Research on Improvement Methods of Automotive NVH Performance

LIU Xing
(Sichuan Aerospace Vocational College, Chengdu 610100, China)

Abstract: The performance of automotive NVH will directly affect the production and sales of automobiles. This article summarizes the generation and control of the main NVH problems in automobiles, and discusses the methods to improve the NVH performance of the vehicle from three aspects: free damping treatment of the body structure, analysis of the contribution of body panels, and analysis of key hard-point forces of the vehicle steering system.

1. Introduction
With the development of automotive technology, the key technology gaps among engine manufacturers, chassis, and body of various vehicle manufacturers have narrowed. The performance of automotive NVH (Noise, Vibration, and Harshness) will directly affect the production and sales of complete vehicles. During the driving of a car, the main sources of vibration noise include: vibration noise generated by engine excitation, vibration noise generated by the interaction of automobile tires and the road surface, and vibration noise generated by friction between the air flow and the vehicle body. After the various vibration noises are superimposed, they are transmitted to the entire body, causing the vibration of the body structure, radiating the noise to the interior of the vehicle, and making the passengers in the vehicle feel uncomfortable.

2. Basic Theory of Vehicle Vibration Performance and Acoustics

2.1 Car Vibration Performance
The vibration performance of a car is mainly evaluated by its ride comfort characteristics. During the driving process of the car, vibration and impact will occur, which will affect the comfort of the driver and passengers. Due to the uneven road surface, the generated incentives will be input to the car, and then passed to the people in the car through the tire system, suspension system, and seat system. Under different driving conditions, different human accelerations are obtained, and the ride of a car is characterized by the response of the human body to vibrations.

The human body's response to vibration depends on the frequency and intensity of the vibration, and also has a direct relationship with the psychological and physical factors of the human body. There are also some differences in the sensitivity of different people to vibration. At present, the evaluation of ride comfort mainly includes two parts, namely subjective evaluation method and objective evaluation method. The subjective evaluation method mainly
considers human factors, and realizes the comprehensive evaluation of vehicles based on actual statistical methods. The objective evaluation method mainly relates to vehicle vibration isolation performance and mechanical vibration physical parameters, and can fully display actual evaluation indicators.

2.2 Basic Theory of Acoustics

Studies have shown that the hearing frequency of the human ear is 20 Hz to 2000 Hz, and the sensitivity to different frequencies is not the same. Sound can form physical phenomena, including sound pressure and sound power. Sound pressure is the change that occurs when atmospheric pressure is disturbed by sound waves. Sound power indicates the strength of the sound source and determines the speed and amplitude of sound propagation.

Due to the wide range of sound pressure energy, for convenient representation, logarithmic coordinates are often used instead of absolute coordinates. At the same time, from the perspective of sound reception, the subjective "loudness" is not directly proportional to the absolute value of sound pressure, but approximately proportional to the logarithm of sound pressure. Therefore, considering these two reasons, logarithmic coordinates are commonly used in acoustics to measure sound pressure, expressed in terms of sound pressure level, and the unit is dB (decibel).

The effective value of the sound pressure at the point to be measured is $p_e$, and the sound pressure level $L_p$ is defined as:

$$L_p = 20 \log \left( \frac{p_e}{p_{ref}} \right) \quad (1)$$

In the formula, $p_{ref}$ is the reference sound pressure, and is taken as $2 \times 10^{-5}$ Pa. This value is the audible valve sound pressure of normal human ear to 1KHz sound.

According to the principle of energy superposition, the average value $L_{pm}$ of the sound pressure level can be obtained:

$$L_{pm} = 10 \log \left( \frac{1}{m} \sum_{i=1}^{m} 10^{0.1L_{pi}} \right) \quad (2)$$

Where $L_{pi}(i = 1,2,...,m)$ is the sound pressure level measured at the $i$ measurement point, and $m$ is the total number of measurement points.

3. Generation and Control of Automotive Major NVH Problems

3.1 Source of Car Noise

Automotive noise mainly comes from engine noise, wind noise, and structural vibration radiation noise. The noise radiated by these noise sources will be introduced into the vehicle through air and solids. In the process of solid-borne noise, that is, the vibration caused by the excitation of the engine and the road surface can be transmitted to the vehicle body through the floor structure, thereby causing continuous vibration of the vehicle body, and then the vibration radiation noise of the body plate wall is transmitted to the vehicle, resulting in the interior of the vehicle noise. In the process of airborne noise, the noise mainly comes from automobile engine noise, tire noise, fluid noise caused by body and air friction, and propagates into the car through the body gap to form interior noise. In general, high-frequency
noise above 800Hz is mainly airborne noise, low-frequency noise from 5 Hz to 300Hz is mainly caused by body vibration, and mid-to-high frequency noise from 30 Hz to 300Hz is mainly caused by body wall vibration.

3.2 Evaluation of Interior Noise
In order to reduce the harm to people caused by noise, many countries in the world have implemented relevant standards for the control of automobile internal noise. In the course of research, the American Society of Automotive Engineers conducted statistics on a large amount of data, and proposed that the noise value inside the cab of a truck cannot exceed 88dB, and also pointed out the maximum value of noise sound pressure level.

Table 1 Maximum Internal Noise of SAE Recommended Trucks in the United States

| Octave Center Frequency (Hz) | 63  | 125 | 250 | 500 | 1000 |
|-----------------------------|-----|-----|-----|-----|------|
| Sound Pressure Level (dB)   | 103 | 97.5| 92  | 86.5| 81   |

Due to the different structures between vehicles, different driving conditions have different effects on vehicle noise, resulting in large differences in noise levels in cars. In order to ensure that the intelligibility of people's voice communication in the cab is not affected, the noise value in the car cannot exceed 70dB.

3.3 Control Method of Automobile Vibration Noise
The first is vibration isolation treatment, adding elastic damping elements such as rubber pads to the vibration transmission path of the car can reduce the transmission of vibration sources to the vibration body and reduce the vibration noise of the interior structure. Both the engine suspension damping and the suspension system shock absorption damping can reduce the body vibration and reduce the interior noise. The second is sound insulation and noise reduction. For the noise of the engine and the outside of the car, appropriate sound insulation materials are selected for sound insulation operations to achieve effective control of noise. The last is the application of sound-absorbing materials. Commonly used sound-absorbing materials are asbestos, slag wool, and felt, all of which are porous materials. The more micropores and gaps inside the material, the smaller the gap, the better the sound absorption effect.

4. Automotive NVH Performance Improvement Method

4.1 Body Structure Free Damping Treatment
If the noise in the car is caused by the vibration of the body structure, and the frequency is concentrated below 200Hz, a method of damping the body structure can be adopted. The additional damping material is locally coated on the floor, and the modal strain capacity analysis of the entire bottom plate is performed, and the modal strain energy of the bottom plate within 200 Hz is superimposed on each other. Perform free damping treatment to keep the thickness of the damping layer at about 2mm. By coating the body structure with a damping material, the low-frequency noise in the vehicle can be effectively reduced.

4.2 Analysis of Body Panel Contribution
During the acoustic-solid coupling finite element calculation, the calculation of the structural
modal factors and the calculation of the plate acoustic contribution found that the structural modal and body plates contributed the most to the interior noise. At the same time, the vehicle body is divided into areas such as the roof, front floor, left front door, and right rear door to display the peak noise data of the vehicle in different areas. By comparison, it is found that the tailgate and the roof cover have a greater contribution to the peak of interior noise. By effectively improving the body structure, the interior noise can be reduced and the interior noise design standard can be achieved.

4.3 Force Analysis on Key Hard Points of Vehicle Steering System

4.3.1 Steering System Model Building
During the establishment of the rack-and-pinion steering system model, the main research contents include the steering wheel, steering shaft, steering gear, steering transmission shaft, and lateral stabilizers that affect steering accuracy. The steering wheel is connected to the auxiliary frame through a rotating pair; the steering shaft is connected to the auxiliary frame through a cylindrical pair; the two ends of the steering transmission shaft are connected to the knuckle arm and the gear shaft respectively; the steering rack and the steering gear adopt a translation pair connect. In order to improve the stiffness of the suspension roll angle, adjust the ratio of the stiffness of the front and rear suspensions to avoid large lateral inclination or lateral vibration of the vehicle body at high speeds, a lateral stabilizer bar needs to be installed in the front suspension. For the establishment of the transverse stabilizer bar model, it mainly involves two left and right symmetrical parts, and a rotating pair needs to be applied at the point of symmetry to ensure that the two parts can rotate relative to each other about their axial directions.

4.3.2 Force Analysis of Key Hard Points in Steering System
Compare actual measurement data with effective simulation of lateral stabilizers, establish a rigid-flexible multi-body dynamics model of the steering system, simulate straight-line driving on a B-grade road at 60km/h, and obtain the hard points of the connection points between the steering system and the body Force changes. A force spectrum analysis is performed on each hard point of the hard point force curve, and the actual force situation of the hard point under static conditions is calculated to obtain a static force curve where each hard point deviates from the equilibrium position. By analyzing the hard-point static force curve, the structure optimization of the steering system can obviously improve the NVH performance of the entire vehicle.

5. Result Analysis
Based on the free damping treatment of the body structure, the change of the body panel structure, and the optimization of the vehicle steering system structure, a multi-body dynamics model of the entire vehicle system was established, and the vibration of both sides of the wheels in the same direction was used to re-perform the vehicle vibration and do a comprehensive calculation analysis about noise performance. The calculation results show that the vehicle body reference point vibration speed and noise sound pressure level are significantly reduced, and the NVH performance of the vehicle is significantly improved.

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