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차량 구조 강성과 소음 음질간의 상관도 연구

최종대, 김상민
현대자동차 연구개발본부 파워트레인연구소 소음진동팀

A Study on the Relationship between Sound Quality and Structural Mechanics in Automobiles

Jongdae Choi, Sangmin Kim
NVH Team, Power-train Research Center, R&D Division, Hyundai Motor Company
jongdae@hyundai-motor.com, kite2001@shinbiro.com

Abstract

In the present study, the influence of car body structures to the noise and vibration characteristics has been sought. The numerical modal analysis for the body-in-white is employed to predict the vibratory response of structure, and then followed by the experimental modal testing to confirm the validity of the model. Using the results of numerical simulations with the designated modal parameters, the optimal structural configuration has been deduced. Special interests have been paid to the sensitivity of sound quality to the structural integrity. Since the structural integrity has a close relationship to the structure-born noise, the substantially low frequency range, which is far below the frequency range almost barely sensible by human auditory organ but still quite influential to overall impression, is especially examined. The subjective assessment agrees with the objective evaluation by means of traditional sound measures as well as psychoacoustic metrics.

Introduction

It is quite well-known that the mechanical rigidity of body structures has a strong influence on the subjective noise and vibration performance of automotive vehicles./1, 2/ During past decades, the automotive engineers have witnessed a great deal of resources devoted to escalate practically the modal parameters beyond the pre-set target. In most cases, however, the human perception of noise and vibration has not been taken into account in this particular research and development process./3/

In the following work, the qualitative aspect of noise and vibration draws special attention as much as the quantitative point of view. Since the classical analysis method lacks the ability of full description of aural images, some state-of-the-art dynamic signature analysis techniques, which have been proven to correlate with the subjective assessment, have been employed for the in-depth psychoacoustic analysis.

Statement of the Problem

Firstly, the structural strength of full vehicle has been examined by means of experimental modal analysis. Table 1 illustrates the baseline modal parameters. Due to the high modal density at low frequency band, the passengers in the vehicle can perceive rather a complicated impression on noise in the stationary as well as the highly transient driving conditions.

Table 1. Modal Properties of Full Vehicle

Freq.(Hz)	Description of Modes
16.7	Local Torsional (Front)
21.8	Local Bending (Front)
24.5	Global Bending Mode
26.2	Local Bending (Rear)
34.2	Torsional (Front) + Bending (Rear)
37.4	Local Torsional Mode (Front)

Leaving the dynamics of power-plant unmodified, it is necessary to see how much the structural strength influences solely by reinforcing the skeleton, or so-called body-in-white. With reference to the modal eigen-frequencies of given body-in-white, its vibratory response needs to avoid as far from the nominal frequency of excitation as possible. From the rule of thumb, the structural response characteristics of the body-in-white preserve for that of full vehicle except dissimilar level and degree of damping.

The numerical approach in structural mechanics has been taken advantage of in modifying the modal parameters. The finite element modeling and subsequent processing yield the solutions of given eigen-value problem of the configuration of Figure 1.

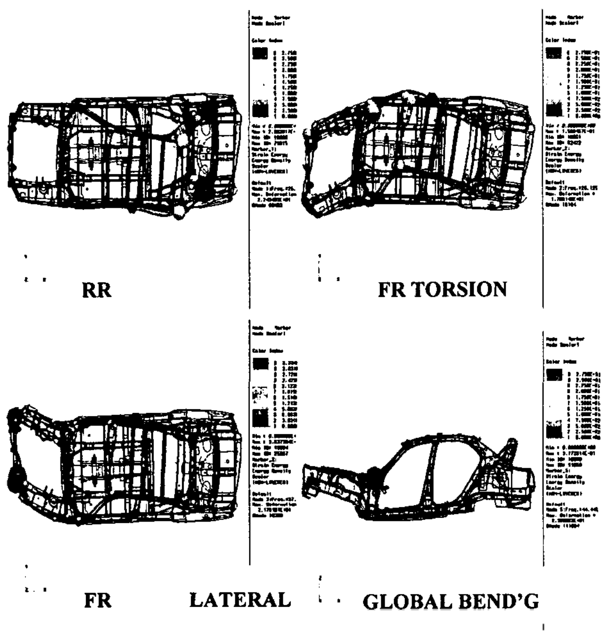

Figure 1. Strain Energy Distribution(BIW)

The mathematical model in Figure 1 has been proven to be approximate enough against the physically built model with resort to the experimental modal analysis. The predicted eigen-values match very closely with those from the experiments. Therefore, the numerical model is employed as a workhorse for further analytical simulation.

Reinforcement of Body-in-White Structure

As mentioned in the previous section, the dynamic characteristics of full vehicle resemble that of body-in-white. Thus, the following modal properties are chosen to modify; global bending, torsional, and lateral modes. Among a variety of different combinations for reinforcing the body, a few cases are selected on heuristic basis to meet the target, and then, the eigen-frequencies of modified structure have accordingly changed as shown in Table 2. The same reinforcement as applied to the body-in-white will be implemented to the full vehicle.

Table 2. Change of Eigen-frequencies due to Reinforcement for Body-in-white

Mode	Original Configuration	Modified Configuration
Torsion	25.8 (Rear)	37.6 (Global)
	28.1 (Front)	
Lateral	37.4 (Front)	45.7 (Front)
Bending	44.5 (First)	53.0 (Global)
	47.7 (Second)	

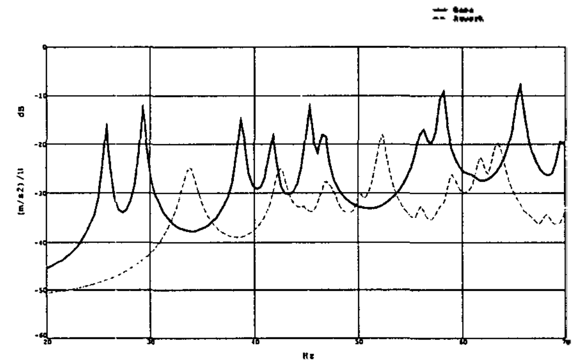

Figure 2. Comparison of Frequency Response Functions of Body-in-white Structure

To check the change of dynamic characteristics after modification, the full-scale modal test is undertaken before and after reinforcement. Table 3 illustrates the shifting in modal frequencies.

In contrast to the modal properties of original configuration, the frequency response function has altered its peaks. Moreover, the amplitudes of the individual peak decrease, shown as in Figure 2, implying that the structure becomes more intact to the excitation. It is also natural and noteworthy that the damping values increase.

To illustrate the change in modal properties, the mode shapes with eigen-frequencies are depicted as in Figures 3 and 4.

Table 3. Change in Eigen-frequencies due to Reinforcement for Full Vehicle

Mode	Original Configuration	Modified Configuration
Torsion	16.8 (Front)	22.1 (Front)
Lateral	37.4 (Front)	44.7 (Front)
Bending	21.8 (Global)	26.2 (Global)

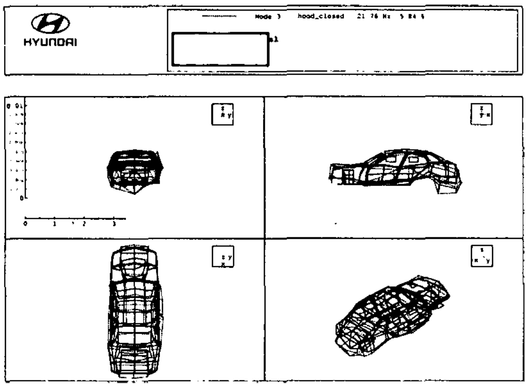

Figure 3. Modal Parameters of Original Configuration

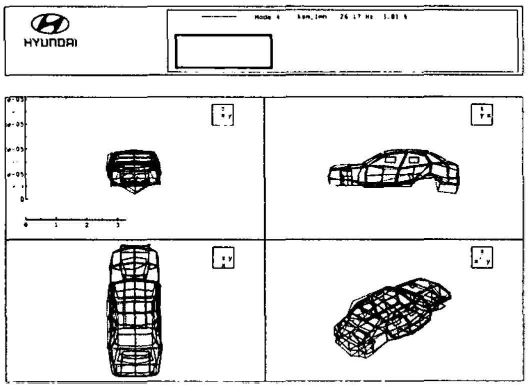

Figure 4. Modal Parameters of Modified Configuration

Sound Quality Analysis of Vehicle Interior Noise

The fundamental frequencies of vehicle structure have changed somewhat. Subsequently, the interior noise is analyzed from the viewpoint of noise or sound quality. The sound quality analysis in the present work comes into play because most of modified frequencies reside in extremely low frequency band, ranging from 20 to 40 Hz. In such low bands, human auditory organs are far less sensible to changes in timbre and it normally does not affect the sound pressure level. Since the trained referees may notice the improvement of quality, the state-of-the-art psychoacoustic analysis techniques are employed in the present analysis.

For the noise quality in the idle operating condition, the standard sound pressure levels have reduced, as shown in Figures 5 and 6. They show clear improvement around the center frequency at 30 Hz.

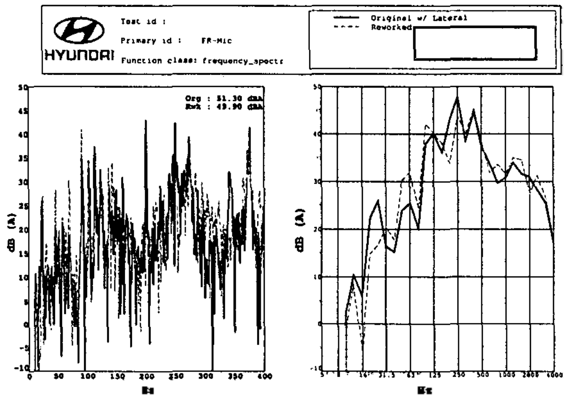

Figure 5. Sound Pressure Level at Idle Operation

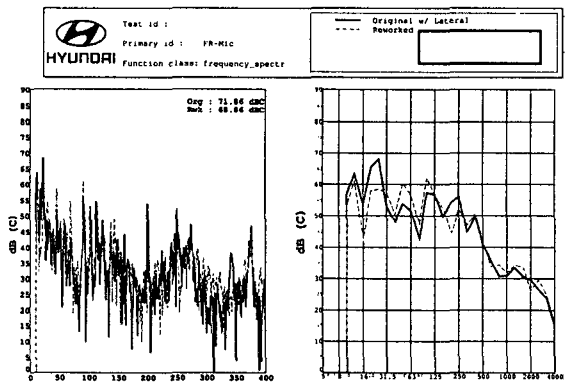

Figure 6. Booming Level at Idle Operation

The noise at run-up driving condition requires more detailed descriptions since it is normally complicated in nature. The order-tracked spectrum at slow accelerated driving condition is illustrated in Figure 7.

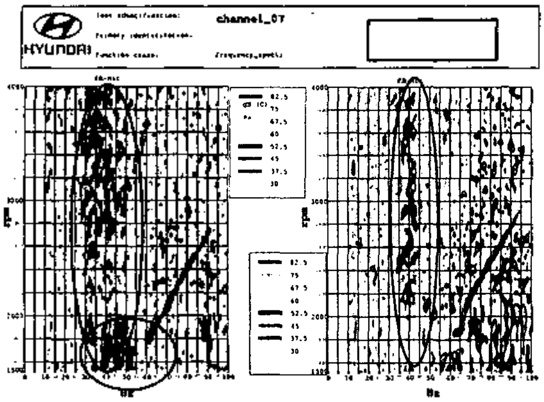

Figure 7. Order-tracked Spectrum at Slow Acceleration

Assuming the quasi-stationarity in noise signature, Hyundai Motors has developed a sound quality index for measuring the degree of annoyance, called HMC annoyance index, which characterizes the low frequency band loudness as well as the high frequency articulation level./4/ With the aid of HMC annoyance index, the corresponding noise quality reveals much improvement over the entire speed range.

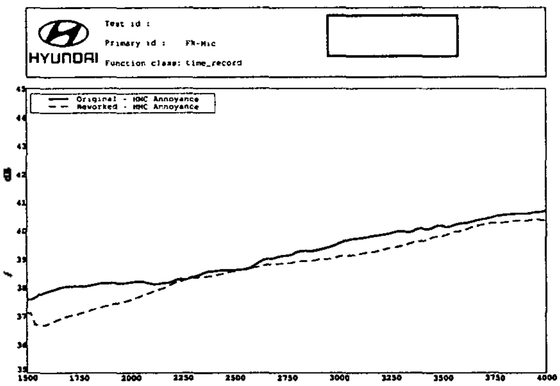

Figure 8. Comparison of HMC Annoyance Index

It has been two decades ever since a sound metric, called Composite Rate of Preference, is in use. This is also developed with basis on the jury assessment. Figure 9 indicates very similar results as HMC annoyance index shows.

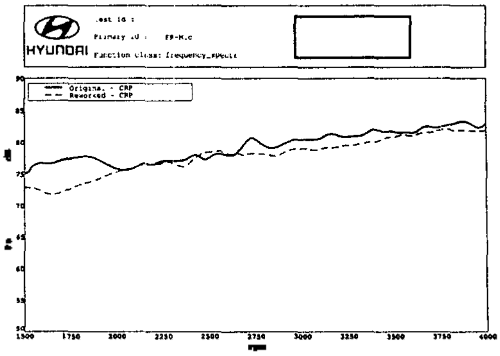

Figure 9. Comparison of Composite Rate of Preference

Conclusions

It has been subjectively witnessed that the structural strength has a significant influence on the interior noise quality. With reference to the traditional noise measure, such as sound pressure level in A-weighting network, does not reflect the refinement so much. Some works are left in the near future to render the reinforcement to be applied to the feasible design of vehicle structure.

Acknowledgement

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