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Investigation and refinement of gearbox whine noise

Mustafa Tosun*, Mehdi Yıldız, Aytekin Özkan

TOFAŞ Turkish Automobile Factory Inc., Turkey

A B S T R A C T

Structure borne noises can be transmitted to interior cabin via physical connections by gearbox as well as other active components. Experimental Transfer Path Analysis (TPA) methods are utilized to investigate main paths of vibrations which are eventually perceived as noise components inside the cabin. In this study, contribution ranking of transmission paths from active system components through the physical connections into the interior cabin are investigated by Operational Path Analysis with Exogenous Inputs (OPAX) method. In addition, the sensitivity and rigidity characterization of the body through dominant paths according to OPAX were measured to reveal the reason for the whine noise to the inner cabin because of the operational forces generated in the dominant structure-borne paths. And also, operational modal analysis was carried out to examine the modes of the dominant path components. The modifications are applied on dominant transfer paths according to dominant paths characterization by operational deflection shape analyses. Thus, the root causes are investigated on vehicle level NVH tests while observing the variations in the interior cabin noise level.

1. Introduction

The noise and vibration performance tend to get worse due to the objective of weight reduction as a tool of improving fuel consumption in the early stage of the product development phase. The change of the dynamic characteristic targets of the components is necessary frequently to be compatible with the performance enhancement to a competiveness trend. In order to optimize the dynamic characteristics of the components, it is necessary to understand the mechanism of the sound and vibration generated by the engine excitation and rough road excitation [1].

In this study, subjective and objective evaluations are carried out under various operating conditions. The gearbox whine noise is perceived during slow acceleration at 3rd gear. Therefore, identification of related noise path through the body and finally to interior cabin have been made performing operational analyses at 3rd gear slow acceleration maneuver.

TPA allows one to assess the possible ways of energy transfer from the various sources of excitation in an assembly to a given target location. It supplies the tools required to locate the most important energy transfer paths for a specific problem and to evaluate their individual effects on the target, thus providing valuable insight into the mechanisms responsible for the problem [4,5]. In addition, ODS (Operational Deflection Shape) analysis is performed to understand which component has a major impact on the formation of the noise in the interior cabin. OMA (Operational Modal Analysis) is also performed on the components in the transmission path to determine the components with the natural frequencies that are coinciding with frequency of interest in which the noise appears.

2. Gearbox whine noise phenomena

Gear whine can be considered to be a major noise contributor, in the vehicle cabin, due to decreased masking effect of engine noise. It has long been recognized that the source of the gear whine is at the gear tooth mesh. The characteristic whine is generated by a constant harmonic displacement excitation, caused by errors in the actual tooth position with its perfect tooth position.

A gearbox can be considered as a self-exciting dynamic system, which is excited by the transmission error displacement. The excitation is transmitted through the gear mesh, gears, shafts and bearings. As the tooth meshing frequency changes different frequencies are excited in the transmission, therefore, as the engine speed increases the modes of the system are excited, amplifying the transmission error and resulting in large forces at the bearing locations, ultimately manifesting as gear whine in the vehicle [2].

As a result, gearbox vibration is transformed into interior gear whine noise via structure-borne. On the other hand, radiation noise from gearbox is transformed into interior gear whine via air-borne. Consequently, it can be concluded that gear whine characteristic depends on the components of noise transfer path characteristic, such as number of teeth, gear shaft structure and vehicle acoustic FRF. In order

* Corresponding author.
E-mail address: mustafa.tosun@tofas.com.tr (M. Tosun).

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to reduce gear whine efficiently, major noise transfer path and transform mechanism of gear whine need to be clarified quantitatively. Then, countermeasures against gear whine have to be incorporated into noise transfer path with high contribution. Meanwhile, it used to be hard to clarify noise path contribution for gear whine because gear whine generally has high frequency [3]. In this study, contribution ranking of transmission paths from active system components through the physical connections into the interior cabin are investigated by a combination of OPAX Method, vibration and acoustic transfer functions and operational deflection shape and operational modal analysis.

3. Problem definition

Subjective evaluations show that issued noise component which is perceived as a whine noise which occurs especially between 1500 and 3000 rpm during slow acceleration at the third gear. Therefore, the tooth meshing orders have been examined for the 3rd gear.

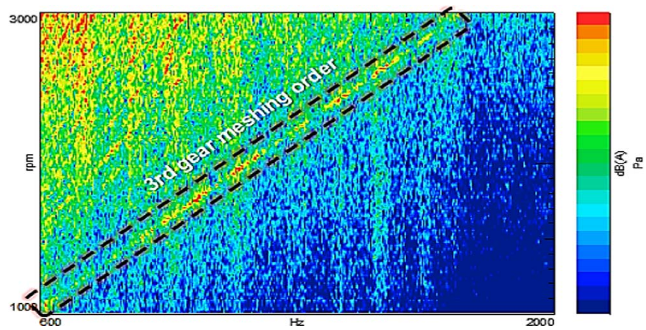

Fig. 1. Color map graph of the interior noise. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The color map of the interior cabin noise during the slow acceleration at 3rd gear is shown in Fig. 1. The first harmonic of the gearbox tooth meshing order which is the most dominant order for the mentioned noise problem is clearly seen in the color map.

The frequency spectrum of 3rd gear meshing order in the interior cabin noise was investigated to understand the dominant problematic frequency areas of the gearbox whine noise as seen in Fig. 2 (see. Figs. 3–5).

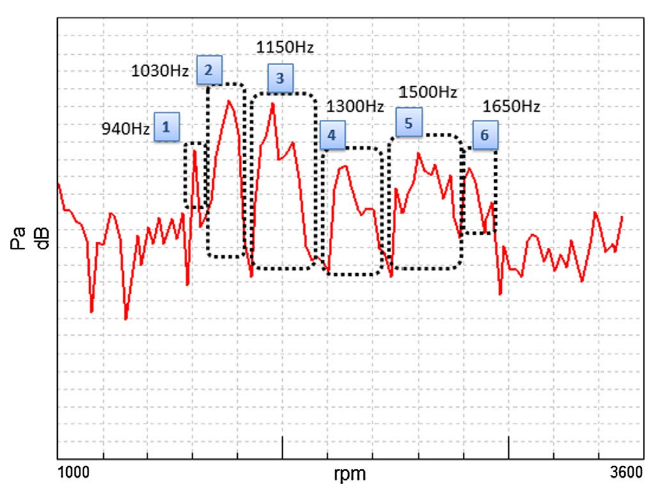

Fig. 2. Frequency spectrum of interior cabin noise at 3rd gear meshing order.

4. Classification of the transfer paths to body structure

To define the dominant paths at gearbox tooth meshing order, OPAX TPA method was used. OPAX method were carried out on a front-

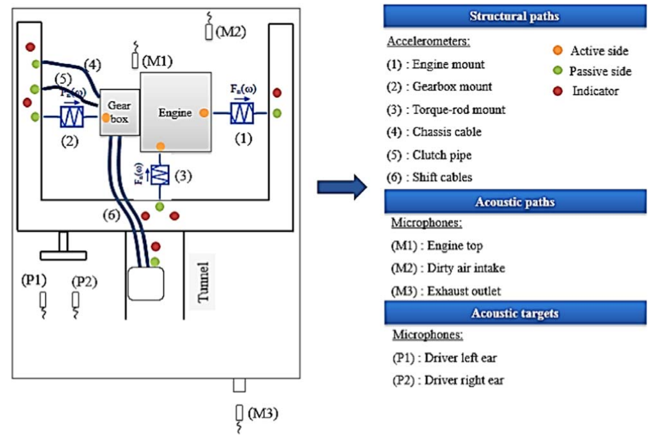

Fig. 3. Accelerometer and microphone positions for TPA.

wheel drive 4-cylinder passenger vehicle to investigate the dominant whine noise paths into interior cabin. The operational measurements were taken at 3rd gear during slow acceleration from 1000 to 3500 rpm and also, FRFs were measured. Tri-axial accelerometers were placed for operational measurements as below:

Structural paths, indicators and acoustic paths were used in the analysis using OPAX method.

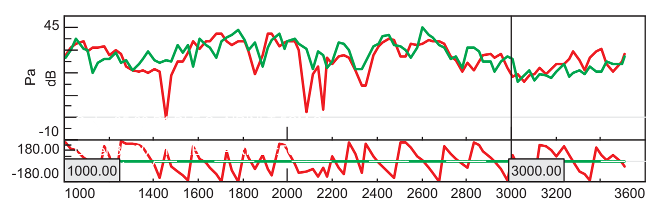

Fig. 4. Comparison of the measured and calculated data.

The analysis results can be seen in the above graph where the green line shows the measured data and the red line shows the calculated data by OPAX method. It is noticed that the calculated and measured data results are quite close to each other. Obtained results can be utilized to make a countermeasure on the dominant paths by the help of good correlation between the measured and the calculated data.

According to analysis results, total contribution on the whine noise in the interior cabin which occurs between 1500 and 3000 rpm caused by 3rd gear meshing order of gearbox is generally caused by engine mount X direction, gearbox mount passive side Y and Z directions, torque mount passive side X and Z directions.

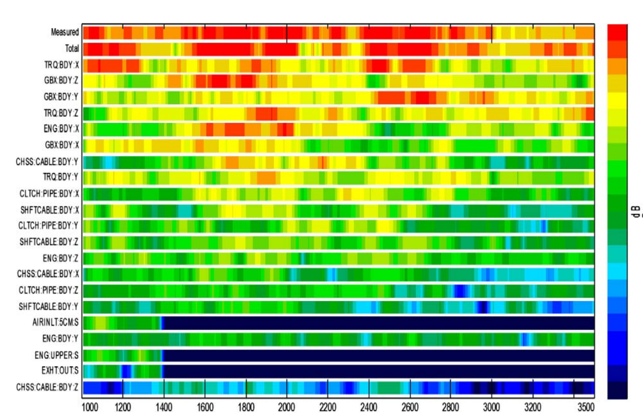

Fig. 5. Structural path contributions.