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대형트럭의 고속 주행시 진동소음 현상에 관한 실험적 연구

이양섭*, 한문식*, 조항원**

Experimental Investigation of Noise and Vibration Phenomena of a Heavy-Duty Truck at High-Speed Driving

Yang Sub Lee*, Moon Sik Han*, Hang Won Cho**

ABSTRACT

대형 화물트럭의 차실 내에 높은 수준의 차바닥 진동을 수반한 높은 소음이 발생하였다. 측정 및 분석결과 문제의 진동 소음은 추진축의 회전 1차 및 2차 성분으로 나타났다. 진동 전달경로상의 구성계 및 구성요소들에 대해 모드해석과 실차 주행 모드 해석시험을 실시한 결과 드라이브라인 및 프레임의 공진주파수가 문제가 되는 소음진동 주파수와 거의 일치하였으며, 또한 캡의 실내음향 공진 모드가 문제되는 주파수에서 존재하였다. 실험결과에 따라 액슬과 액슬간의 축의 장착각도를 변경하여 가진력을 줄이고, 비틀림 동흡진기를 추진축에 장착하여 드라이브라인계 공진을 제어하므로써 문제의 실내진동소음을 현저히 개선하였다.

Key Words : Cargo truck(화물트럭), Noise(소음), Vibration(진동), Modal Analysis(모드해석), Operational vibration analysis(주행진동모드해석,) Torsion(비틀림), Resonance(공진), Dynamic damper(동흡진기), Cavity mode (음향모드)

1. Introduction

Vehicle interior noise can be categorized into airborne noise and structureborne noise. Engine combustion and intake/exhaust systems are usually main sources of the airborne noise. Engine excitation and road input are common main sources of the structureborne noise of passenger cars, but powertrain vibration often induces high structureborne interior noise for vehicles such as a cargo truck which has a long driveline with several propeller shafts and axles. Especially in case

* 계명대학교 자동차공학부
** 대한화학공업주식회사

the resonance of the driveline is within the driving speed range, the driveline experiences high vibrations, which subsequently excite a frame and a cab to induce high interior noise. The induced interior noise and floor vibration levels are determined by the vibration level of the driveline itself and the acoustical/vibrational characteristics of the frame and the cab.

In this paper we carry out systematic experimental investigation of a 21.5 ton heavy-duty cargo truck for identifying the cause of high floor vibration and interior noise at high speed driving and for proposing countermeasures to reduce the problematic noise and vibration[1,2]. Countermeasures based on the experimental investigation results significantly reduce the vibration and noise at the high speed driving of the cargo truck.

2. Analyses

2.1 Noise and Vibration Mechanism

A 21.5 ton cargo truck with several propeller shafts and axles produced high problematic interior noise and floor vibration during high speed driving with high gears engaged. The problematc noise and vibration become severer especially when the cargo truck is driven with high acceleration, under heavy loading conditions or on uphill roads. On the other hand, the noise and vibration phenamena become less distinctive when the cargo truck is decelerated. These types of vibration and noise phenamena usually results from the imbalance or torque variations of propeller shafts when the cargo is accelerated. The resulting noise and vibration levels depend on the acoustical and vibrational characteristics of the driveline itself, the driveline components, a frams and a cab.

To analyze the noise and vibration phenomena, noise and vibration levels are measured at the driver's ear position and on the floor of the cab, respectively, while the revolutions of both the propeller shaft and engine crankshaft were measured by tachometers[3]. Figure 1 shows the measurement setup for the driving test. The test results indicated that the high noise and vibration were related to the 1st (D1) and 2nd (D2) order frequency components of the revolution of the propeller shaft rather than of those of engine revolution[4]. The results are summarized in Table 1. As seen in Table 1, the floor vibration of our concern has high levels of both the D1 and the D2 frequency components of the propeller shaft revolution, but the interior noise of our concern is more distinctive in D2 component than in the D1 component.

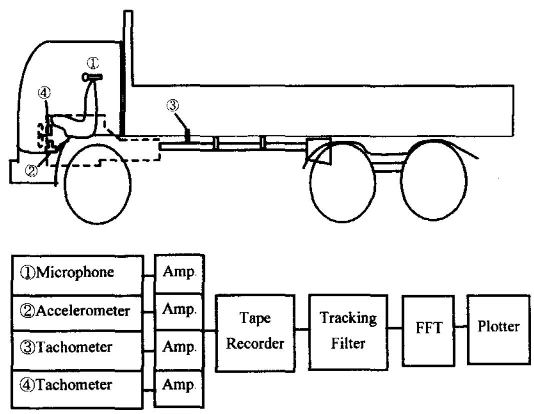

Fig. 1 Measurement setup at driving condition

Table 1 Measured vibration and noise level

Measured Quantity	Measured Level		Speed Range
	D1	D2	
Vibration	127-128dB (43Hz*)	128-129dB (83Hz*)	75-100 kph
Noise	64-68dBA (46Hz*)	70-73dBA (84Hz*)	75-100 kph
Measured Condition : 15 ton payload, highway road			
* : Center Frequency of a Peak			

2.2 Noise and Vibration Transfer Mechanism

Noise and vibration transfer paths from the driveline into the cab are described in Fig. 2. The driveline vibration excites axles, the frame and the cab in sequence which induce the high vibration and noise inside the cab. The resulting noise and vibration levels depend on the acoustical and vibrational characteristics of all systems and components existing through the transfer paths.

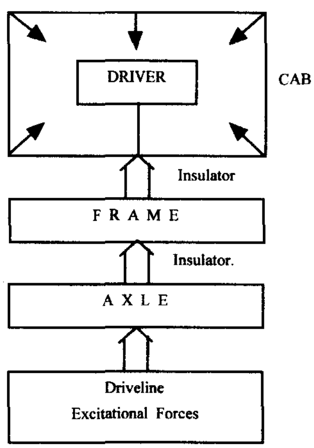

Fig. 2 Noise and vibration paths

2.2.1 Sources of Noise and Vibration

As shown in Table 1, the problematic noise and vibration are dominated by the D1 and D2 order components of the propeller shaft revolution. The noise and vibration with the D1 component result from the rotational imbalance of each propeller shaft. The noise and vibration of the D2 component are attributed to torque variations in the propeller shaft which occur twice per propeller shaft revolution[4] because of the operating angles of universal joints

2.2.2 Vibrational Characteristics of Driveline System

The D1 and D2 components of excitation forces generated by the propeller shaft vibrate axles and powertrain systems/components as well as the drivline system itself as a whole. Modal tests were carried out with an impact hammer to obtain the vibrational characteristics of each system and component[5]. Operational vibration analysis (OVA) was also performed for the systems and components at the problematic speed range to investigate which systems and components are excited in their resonant modes over the problematic speed range[6].

The modal test results indicated that the driveline system had broad banded resonance peaks at 50 Hz and 84 Hz. Two rear axles both have bending modes at 50 Hz, and the bending shape of the two axles at 50Hz can be clearly seen at high-speed driving as in Fig. 3. The whole driveline system itself has a torsional mode at 84 Hz (see Fig. 4)

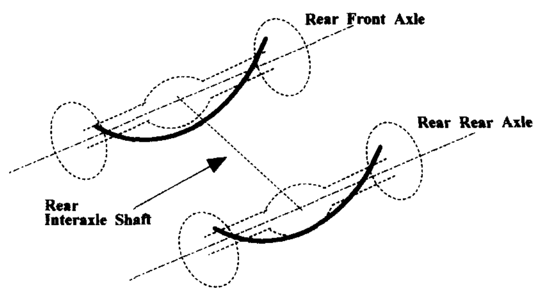

Fig. 3 Operational bending deflection shape of the two rear axles at 50 Hz

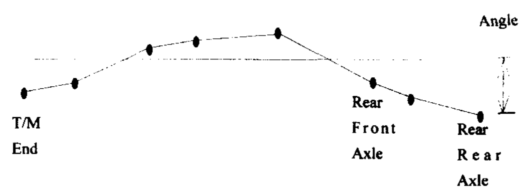

Fig. 4 Torsional mode shape of the whole driveline system at 84 Hz

2.2.3 Vibrational Characteristics of a Frame

The frame shows torsional modes over the problematic speed range in OVA driving tests as well as modal tests. However, the resonant frequency and vibrational mode shapes vary with the amount of loaded weight. That is, the speed range (frequency range) at which the torsional mode is excited depends on loaded weight. Figure 5 shows the typical torsional behavior of the frame at the problematic speed range.

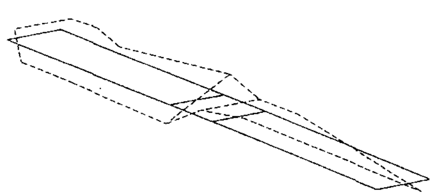

Fig. 5 Operational torsional deflection shape of the frame at 80-84 Hz

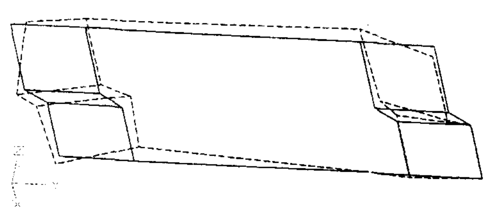

Fig. 6 Operational lateral deflection shape of the floor at 80Hz

2.2.4 Acoustical and Vibrational Characteristics of a Cab

The vibration and noise which a driver finally perceives are cab floor vibration and interior noise radiated by inside panels of a cab, and therefore vibrational and acoustic characteristic of the cab is one of the main factors determining the finally perceived noise and vibration levels. As shown in Figure 6, the floor of the cab experienced the high level of lateral vibration of 80Hz in the OVA driving test. The cab has the lateral width of 2.1 m which forms a lateral acoustical resonant mode of 83 Hz inside the cavity. The lateral cavity mode of 83Hz coincides with one of the problematic noise and vibration frequencies of the cargo truck.

3. Results

In general, noise and vibration levels are determined not only by the characteristics of the whole system itself but also by subsystems and components. Improvement of the noise and vibration can be made by modifying the vibrational characteristics of systems and/or components.

Table 2 Recommended countermeasures

Parts	Countermeasures
Excitation Forces	-reduction of propeller shaft imbalance -adjustment of universal joint angle -adjustment of rear interaxle shaft installment angle
Driveline and Axles	-application of a torsional dynamic damper to control the resonance of driveline system -modification of axles to shift axle resonances out of driving speed range
Frame	-application of a dynamic damper to control the resonance of the frame -reinforcement of frame to shift frame resonances out of driving speed range or to avoid coincidence of its resonances with those of other systems and components
Cab	-reinforcement and damping treatment of cab panels not to be sensitive to excitation frequencies
Isolation	-improvement of mounting systems such as cab mounting systems

Based on the OVA and modal tests, recommended countermeasures for reducing the noise and vibration of the truck are summarized in Table 2. Some of recommended countermeasures in Table 2, however, have limitations in reality to be applied in views of cost, limitation of geometric space, efficiency, quality control, etc. In this paper, to reduce the torque variation of the rear interaxle shaft, we adjusted the installment angle of the rear interaxle shaft by modifying the structures of both the rear axles and rear interaxle shaft.

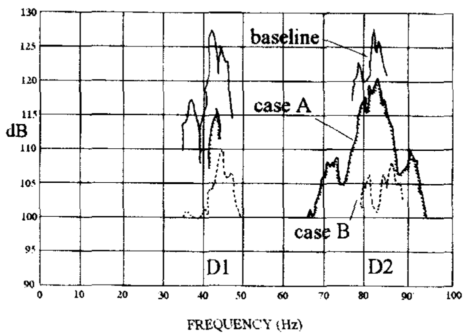

Fig. 7 Vibration levels on the floor of a cab

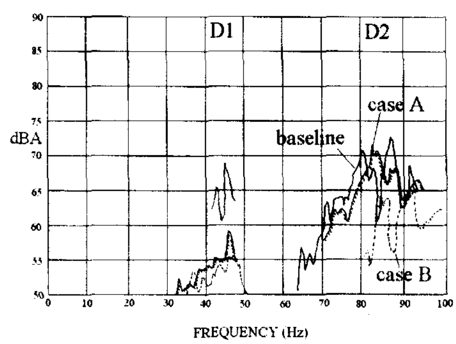

Fig. 8 Noise levels at a driver's ear position

The hatched solid lines (case A) in Figs. 7 and 8 show the vibration level on the floor of the cab and the noise level at a driver's ear position, respectively, over the frequency ranges of the problematic speed when the installment angle of the rear interaxle shaft was optimally adjusted. The adjustment of the installment angle made significant improvement in both the problematic noise and vibration of the D1 component (43 Hz), but slight improvement of the D2 component (85 Hz), compared with the original (baseline) rear interaxle shaft (solid line).

Since the improvement of the D2 component is not sufficient, the torsional dynamic damper of about 80 Hz was applied to the main propeller shaft to control the torsional resonance of the driveline at 84 Hz (see Fig. 4). The dotted lines (case B) in Figs. 7 and 8 show the floor vibration and interior noise levels, respectively, when the torsional dynamic damper is installed together with the modified axles and rear interaxle shaft. The torsional dynamic damper significantly reduced the noises and vibration of the D2 component.

4. Conclusions

Sources of the high interior noise and cab floor vibration of the heavy-duty cargo truck have been investigated experimentally. The high interior noise and floor vibration around 43Hz (D1 component) and 84Hz (D2 component) of the cargo truck are attributed to the excitation forces of the driveline which subsequently induce the vibration of the axles, frame, and cab. Driveline system has broad banded resonances of 50 Hz and 84 Hz. The frame also has very sensitive vibrational characteristics around one of the problematic frequencies, and the cab has an acoustic cavity mode at one of the problematic frequencies. Based on the experimental analyse results, we first reduced the imbalanced excitation forces of the shaft by modifying the driveline, which results in significant improvement in noise and vibration at 43Hz. We then applied the torsional dynamic damper to the main propeller shaft to control the resonance of the driveline, which greatly reduced the noise and vibration levels of 84Hz.

Since experimental NVH investigation and countermeasures for a long-wheelbase trucks with a multi-piece shaft after production require a great deal of time, effort, cost and technical difficulty, noise and vibration characteristics of the heavy duty vehicle should be carefully defined in advance at its initial design stage.

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