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AUTOMOTIVE & TRANSPORTATION

The Science of Noise, Vibration, & Harshness Control in Electric Vehicles

NAGASE Global Marketing Division
Insights Practice

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Introduction

In a world where electric vehicles (EVs) are gaining popularity and becoming more mainstream, understanding the science behind sound is essential in designing effective noise control solutions. Human perception of sound heavily relies on the frequency of sound waves, with our ears having evolved to be particularly sensitive to higher frequency sounds.

As such, it is crucial for developers of noise, vibration, and harshness (NVH) solutions to take this increased perception of higher frequency sounds into account when working with EVs. In this article, we will look at:

- An overview of different vehicle types and their differences
- Sources of Noise, Vibration, & Harshness in vehicles
- NVH control measures

The global market for Electric Vehicles (EVs) is projected to grow at a CAGR of +22% through 2030 while the market for light duty vehicles will grow at a CAGR of 3.7% during the same period. This growth in market share of EVs will be fueled by rising environmental consciousness among consumers, unpredictable and rising gas prices, and the incentivization by governments and policy makers across the World. Growth in EVs will also fuel manufactures' demand for Noise, Vibration, and Harshness (NVH) Control solutions for EVs. Fundamental differences in the architecture of traditional, internal combustion engine (ICE) vehicles, and electric vehicles (EVs), render existing NVH solutions ineffective for EVs and necessitate the development of new solutions.

Controlling NVH in EVs can be accomplished through a variety of electrical (motor configurations), mechanical (drive train and gear assembly optimization), electronic (acoustic sensors and active noise cancelation), and materials-based techniques.

Overview of Automotive Vehicle Types

Noise, Vibration, and Harshness in vehicles create usability as well as safety issues in vehicles. While there are several internal (e.g., automotive design, combustion engine, drivetrain, etc.) and external sources (e.g., road, wind, traffic, etc.) of noise, vibration, and harshness, addressing NVH first requires an understanding of the different vehicle types.

Gasoline & Diesel Internal Combustion Engine Vehicles (ICE)

Gasoline and diesel internal combustion engine (ICE) vehicles are powered by internal combustion engines that utilize combustion of fuel to generate energy. In gas-powered ICE vehicles, a spark-ignited internal combustion system is commonly used. Here, the fuel is injected into the combustion chamber with air, creating a mixture which is then ignited with a spark plug. On the other hand, diesel vehicles use compression-ignited internal combustion systems whereby the air-fuel mixture is compressed by piston movements, leading to ignition. Regardless of engine type, both gasoline and diesel-powered ICE vehicles convert internal combustion energy into rotational force for propulsion. The average noise levels of 73.5 db(A) in ICE vehicles even at normal operating speeds exceed healthy levels for humans.

Hybrid Electric Vehicles (HEV)

Hybrid electric vehicles (HEV) are a type of powertrain technology that combines the benefits of traditional gasoline engines and electrical motors. Both power sources work together to reduce overall fuel consumption, resulting in substantial efficiency gains on short trips as well as long-distance driving. HEV's typically have a larger battery than an ordinary car due to the need for storing energy that would normally only be used when the vehicle is idling or coasting. This allows drivers to recover energy while braking or going downhill, thereby supplying more power when it is needed. Moreover, HEVs generally feature regenerative braking systems and special functions like engine-off coasting which can dramatically improve fuel economy upwards of 40%. With an increasing focus on environmental sustainability and affordable transportation, HEVs could just be the spark that drives a new era of smarter urban mobility. The average noise levels of 71 db(A) in HEV vehicles even at normal operating speeds exceed healthy levels for humans.

Plug-In Hybrid Vehicles (PHEV)

Plug-in hybrid vehicles (PHEV) are motorized vehicles that combine a gas-powered engine with a battery and an electric motor. The battery, which can be recharged via an electrical outlet, stores enough power to enable the vehicle to operate solely on electric power for short distances; switches over to exclusively gas-powered operation when the charge level is low; and shares both sources of power while running at higher speeds or in more demanding conditions. This type of hybrid differs from

traditional hybrids, such as the Hybrid Electric Vehicle (HEV), because PHEVs have larger batteries and require more reliance on electric power. Most HEVs cannot be plugged in to charge their batteries, as they rely primarily on regenerative braking technology to generate energy. While HEV batteries are recharged automatically during regular driving, PHEVs require occasional plugging in for recharging purposes and typically require less gasoline overall due to the significantly increased use of electric power. The average noise levels of 70 db(A) in HEV vehicles even at normal operating speeds approach the safe limits for humans.

All Electric Vehicles (BEV)

All-Electric Vehicles (BEVs) are vehicles that use electricity from an external source to power their motor. They have no carbon combustion engine, fuel tank or exhaust pipe and rely solely on the stored energy of batteries to be able to move. BEVs offer an environmentally friendly alternative to traditional gasoline powered models; their quiet and efficient operation produces zero tailpipe emissions and require far less electricity for maintenance than petrol cars. Additionally, because the powertrain components are much simpler, these vehicles can typically generate stronger acceleration performance than other types of cars. To add further incentive in favor of purchasing a BEV, charging already takes place much faster than filling up your gasoline tank, making it a great choice for those looking for a faster and more convenient journey. The average noise levels of 68 db(A) in BEV vehicles at normal operating speeds are within the safe limits for humans.

Sources of Noise, Vibration, & Harshness

Nature of Sound Waves

Have you ever wondered why our ears are more sensitive to higher frequency sounds than lower ones? This natural tendency of human hearing is not only an interesting phenomenon, but it also has practical implications in our daily lives, especially as we transition towards greater adoption of electric vehicles (EVs). Sound waves are a type of mechanical wave that travels through a medium (usually air but can also be water or solids) by the vibration of particles. These vibrations cause a series of compressions and rarefactions, which result in the propagation of the wave. The properties of a sound wave can be described by its frequency, amplitude, and speed. The frequency, measured in Hertz (Hz), determines the pitch of the sound, while the amplitude is related to the loudness or intensity. The speed, on the other hand, depends on the medium through which the sound wave is traveling. Human ears are sensitive to a wide range of frequencies, typically between 20 Hz and 20,000 Hz. However, our ears are more attuned to hearing high-frequency sounds than lower frequencies. This can be attributed to the anatomy of our ears and the way our brains process auditory information. The human ear consists of the outer, middle, and inner ear, with the cochlea in the inner ear being responsible for translating sound waves into electrical signals that our brains can interpret. Within the cochlea, there are tiny hair cells that resonate at different frequencies, with those at the base being more sensitive to higher frequencies.

One possible explanation for this sensitivity is that higher frequency sounds carry more information and are more critical to our survival. For example, human speech occupies a frequency range of about 300 Hz to 3,400 Hz, with the most important frequencies for intelligibility being between 2,000 Hz and 4,000 Hz. Additionally, many environmental sounds, such as rustling leaves, snapping twigs, or the cries of infants, fall within the higher frequency range. Being able to detect these sounds has historically been essential for communication and avoiding danger. The knowledge of human hearing sensitivity has practical implications for noise control solutions in electric vehicles.

Since our ears are more attuned to high-frequency sounds, noise reduction efforts should prioritize these frequencies to achieve the most significant perceived decrease in noise levels. In recent years, researchers have been working on various noise control solutions for EVs, including active noise control, sound absorption materials, and new tire designs. For example, active noise control systems utilize microphones to detect unwanted noise and counteract it by producing anti-noise waves. Meanwhile, sound-absorbing materials can be strategically placed within the vehicle to help dampen high-frequency sounds, and tires with specialized tread patterns can reduce road noise.

Main Sources of NVH in ICE and Electric Vehicles

The primary causes of noise in ICE vehicles can be attributed to the engine combustion process, exhaust, intake, and mechanical transmission. The engine generates a significant amount of noise during its operation, mainly due to the constant movement of pistons and the ignition of the air-fuel mixture. Additionally, the exhaust system releases gases at high pressure, creating noise from the tailpipe, while the intake system contributes to noise as air is pulled into the engine. In the case of EVs, the absence of an internal combustion engine notably reduces the noise level. However, EVs experience electric motor noise, high-frequency noises from power electronics, and noise from gearsets and electrically driven auxiliaries such as cooling pumps. Vibration sources in ICE vehicles primarily stem from the engine, transmission, and drivetrain. The complex and constantly moving parts in the engine generate a considerable amount of vibration that can propagate through the vehicle's structure. Furthermore, the transmission and drivetrain can also generate vibrations, particularly in situations where there is a misalignment or imbalance. In EVs, the vibration sources are more limited due to the simpler and smoother operating electric motor. Nevertheless, the presence of gearsets and power electronics can still contribute a certain level of vibration to the overall NVH. In general, harshness refers to the unwanted rough feeling perceived by the occupants of a vehicle. In ICE vehicles, harshness can be caused by imbalanced engine combustion, worn or damaged components, and poorly designed suspension systems, among others. These factors can contribute to an unpleasant and uncomfortable ride. Conversely, electric vehicles benefit from a smoother, quieter ride experience, primarily due to the efficient operation of the electric motor, fewer moving parts, and typically simpler designs. However, EVs are not immune to harshness caused by tire and road interactions or inadequate suspension systems, which can still lead to an uncomfortable experience.

Sound Frequencies & Propagation in ICE Vehicles and EVs

Internal combustion engines generate noise from various sources, including the engine block, exhaust system, intake system, and ancillary components such as accessories, cooling systems, and tires. The fundamental frequency of ICEs is primarily determined by the firing frequency or "order" of engine operation, typically falling between 25 Hz and 500 Hz. This low-frequency noise range is a dominant characteristic of ICE-powered vehicles. On the other hand, electric vehicles (EVs) exhibit significantly different noise profiles. Unlike ICEs, EVs predominantly produce high-frequency noise. The primary sources of noise in EVs are electric motor, power electronics, cooling systems, and tire-road interaction. Their noise frequency ranges from approximately 100 Hz to 10,000 Hz, with most of the energy concentrated between 1,000 Hz and 3,000 Hz.

Analyzing the noise spectra and comparing the sound levels across frequency bands provide a clearer picture of the differences in noise emitted by ICEs and EVs. ICE-powered vehicles exhibit more significant peaks in the low-frequency range due to the combustion pulses and mechanical vibrations generated within the engine block. This low-frequency noise is more likely to create vibrations in nearby structures and can propagate more extended distances. EVs, on the other hand, display more significant sound levels in the high-frequency range due to the rotation of electric motor and the air turbulence created by the cooling fan, contributing to a whining or whirring sound. High-frequency noise tends to dissipate more quickly with distance and is less capable of causing structural vibrations.

The human ear is more sensitive to certain frequency ranges than others, and psychoacoustic perception plays a significant role in how ICE and EV noise is experienced. Due to the low-frequency content, ICE noise is often perceived as rumbly or even "boomy," especially when experienced inside the cabin or nearby buildings. Conversely, EV noise is perceived as more tonal, sometimes described as "whiny" or "buzzing." While EV noise may not carry as far, it is often considered more annoying, especially at higher frequency ranges.

NVH Control Measures

Now that we know the importance of sound frequencies and the key differences between ICE vehicles and EVs as they pertain to sound, let's review the main control strategies for NVH. There are several 'active' mechanical and electro-mechanical solutions that industry players are adopting to eliminate or reduce noise and vibration at the source inside vehicles. However, in this article, we will be focusing mainly on the use of 'passive' control solutions such as Sound Absorbers, Sound Barriers, and Vibration Dampers.

Sound Absorbers

Sound absorbers are porous, fibrous, or cellular materials that, when placed in contact with a rigid surface, convert sound into thermal energy. The porosity and thickness of the material determine the absorption of various frequencies. Sound absorbers are typically used in hoodliners, dash absorbers, headliners, trunk trims, carpeting, and rear seats. Materials that are typically used as sound absorbers are Glass Fiber, Felt, Melt Blown Fiberpad, Polyurethane Foams, and Melamine Foams. Porous materials like these generally have good sound absorption characteristics at high frequencies but poor sound absorption at low frequencies. This is because lower frequency sounds have longer wavelengths that sound absorbers cannot contain at practical thicknesses.

Sound Barriers

Sound barrier materials used to control high frequency sounds in vehicles are typically highly densified and durable materials designed to block short wavelength, high frequency sound waves. These materials are usually composed of materials layered together in a variety of designs to optimize acoustic absorption. In a vehicle, the body panels (such as steel or aluminum panels) are very effective in blocking sound propagation from the outside to the inside of the vehicle. However, these vehicle components cannot reduce noise propagation inside the vehicle. Sound barriers can reduce sound due to their design and material structures. Sound barriers are an incredibly effective way of reducing high frequency sound transmission, primarily because the mass of the material dampens vibrations. When high frequency sounds - common in EVs – impinge on a barrier, their shorter wavelengths face difficulty vibrating through it and so effectively get blocked out instead. By contrast, lower frequencies have longer waves, which can more easily slip past barring materials making these types harder to contain with regular noise-barriers alone. Sound barriers are typically used in dash panels, seatbacks, flooring, glass panes, sheet metals on the roof and floor, and between mechanical and electric components. Materials that are typically used as sound barriers in EVs are metal panels, Polycarbonate panels, sheet molded compounds, loaded Ethyl Vinyl Acetate, loaded Polyvinyl Chloride, loaded Asphalt Mastics, LDPE & HDPE, thermoplastic Olefins, and loaded Polyurethanes.

Vibration Dampers

Vibration dampers are components used in vehicles that serve the purpose of decreasing vibrations and smoothing out riding experience. They work by absorbing the mechanical and vibrational energy from impacts and convert it into work that is then dissipated as heat. This reduces the harshness of engines, accelerations, bumps, and road vibration on passengers, the chassis, and attached components. Vibration dampers are typically used around engines, valve covers, oil pans, outer doors, floors, wheelhouse, etc. Commonly used materials include rubber, steel-spoked wheels, hysteresis dampers with various oils containing silicone or aqueous viscous materials. Vibration dampers can also reduce structure-borne noise in a vehicle by preventing sounds generated from vibration from achieving resonant frequencies. Acoustic materials that are typically used to control both vibration and sound propagation are Asphalt Dampers, Metal Polymer Composites, Hight Resilience Foams, Fiberglass, Polyurethane Foams, and Polyester Fibers.

NVH Control Solutions by NAGASE

In conclusion, the understanding of sound-based science and noise control solution mechanisms is essential for electric vehicle experts and engineers looking to improve their NVH management strategy. It is critical to build a strong base of knowledge around topics such as vehicle acoustic response, frequency range analysis, Acoustical Materials, Digital Signal Processing (DSP) algorithms, among many others in pursuit of an optimal NVH experience. NAGASE's extensive resources and research into passive and active noise control technologies provide automakers with an opportunity to create innovative solutions that can lead the EV industry forward.

For more information on how we can help you achieve your noise reduction goals, please visit our website at nagase.com.