

Prediction of Interior Noise Based on Hybrid TPA

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ABSTRACT

This paper presents a practical real approach for predicting the interior noise caused by the vibration of the powertrain by using the hybrid transfer path analysis (TPA) method. The traditional TPA has been used for the identification of powertrain noise sources. However, with only experimental data for the identification of vibration and noise, it is difficult to determine the effects of modifications to the structure of a powertrain. In order to solve this problem, the vibration of the powertrain in a vehicle is numerically analyzed by using the finite element method (FEM). The vibration of other parts in a vehicle is investigated by using the experimental method based on vibro-acoustic transfer function (VATF) analysis. These two methods are combined for the prediction of interior noise caused by a powertrain.

INTRODUCTION

Noise vibration harshness (NVH) technology in automobile engineering has become an important performance target in car development in the search for vehicle comfort. In a vehicle, there are many noise and vibration sources, which influence the NVH performance, such as the powertrain, tire, wind, car body and suspension. Among these sources, it is known that the powertrain is the dominant contributor to the interior noise [1]. Therefore, many researchers have tried to develop a simulation method to predict the interior noise caused by a powertrain [2,3]. The interior noise due to a powertrain is the result of two transfer paths. One is the air-borne transfer path for the powertrain noise. The other one is the structure-borne transfer path for the powertrain vibration. In order to predict the interior noise due to the structure-borne

transfer path, the traditional transfer path analysis (TPA) has been used based on the experimental method [4]. Although it is a useful tool for source identification, the experimentally derived TPA is not convenient for use in determining the effects of modifications to the powertrain structure for reducing interior noise since it uses the experimental method. This paper presents a hybrid method for the prediction of interior noise based on the hybrid TPA. The traditional TPA predicts the interior noise by multiplying the excitation force measured at the mount points by the measured vibro-acoustic transfer function (VATF) of the vehicle. In the hybrid TPA, instead of the measured excitation force, the simulated excitation force is used since it is difficult to measure the excitation force at the mount points of a powertrain directly. The simulation of the excitation force is also not easy because it requires a detail FE-modeling of a powertrain. However, the simulation method is necessary to predict the interior noise for assessing modifications of the powertrain structure for reducing interior noise. In the paper, results from the simulation of the excitation force is presented. It is validated by the measured excitation force. The measured excitation force is estimated by multiplying the measured dynamic complex stiffness of the mount rubber by the displacements measured on the both sides of the isolation of the mounting system of the powertrain. In this paper the interior noise is also predicted based on the hybrid TPA. The simulated excitation force is used in the prediction of this interior noise. In order to predict the interior noise based on the hybrid TPA, the VATF of the vehicle is also necessary and is measured by using the vibro-acoustic reciprocity method [5,6]. The predicted interior noise is compared with measured interior noise.

THEORY OF HYBRID TRANSFER PATH ANALYSIS

The traditional TPA method is an experimental method for predicting the interior noise [4,7]. This method is useful for the identification of noise sources along the vibration transfer path. However, after identification of the noise source, if a design modification of the powertrain structure is necessary for the reduction of interior noise, a simulation tool for the prediction of the interior noise is required. In this case, the hybrid TPA is one of the best solutions. The prediction of interior noise inside a car based on the traditional TPA is expressed as

$$p_j(\omega) = \sum_i |p_i(\omega)|^{j\phi(\omega)_i} \quad (1)$$

$$= \sum_i |f_i(\omega)|^{j\phi_{fi}} \left| \frac{p_j(\omega)}{f_i(\omega)} \right|^{j(\phi_p(\omega) - \phi_{fi})_i} + \sum_k |q_k(\omega)|^{j\phi_{qk}} \left| \frac{p_j(\omega)}{q_k(\omega)} \right|^{j(\phi_p(\omega) - \phi_{qk})_k}$$

where p_j is the interior sound pressure at j point inside a car, f_i is the excitation force at the i -th path, q_k is the air-borne source at the k -th path and ϕ is the phase corresponding to each source and response. The first term of equation (1) is related to the structure-borne path and the second term is related to the air-borne path. Therefore, the interior noise based on the traditional TPA for the structure-borne path is predicted by using the first term in equation (1). Therefore, equation (1) can be rewritten by neglecting the second term as

$$p_j(\omega) = \sum_{i=1}^n p_i(\omega) = \sum_{i=1}^n f_i(\omega) \times H_{ij}(\omega) \quad (2)$$

where $p_j(\omega)$ is the complex sound pressure due to i -th path in the frequency domain. In equation (2), the vibroacoustic transfer function of a vehicle, $H_{ij}(\omega)$, is obtained by using the experimental method based on the theory of the vibro-acoustic reciprocity. The excitation force $f_i(\omega)$ is calculated by multiplying the dynamic stiffness by the displacement difference based on the traditional TPA. Its mathematical expression is

$$f_i(\omega) = k^*(\omega) \times \Delta x(\omega) = k_i(\omega) [x_1(\omega) - x_2(\omega)] \quad (3)$$

where $k^*(\omega)$ is the complex dynamic stiffness measured by the elastomer testing system with electric actuator. In equation (3), the displacements $x_1(\omega)$ and $x_2(\omega)$ are measured on the mount bracket before and after isolation, respectively, while a car is being driven. In general, the powertrain is installed on the car body by using a mounting system as shown in Figure 1. This mounting system consists of four mounts, i.e the engine

(E/G) mount, front-roll (F/R) mount, rear-roll (R/R) mount, and transmission (T/M) mount. The mounting system is connected to the sub frame or the suspension frame of a vehicle. Therefore, these mounts are the major transfer paths of the powertrain vibration for the interior noise. These mounts play the role of supporting the weight of the powertrain and reducing the transfer of vibration energy. These mounts are composed of the isolation rubber and bracket. The combustion force due to the firing inside the test engine which excited the piston. Its dynamic force is transferred to these brackets through the cylinder block. This dynamic force also excites the car body through the isolation mounting system as shown in Figure 2. This dynamic force exciting the car body can be obtained by two methods. One is the experimental method based on the traditional TPA and its mathematical form is given by equation (3). In order to use equation (3) the operational vibration should be measured on the mount bracket after and before the isolation of the mount system of the powertrain while a car is being driven. The traditional TPA uses the excitation force obtained by this experimental method. The hybrid TPA uses the simulated excitation force instead of the measured excitation force. The simulated excitation force is calculated by numerical analysis using a FE model of a powertrain [8]. The advantage of the hybrid TPA is that it permits the estimation of the effects of modifications to the powertrain.

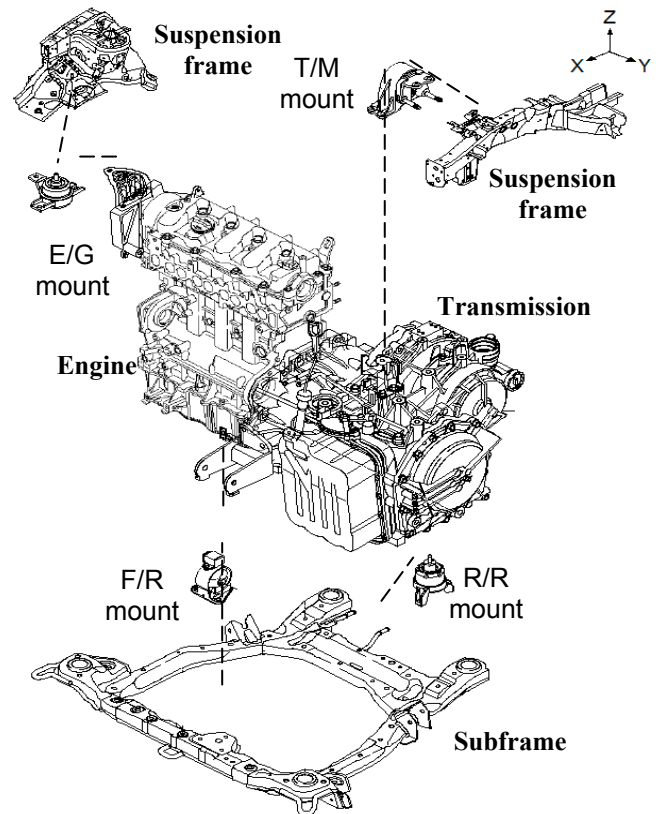


Figure 1 Diagram of selected joints of the vehicle for the transfer path analysis.

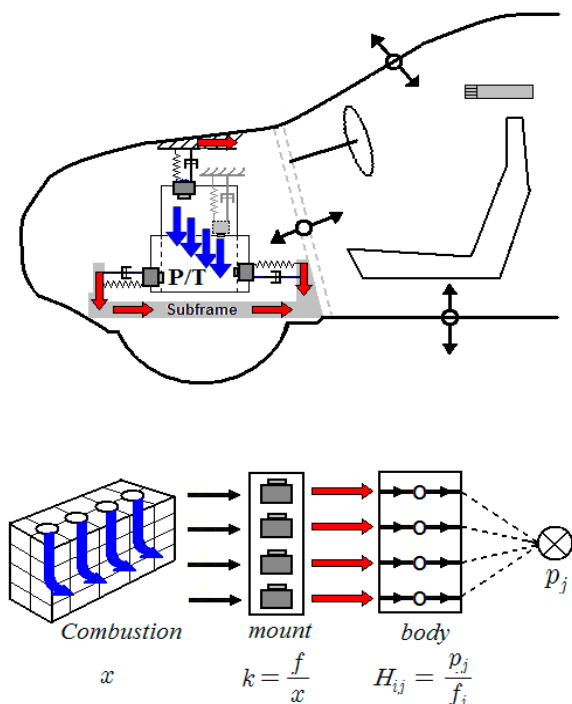
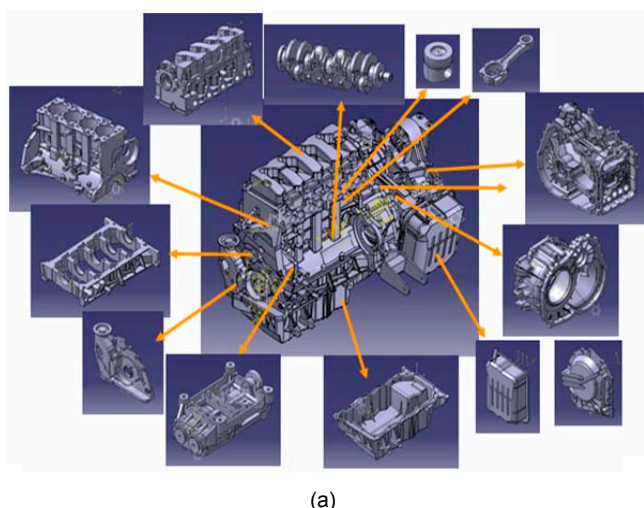


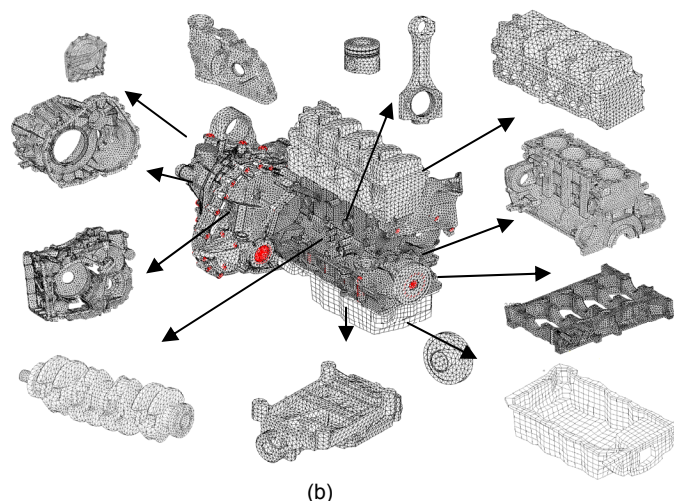
Figure 2 Diagram of the hybrid transfer path analysis for using the FE model of a powertrain

Table 1 Specification of the powertrain.

Powertrain	Specification
Displacement	2.2L
Number of cylinder	4
Type of fuel	Diesel
Balance shaft	Lanchester type
Transmission	Automatic
Vehicle	SUV



(a)



(b)

Figure 3 Models of all components of the test powertrain (a) geometrical model; (b) finite element model.

SIMULATION OF EXCITATION FORCE OF POWERTRAIN

SIMULATION OF EXCITATION FORCE USING NUMERICAL METHOD

For the analysis of the vibration characteristics of the test powertrain based on the numerical method, a FE model of the powertrain is required and should be validated by the measured results obtained throughout the experimental modal analysis (EMA). A FE model is also used for the analysis of the forced vibration of the powertrain to predict the excitation force at the four mount points. The specification of the powertrain used for this test are listed in Table 1. Figure 3(a) shows the geometrical model for the components of the powertrain and Figure 3(b) shows the FE model of the powertrain used for this research. The powertrain is composed of a piston, connecting rod, crankshaft, cylinder block, cylinder head, bedplate, oil pan, transmission case, transmission gear and mount brackets. For the FE model of all components, one-dimensional, two-dimensional and three-dimensional finite element models are used. Most of components are connected by the rigid body element 2 (RBE2). The transmission gear in automatic transmission is modeled by a concentrated mass with mass and moment of inertia. All bearing parts are connected with the spring and damping model. Finally, this FE model is confirmed with the results of experiment modal analysis and the numerical modal analysis using the FE model of the powertrain is performed [9]. Throughout the analysis using the FE model, modal parameters such as the mode shape, natural frequency and modal vector are calculated. These results are compared with those of the experimental modal analysis to confirm the accuracy of the FE model. For this validation, modal assurance criterion (MAC) analysis is generally used [10]. As the MAC analysis is one method of evaluating the orthogonal property for natural vectors of the vibration system, if the two modal vectors are parallel, the MAC values becomes one. If two natural vectors are