Intermediate Index of Structural Transmission Characteristics to Enhance Engine Combustion Noise Quality

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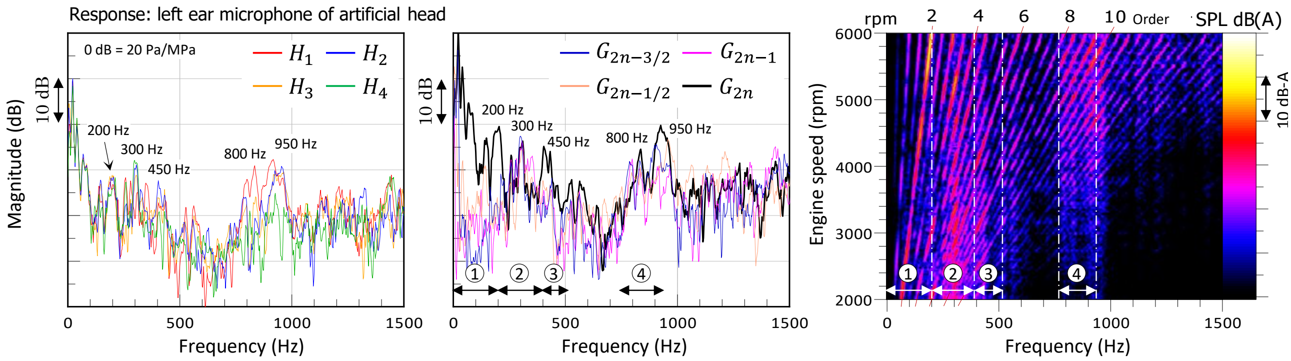
An order-based structural response function (Ord-SRF) was developed as a simple intermediate index that indicates the quality of transmission characteristics when implementing measures for transmission systems to enhance the sound quality of combustion noise. In order to efficiently make enhancements in the perceived fluctuation of combustion noises such as rumbling, rattling and knocking, it is necessary to reduce the number of frequency spectra that are dominant in the critical band(3). Equation (1) is a relational expression that applies to the Fourier spectrum $SPC(\omega)$ of combustion noise in the interior of a vehicle equipped with an inline four-cylinder engine(1). $CP_k(\omega)$ is the Fourier spectrum of in-cylinder pressure in the kth cylinder. $H_k(\omega)$ is the structural response function (SRF) from the in-cylinder pressure in the k-th cylinder to the sound pressure of vehicle interior noise.

$$SPC(\omega) = \sum_{k=1}^{4} H_k(\omega)\, CP_k(\omega) \qquad \cdots \quad (1)$$

In the case of a vehicle equipped with an inline four-cylinder engine, half-order components and odd-order components of combustion noise can be canceled out between cylinders if the $H_k(\omega)$ characteristic can be controlled appropriately. The order-based structural response function (Ord-SRF) shown in Table 1 was devised as an evaluation function to measure this canceling effect. This is the sum of the structural response functions from each cylinder for each typical order component, with the different combustion timing of each cylinder taken into account. This index makes it possible to identify which order components of the combustion noise in a frequency domain are more likely to be excited. Figure 1 shows an example of its application: (a) is the conventional SRF, (b) is the Ord-SRF, and (c) is a spectrogram of combustion noise. Comparison of (b) and (c) shows that there is a high correlation between the Ord-SRF response amplitude and the combustion noise order component. In either graph, only the even-order components are dominant in bands (1) and (3). In bands (2) and (4), the above cancelling effect between cylinders is not functioning sufficiently, so all the components are of higher magnitude. In the latter bands, the frequency spectra are packed closely together, so there is a greater risk that the combustion noise sound quality will be lowered. These results demonstrated that the Ord-SRF can serve as a useful intermediate index when structural measures are being implemented.

Table 1 Order-based structural response function for the vehicles equipped an in-line four-cylinder engine

	Angular frequency ω	Order-based structural response function $G(\omega)$
Even and half order	$(2n-3/2)\Omega_1$	$G_{2n-3/2}(\omega) = H_1(\omega) + j\,H_2(\omega) - j\,H_3(\omega) - H_4(\omega)$
Odd order	$(2n-1)\Omega_1$	$G_{2n-1}(\omega) = H_1(\omega) - H_2(\omega) - H_3(\omega) + H_4(\omega)$
Odd and half order	$(2n-1/2)\Omega_1$	$G_{2n-1/2}(\omega) = H_1(\omega) - j\,H_2(\omega) + j\,H_3(\omega) - H_4(\omega)$
Even order	$2n\Omega_1$	$G_{2n}(\omega) = H_1(\omega) + H_2(\omega) + H_3(\omega) + H_4(\omega)$



(a) Structural response function (b) Order-based structural response function (c) Combustion noise in vehicle interior

Fig. 1 Structural response function, order-based structural response function and spectorogram of combustion noise in vehicle interior