sound pressure, and immediately the distance to gearbox is about 20 cm.

The vibration of gearbox under normal circumstances is caused by the fluctuations of engaging force in the work process, the center-distance deviation of gear shaft within the allowing scope and other factors. Such vibration is generally the modulation vibrating of force. If the gear or bearing fails, impact occurs, and the vibration signal changes transiently [9, 10]. Therefore, the accelerometers can be arranged at different locations to monitor the vibration signal in these points of noise tests during the experiment. To more accurately find the part of the radiation peak noise, the sound-level meters can be arranged at different locations to detect the vibration signals and to find the fault site. From this perspective, five measuring points were arranged on the accelerometers in the bottom of the gearbox input, the bottom of the output side, the left side of the gearbox housing, the left side of the gearbox housing, and the plane center of the right side of the gearbox housing [11, 12]; the measuring points number is successively (7), (8), (10), (11), and (5). Meanwhile, the three measuring points (4), (9), and (6) are, respectively, arranged on the sound-level meters in the bottom of the gearbox input, the left side of the gearbox housing, and the right side of the gearbox housing. Thereinto, the measuring points of the weakest thickness shell and the middle part of the most powerful vibration were focused on.

2.2. The Analysis Results of the Test Signal. Gearbox of heavy vehicles is composed of many gears, it requires multiple changes of gear to achieve the different-ratio, and it withstands the great changes of torque. Therefore, inappropriate design can easily arouse local modal resonance. There is a very close relationship between the vibration and noise, which lays the foundation for the study on the sound radiation mechanism of the vibrating structure and the fault diagnosis method of machinery on basis of acoustic radiation [13, 14]. The spectrum analysis of vibration signal has a certain function on the rotating frequency of gearbox. In the acceleration experiments condition of heavy-duty vehicle in the study, the rotating speed signal of input shaft was inconveniently collected, and the rotating speed signal of input shaft was estimated by the engine ignition frequency.

The engine of heavy vehicles is six-cylinder machine; the maximum speed of engine is 2340 rpm. The gear ratio of gearbox is 3.48 in the 6-speed; the transmission routes in the 6-speed are successively 50/56, 48/69, 40/51, and 42/12. Thereinto, the last of two gear-pairs are the gears of the vice-box. As shown in Figure 1, when the rotational speed of engine is 1625 rpm, the third-order excitation frequency of the engine is 81.3 Hz (corresponding to point 1 in Figure 1), and the vibrations of 1387.5 Hz occur (corresponding to point 2 in Figure 1), which coincide with the vice-box vibration frequency 1390 Hz of the first pair meshing gears. When the rotational speed of engine is 2250 rpm, the third-order excitation frequency of engine is 115 Hz (corresponding to point 3 in Figure 1), and the corresponding gear meshing frequency is the vibrations of 1380 Hz (corresponding to point 4 in Figure 1), which coincide with the vice-box vibration frequency of 1359 Hz in the first pair meshing gears. Therefore, the near-field noise spectrum on the gearbox left shows the same spectrum signals with the spectrum of 1380 Hz in the measurement point of pass-by noise; however, the frequency signal is undetected in the other parts. Therefore, the natural frequencies of the gearbox (type I) are excited by the meshing frequency of vice-box gears in the 6-speed, which cause the severe vibration on the left part of a large plane and irradiate noise.

3. Noise Control of Transmission

3.1. Different Gearbox Noises. Due to the natural frequency of the gearbox aroused in the six-speed, by swapping with the constant-meshing gear pairs and the adjacent gear-pairs in this study, the gearboxes of type I turn into the gearboxes of type II, which is a different speed-ratio. The test of pass-by noise was carried out to verify the effect of the gearbox noise by replacing the different-ratio gearbox (type II). The

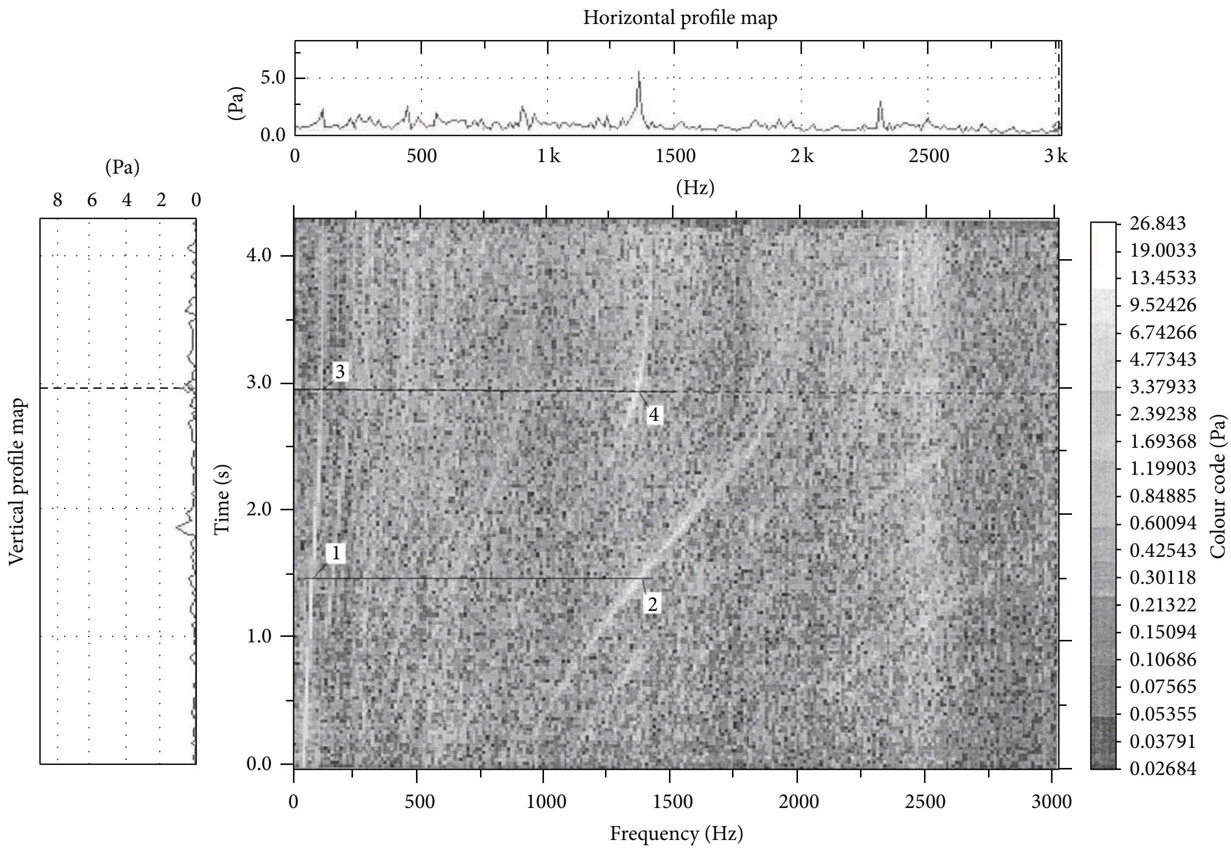

Figure 1: In the conditions of pass-by noise in the 6-speed, the three-dimensional distribution of spectral array on the near-field noise of the left gearbox.

experimental results are shown in Figure 5. As seen from Figure 5, the time-curve peak value of pass-by noise in the 6-speed disappeared away, the pass-by noise reduced 5.6 dB(A), and the pass-by noise of the vehicle is reduced to the limit of GB1495-2002. Thus, the gearbox of type II, which is with the different speed-ratio of gear meshing, avoids the natural frequency of the gearbox and achieves the lower noise values. Also, it proved that the gearbox noise of type I is high, and it is needed to further optimize design to control noise.

Known from the noise testing and analysis of the above gearboxes, the peak frequency of noise source appears in the subbox, and thus it is needed to transform the subbox. In view of the helical gear we have the following advantages [15]: (1) the performance of gears meshing is good. It is a gradual process when beginning to engage and disengage in helical-gear teeth, and thus transmission is smooth and noise is little. Simultaneously, this engagement also reduces the impact of the manufacturing errors on the drive. (2) The degree of coincidence is great. It can reduce the load of each pair of gear teeth, and thus the carrying capacity of the gear improves, the service life of the gear extends, and the transmission is smooth. (3) The least teeth number of undercutting in helical standard gear is less than that of spur gear; thus the drive of helical gear can be a more compact mechanism. Due to the fact that the front two advantages in the driving of helical gear are the benefit of the noise reduction, in this paper, the vice-box of this type gearbox was considered to transform with helical gear to reduce noise. Therefore, the two pairs of spur gears of 40/51 and 42/12 in the vice-box of gearbox were replaced with the two pairs of helical gears of 46/58 and 46/13; that is, the speed-ratio maintains the state of being unchanged. First, the bench test was carried out to verify the effect of noise reduction. When the load is 1400 N·m in the bench test, the variation curve of radiation noise level with the input shaft rotated-speed of gearbox on the transmission was shown in Figure 2. As seen from Figure 2, the noise reduction effect of the helical gears in the vice-box (type III) is 3–8 dB in the bench test. Bench experiments verify preliminarily the noise reduction effect of the helical gear. Subsequently, the vehicle was replaced in the gearbox of type III and the test of pass-by noise was carried out. The experimental results are shown in Figure 3. Therefore, there are no prominent peaks in the time curve of pass-by noise in the 6-speed, the pass-by noise reduced 3.9 dB in the 6-speed, and the pass-by noise reached below the GB1495-2002.

3.2. The Noise Difference Reasons of the Different Gearbox. The pass-by noise peak of vehicle in the 6-speed reduced 3.9 dB in the gearbox of type III by the vice-box with helical structure. But Table 1 shows that the pass-by noise peak with the gearbox of type III is still higher than that with the gearbox of type II in each speed, and a maximum gap is up to 2 dB.

Table 1: The pass-by noise values of assembling the three gearboxes.

Noise (dB)	4-speed	5-speed	6-speed	7-speed	8-speed
Type I	78.9	80.3	86.9	82.5	81.4
Type II	78.6	79.5	81	81.3	81.4
Type III	79.1	80.3	83	83.4	82.4

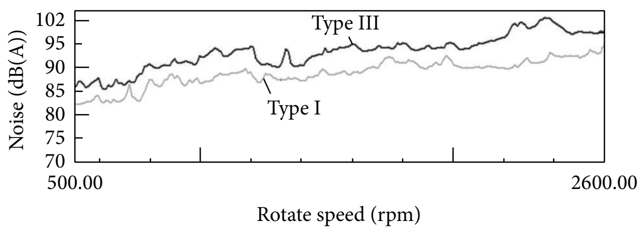

Figure 2: The transmission noise with the changing of the input speed.

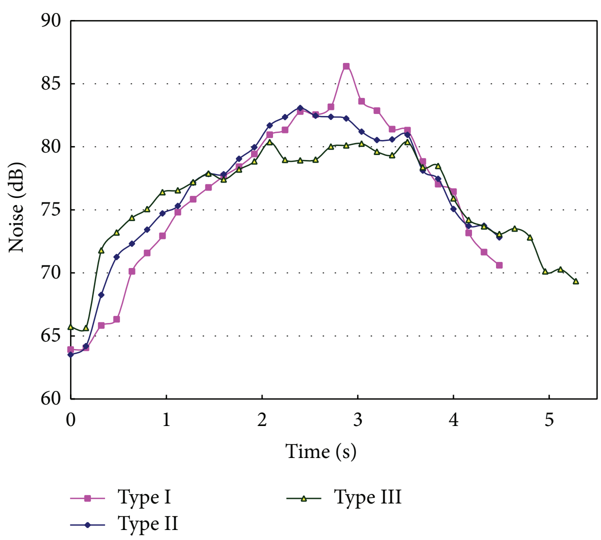

Figure 3: The time curve of pass-by noise with the different gearboxes in 6-speed.

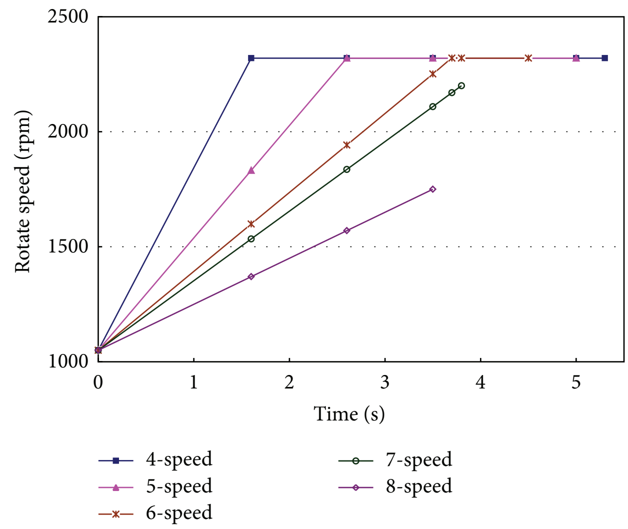

Figure 4: In the testing condition of pass-by noise, the change of engine revolving speed in the different speed.

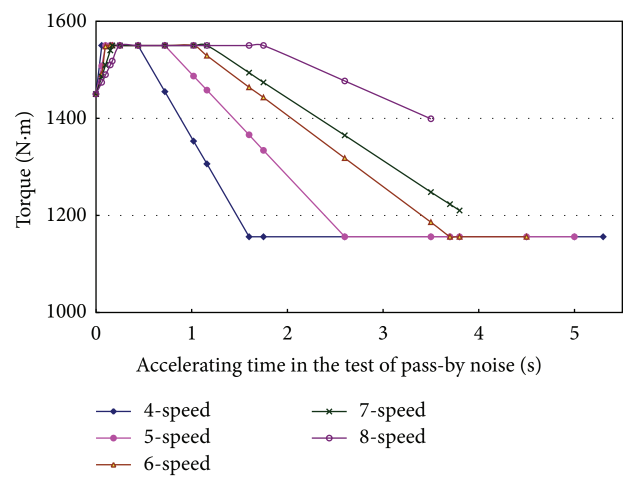

Figure 5: In the testing condition of pass-by noise, the change of engine torque in the different speed.

Besides, there presents a small difference of noise in the 4-speed and 5-speed; the difference of noise value is too large in 6-speed, 7-speed, and 8-speed. The three gearbox housings of type I, type II, and type III are the same; the differences of the gearboxes type I and type II are that the constant-meshing gear pairs swap with the adjacent gear pairs, and the speed-ratio changed; the gearbox of type III is the gearbox of type I with vice-box replacing the helical gear-pairs, and the speed-ratio is unchanged. In the lower speed (such as 4-speed and 5-speed), the speed-ratio is relatively large, the speed of vehicle is relatively slower, the acceleration ability of vehicle is strong, and the main noise is the engine noise, so the noise effect of replacing the gearbox is little; however, in 6-speed, 7-speed, and 8-speed, the output torque of engine increases with the speed-ratio decreasing, and thus the gearbox noise is increasingly apparent. Finally the main noise is the gearbox noise. Therefore, the high-speed noise is too large. In addition, the transmission chain does not go through vice-box gear from the 7-speed; the method of replacing helical gear in the vice-box cannot reduce noise in 7-speed and 8-speed. Regardless of the gearbox of type III and type II, the transmission chain goes through the coarse teeth of 1-speed and radiation noise is greater in the 7-speed.

In addition, as seen from Table 1, the pass-by noise with the gearbox of type II is lower than that with the gearbox of type III in each corresponding speed. As shown in Table 2, the speed-ratio of gearbox type III is lower than that of the gearbox type II as a whole, and the speed-ratio is the same in the border upon speed; namely, the speed-ratio of type III in the 3-speed is the same as that of type II in the 4-speed. The acceleration process with the engine of full-throttle was calculated by each speed-ratio; the variable curve of engine rotating-speed in each speed is shown in Figure 4. The calculated torque variation curve of the engine is shown in Figure 5 on the basis of Figure 4 and the external

Table 2: The speed-ratio of the three gearboxes.

Speed-ratio	3-speed	4-speed	5-speed	6-speed	7-speed	8-speed	9-speed
Types I and III	7.31	5.71	4.46	3.48	2.71	2.11	1.64
Type II	9.39	7.33	5.73	4.46	3.48	2.71	2.10

characteristic of the engine. The pass-by noise of vehicle with the gearbox of type III is relatively large in the same speed. The reason is that, with the speed increasing, the speed-ratio is getting smaller, the output torque of the engine is increased, the transmission input torque is large, and thus the noise becomes large. Therefore, the noise of the gearbox type II is lower, and it makes the pass-by noise of vehicle with the gearbox of type III lower than that with the gearbox of type III.

4. Conclusion

In this paper, the spectrum analysis technology of vibration and noise was used to test and analyse the key parts of the gearbox; it is able to accurately locate the noise source, and it provides the basis for the noise control. In the premise of finding the noise source of gearbox, to the problem on the gear meshing noise of vice-box being too large, it has reduced the pass-by noise of 5.6 dB(A) and 3.9 dB(A) by replacing the gearbox of different speed-ratio and the gearbox with the vice-box of helical-gear structure. Therefore, the pass-by noise value of the vehicle is reduced to below GB1495-2002 limit, and it verifies the effects of different speed-ratio and helical gear on the noise. Meanwhile, the reason of the effect of different-ratio gearbox on the pass-by noise of vehicle was analyzed, and it provides some guidance for the noise control of transmission system.

The noise control is a system, with complex and lengthy process. Next step is to study the vibration characteristics of the gearbox internal parts by the analysis method of experimental modal and optimized design by combining with the tools such as finite element method, and it attains a better control of the noise phenomenon on the gearbox.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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