Advancements and Applications of Rubber Dampers in Mechanical Systems: A Review

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Abstract: *Rubber dampers are indispensable components in mechanical systems, crucial for mitigating vibrations and reducing noise and structural stress. Their ability to absorb and dissipate energy through viscoelastic deformation makes them versatile across diverse applications in automotive, aerospace, industrial machinery, and civil engineering sectors. This review explores the fundamental principles, design considerations, and applications of rubber dampers. It discusses their unique properties such as elasticity and damping characteristics, highlighting their role in enhancing mechanical system performance and longevity. Practical examples and case studies underscore the effectiveness of rubber dampers in attenuating vibrations caused by engine operations, machinery movements, and environmental factors.*

Keywords: *Rubber dampers, vibration mitigation, viscoelastic deformation, mechanical systems, noise reduction.*

I. INTRODUCTION

Rubber dampers play a crucial role in mitigating vibrations across various mechanical systems, offering effective solutions to reduce unwanted noise and structural stress. Their ability to absorb and dissipate energy through viscoelastic deformation makes them invaluable in applications ranging from automotive and aerospace industries to industrial machinery and civil engineering. The unique properties of rubber, such as its elasticity and damping characteristics, allow these dampers to efficiently attenuate vibrations caused by engine operations, machinery movements, or environmental factors. This introduction explores the fundamental principles behind rubber dampers, their design considerations, and their significance in enhancing the performance and longevity of mechanical systems.

Rubber dampers or shock absorbers are used to reduce the transmission of shock to the surrounding structure. Shock absorption is possible as the rubber absorber deflects under the applied shock load. The construction of rubber dampers (also known as rectangular buffers) is such that rubber is bonded to a metal plate which incorporates a number of fixing holes allowing for simple installation.

A wide range of dimensions and rubber hardness options are available from stock or alternatively rectangular buffers and rubber dampers can be specially manufactured to meet the customer's individual requirement.

At GMT Rubber we experts at creating bespoke solutions for our customers shock and vibration problems. Please contact us if you are having any trouble, or would like some advice.

Figure 1. Rubber dampers

A. Types of Fire Dampers

Two types of fire dampers are available, based on builder requirements:
- Dynamic fire dampers
- Static fire dampers

Dynamic fire dampers are typically situated within HVAC system vertical barriers. They remain spring-loaded and continue to function during fires. When a fire is detected, built-in fans activate spring-loaded dampers, cutting off airflow and protecting the building.

Static fire dampers are designed to instantaneously halt airflow upon fire detection. These dampers are found within horizontal barriers. When activated, all fans stop due to air pressure loss, preventing fire spread.

Although various damper types exist, they all serve the same premise – managing airflow. Some provide comfort by blending hot and cold air for ideal indoor temperatures, while others are essential for safety. Fire dampers, smoke dampers, and combination fire/smoke dampers are critical to preserving life when fire threatens. Choosing between dynamic and static types, and employing these dampers ensures building safety and code compliance.

II. VEHICLES NOISE

The regulation of road transport noises as it effects outsider observers (i.e., someone who is not within the vehicle) is a topic of law in the majority of nations. While there is no any governmental oversight of interior vehicle noise, such oversight is crucial because excessive sound level is unpleasant and exhausting for the minority of driving and travelers [1].

In these perspective, a car's internal sound management should be a key component of its design. Unfortunately, how much of this (i.e., the reducing of interior noise) is done dependent largely on "market" factors, i.e., how much a lower internal sound levels are a sales point for that specific category and model of a transport.

Given the current situation—where there are almost no legislative restrictions on the internal sound levels of vehicles in the majority of nations—this is only reasonable. However, it is not always true that a plan of sound reductions from the perspective of "interiors" or occupation will inevitably result in a lower level of "external" sound [2]. It is quite easy to design and build a car that is incredibly silent for its occupants but yet has excessive airborne exhaust noise, engine noise, or even road noise to the outer listener by properly using voice elements, isolator, and suppressing of vibrating forces.

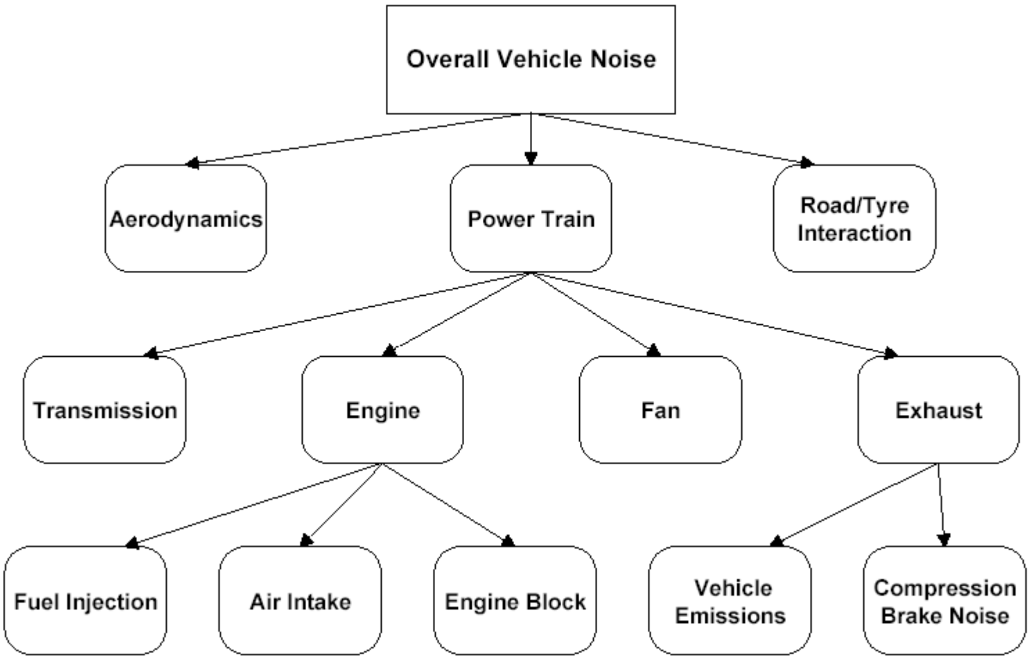

Figure 1 Different types of noise produce in vehicle

In generally, nevertheless, it is reasonable to assume that lowering exhaust sound to a level where it blends in with engines sound will satisfy all regulatory criteria. Additionally, this will categorize the aforementioned car as "silent" or "fairly quiet" from the perspective of an outside observer.

Typically, such a level of silence can be accomplished without significantly reducing power. The only situation where this strategy might run into actual issues is with some sporty cars that have low platform clearance. In this instance, challenges arise from accommodating the required silencer volumes.

A. Methods of Analyzing Vehicle Noise

Road driving noise and vibration analysis uses a wide variety of techniques. They cover the entire spectrum, from simple "cut-and-dry" techniques to the use of sophisticated test rigs and instrumentation, etc., to enable in-depth analysis of sound

issues. The automotive sector frequently uses specialized equipment, such as tyre thumping meter, to analyze certain sound source.
Some of the test and evaluation methods used for the analysis of road vehicle noise are listed in Table 1.1, but this list is not exhaustive. On the other hand, every automobile manufacturer may not employ such an extensive range of testing and measurement equipment.
Column 1 contains a partial list of some of the testing and assessment techniques used to analyze road driving sound, but it is not all-inclusive. On the other hand, not all automakers might use such a wide variety of test & measuring tools.

B. Engine Noise

In road cars, the engine is the main source of noise. Isolating yourself from engine noise may help to lessen its impact. The engine unit is mounted on flexible mounts to do this. Unfortunately, using this approach makes perfect isolating difficult. The level of flexibility required for total engine unit isolation would lead to a mount that is far too flexible. The fact that the supports to which the robust mounting are fastened is themselves quite flexible and could be aroused by, for examples, highway sound, further complicates the issue. The supports may also be aroused by its own excitation's feedback from the suspension's unsprang masses. Because of this, the designers must find the best compromise feasible.

III. LITERATURE REVIEW

Gao, P., et al. (2021) [3] This article focuses on developing a novel torsional vibration absorber using magnetorheological elastomers (MREs) to enhance vibration reduction in vehicle powertrain systems. The study includes detailed design, manufacturing processes, and experimental evaluations to validate the absorber's effectiveness through vibration transmissibility tests and engine performance experiments.

Yoon, T., et al. (2020) [4] Investigates the complex dynamics of diesel engine exhaust systems, particularly focusing on the nonlinear behavior and hyper-elastic properties of rubber components. Through modal testing and finite element analysis (FEA), the study optimizes computational efficiency using component mode synthesis (CMS) for accurate vibration prediction and validation through experimental modal analysis.

Yaser, K. S. T., & Sasikumar, K. (2021) [5] Addresses high vibration stresses in diesel engine fuel systems, proposing vibration dampers to mitigate fatigue failures. The paper details experimental stress measurements and optimization strategies, confirming the effectiveness of dampers in reducing stress levels and enhancing durability under various operational conditions.

Wang, D., et al. (2020) [6] Presents a comprehensive study on vehicle vibration during automatic start-stop operations using a semi-active hydraulic damping strut (HDS). Through dynamic modeling and experimental validation, the study optimizes HDS parameters to reduce seat rail accelerations and validates model predictions against real-world measurements.

Paillot, G., et al. (2023) [7] Introduces a hybrid self-supplied damper concept for vibration mitigation in combustion engines, validating its capabilities through experimental tests. The study demonstrates effective torsional vibration cancellation while discussing inherent limitations and practical implications for future applications.

Jiang, C., et al. (2024) [8] Investigates the impact of yaw damper performance degradation on high-speed trains (HSTs), emphasizing the role of damping valve obstruction in inducing low-frequency carbody hunting. The study develops a dynamic model to simulate and understand the complex dynamics of damping degradation and its implications on ride comfort.

Qin, Y., et al. (2020) [9] Provides a state-of-the-art review on noise, vibration, and harshness (NVH) characteristics in hybrid electric vehicles (HEVs), categorizing NVH issues and discussing suppression methods. The paper highlights advancements in NVH reduction technologies and outlines future directions for improving vehicle comfort and energy efficiency.

Li, M., et al. (2021) [10] Focuses on optimizing vehicle body structures to reduce interior noise levels and enhance side impact safety. Using finite element modeling and neural network predictions, the study develops an optimization framework that successfully reduces noise levels and improves structural integrity.

Nygren, J., et al. (2023) [11] Proposes a methodology for assessing vehicle-specific noise exposure costs (NEC) using microscopic traffic simulations and macro-level noise impact assessments. The paper illustrates the methodology's application through case studies, highlighting its effectiveness in capturing vehicle-specific noise impacts under varying traffic conditions.

Coelho, M. C., & Guarnaccia, C. (2020) [12] Presents a vision paper on assessing driving behavior volatility in connected and autonomous vehicle environments to reduce road conflicts, emissions, and noise pollution. The study evaluates driving behavior patterns and their impact on road safety and environmental quality, proposing strategies for enhancing driving behavior predictability and safety.

Lee, H., & Lee, D. J. (2020) [13] Investigates the aerodynamic performance and noise characteristics of multirotor unmanned aerial vehicles (UAVs). Using numerical simulations, the study analyzes rotor-to-rotor interaction effects on wake structures and sound pressure levels, emphasizing the impact of rotor spacing on UAV performance and noise emissions.

IV. THE IMPORTANCE OF NVH TESTING IN ELECTRIC VEHICLES

The importance of NVH (Noise, Vibration, and Harshness) testing in electric vehicles (EVs) is pivotal as these vehicles represent a paradigm shift in automotive technology and consumer expectations. NVH testing specifically tailored for EVs addresses unique challenges and opportunities inherent to their design and operation. The Noise, Vibration, and Harshness (NVH) of electric vehicles are the most essential factors for car manufacturers when it comes to perceived product quality. Since the development cycles in the automotive industry are constantly reducing to meet the market demands, performing precise NVH analysis is becoming increasingly difficult.

Moreover, new and trendy vehicle designs lead to vehicle weight reductions through material changes, resulting in further NVH conflicts. Hence, developing pleasant, adequate, and harmonious passenger cabins of electric vehicles is a challenging task for acoustic engineers. In addition, the silent nature of electric powertrains makes NVH even more apparent.

A. Acoustic Comfort

NVH testing for electric vehicles addresses the challenge of maintaining acoustic comfort in the absence of traditional engine noise. While EVs are inherently quieter than internal combustion engine vehicles, they still produce noise from sources such as electric motors, inverters, and HVAC systems. NVH testing involves evaluating and optimizing the acoustic insulation of the vehicle cabin to ensure that these remaining noises are minimized and that the overall noise level meets customer expectations for a quiet and comfortable driving experience. Engineers use techniques such as sound insulation materials, strategic component placement, and active noise cancellation technologies to achieve optimal cabin acoustics in EVs.

B. Vibration and Harshness Management

Electric motors in EVs generate vibrations and frequencies that differ from those of combustion engines. NVH testing focuses on identifying and mitigating these vibrations to prevent discomfort and ensure a smooth driving experience. This includes analyzing the vibration characteristics of electric motors, drivetrains, and suspension systems under various operating conditions. Through advanced simulation tools and physical testing, engineers can pinpoint the root causes of vibrations and implement design modifications or damping solutions to minimize their impact on vehicle occupants. Effective management of vibration and harshness in EVs enhances ride quality, reduces fatigue during extended driving, and improves overall vehicle refinement.

C. Powertrain Integration

EV powertrains are complex systems comprising electric motors, batteries, inverters, and electronic controls. NVH testing evaluates how these components interact and contribute to overall noise and vibration levels in the vehicle. It includes testing powertrain configurations under different load and driving conditions to assess their NVH performance. Engineers strive to optimize the integration of powertrain components to reduce noise emissions and vibrations while maximizing energy efficiency and performance. This holistic approach ensures that EVs deliver a quiet, smooth, and responsive driving experience across a range of driving scenarios.

D. Customer Expectations

Consumer expectations for EVs often include superior NVH performance compared to traditional vehicles. NVH testing plays a crucial role in validating these expectations by quantifying and optimizing noise, vibration, and harshness levels in EVs. By conducting thorough NVH testing, automakers can enhance customer satisfaction and perception of vehicle quality. Factors such as interior cabin noise levels, smoothness of acceleration, and absence of unwanted vibrations directly influence customer satisfaction and contribute to the overall appeal and market acceptance of EVs.

E. Regulatory Compliance

EVs, like all vehicles, must comply with regulatory standards for noise emissions, particularly for pedestrian safety. NVH testing ensures that EVs meet these standards while optimizing vehicle performance and efficiency. Engineers conduct tests to measure and analyze exterior noise levels generated by EVs during operation, ensuring compliance with local and international regulations. By addressing regulatory requirements early in the development process, automakers can avoid costly redesigns and ensure that EVs meet noise emission limits without compromising vehicle performance or customer comfort.

F. Innovation and Differentiation

Comprehensive NVH testing encourages innovation in EV design and technology. By identifying and addressing NVH challenges early in the development cycle, automakers can differentiate their EVs in a competitive market. Innovations such as advanced soundproofing materials, active noise cancellation systems, and optimized powertrain configurations contribute to quieter, more refined EVs that appeal to discerning customers. NVH testing drives continuous improvement in vehicle design, enabling automakers to deliver EVs that not only meet but exceed customer expectations for comfort, performance, and environmental sustainability.

V. CONCLUSION

Rubber dampers represent a pivotal technology in the field of mechanical engineering, offering robust solutions for vibration attenuation and noise reduction. Their effectiveness in various applications, from automotive to aerospace industries, underscores their versatility and importance in improving overall system performance and durability. Advances in material science and design optimization continue to expand the capabilities of rubber dampers, ensuring they meet evolving demands for quieter and more efficient mechanical systems. Future research directions may focus on further enhancing damping properties, exploring novel applications, and integrating advanced technologies to address complex vibration challenges in modern engineering practices.

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