



NVH Application Note

NVHAN-023 Enclosure Design for Brake Noise Evaluation

Link Engineering has over 25 years of experience in Noise, Vibration, and Harshness (NVH). Whether you need a complete NVH test system, a laboratory screening of brake system NVH performance, vehicle subjective testing, or a fundamental NVH investigation, we have the experience and expertise to assist you. Please do not hesitate to contact Jim Thompson at 734-453-0800 or sales@linkeng.com. To learn more about our NVH activities and expertise, visit our website at www.linkeng.com.

Introduction

The brake noise test enclosure must perform at least four basic Noise, Vibration, & Harshness (NVH) functions:

- Isolation of test environment from exterior noise
- Isolation of the brake systems and test equipment from exterior vibration
- Containment of brake noise emanating from the test, to prevent it from contaminating other tests or the general environment exterior to the enclosure
- Providing a free field sound environment that simulates that seen by the braking system during normal operation on the road.

The goal of this document is to share with you Link’s engineering practices to provide the high performance enclosures.

Isolation from Exterior Noise and Containment of Interior Noise

These two functions are combined because they are the same. The enclosure construction that attenuates exterior noise also attenuates noise from within the enclosure as it is transmitted to the exterior environment. The reduction in sound energy as it passes from the interior to the exterior or vice versa is called sound transmission loss. It is defined as shown below:

$$L_{TL} = 10 * \text{Log}_{10} \left(\frac{1}{\tau} \right) \tag{1}$$

where : τ = transmissibility

$$L_{TL} = 10 * \text{Log}_{10} \left(\frac{W_{\text{internal}}}{W_{\text{external}}} \right) \tag{2}$$

$$L_{TL} = L_{P_{\text{Interior}}} - L_{P_{\text{Exterior}}} + 10 * \text{Log}_{10} \left(\frac{S}{A} \right) \tag{3}$$

where : S = surface area of the enclosure
 A = receiving room sound absorption

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Please note that Equation 3 only applies when the interior room has hard reflecting surfaces to provide a diffuse sound field. In this case, the interior and exterior sound levels should be averaged.



A less rigorous quantification of a room is noise reduction (NR). This is simply the difference in the interior and exterior sound pressure levels. Since noise enclosures are located in a wide range of environments, this discussion will focus on the concept of noise reduction.

1. Construction for Noise Reduction

To achieve good noise reduction, there are several basic enclosure construction concepts that are followed. The first of which is that the walls of the room must be sufficiently massive. There is no substitute for surface mass in attenuating low frequency noise. The following construction is the standard utilized by Link.

A major problem in enclosure construction is flanking. Flanking is defined as paths used by the sound energy to go around the treatments designed to attenuate the noise. One common problem is the cross bracing between the inner and outer walls such as shown below. The Link approach is to keep cross bracing, which connects the inner and outer walls, to an absolute minimum. Any structure, whether it is a bracket, a screw, or anything else that connects the inner and outer

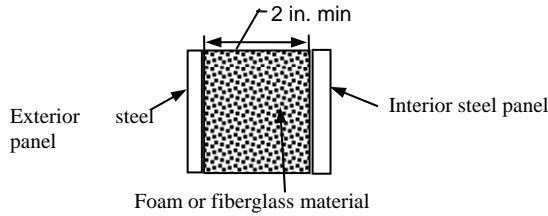
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walls, will reduce the noise reduction performance and is avoided in units developed by Link.

All connections of panels for the enclosure are watertight. This is critical because a small opening serves as an excellent flanking path. For an enclosure designed to provide 50 dB of Noise Reduction, an opening as small as 0.1 percent of the surface area will result in a Noise Reduction of 30 dB. Seals, baffles, and plenums should be used to prevent direct openings in the enclosure. Link is careful to minimize openings of all kinds.

2. Doors and Windows

Doors and windows should be kept to a minimum. Although it is convenient to have multiple openings and easy viewing in to the room, doors and windows are frequent causes of poor Noise Reduction performance. All doors are mechanically fastened at no less than two points when shut. All doors have heavy inner and outer seals that undergo significant deflection when closed.

Obviously, there can be no air gaps. Doors are constructed in the same manner described above for the walls. This includes the interior insulation. In some instances it is necessary to build doors of heavier materials to avoid distortion.

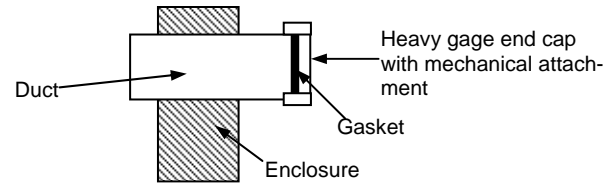
All windows are of double pane construction. The opening is completely sealed with metal gages similar to the walls on both the inside and the outside. The glass is mounted in rubber, silicone, or other resilient material with no direct connection to the inner or outer surfaces.

3. Air Ducts and HVAC Connections

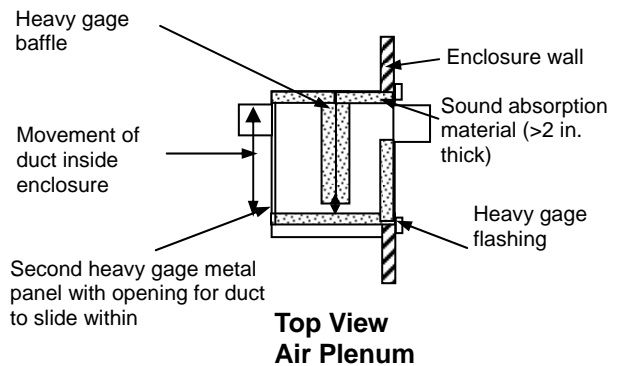
Obviously, ducts cannot run directly from the interior of the enclosure and terminate with an opening in the exterior space or vice versa. It is best not to run ducting directly through the enclosure walls as the duct material serves as a noise and vibration transmission path that can short circuit the wall treatments. If it is necessary to run a duct directly through the enclosure wall, the duct is made of heavy gage material simi-

lar to the enclosure walls and is completely sealed at the entrance and exit points.

If there are duct openings into the enclosure that are not always connected to an HVAC system, these ducts are sealed with a heavy gage end piece that is mechanically attached to the duct and uses gaskets to ensure a watertight seal as shown below.



It may be necessary to provide movable ducting into or out of an enclosure for various needs. To do so simple paper or other lightweight panels are not sufficient to fill the openings. Instead a plenum chamber is provided to seal the opening and avoid a flanking path. Such a construction is shown below.



Note:
All interior surfaces are to be covered with a min of 2 inches of absorptive material

4. Required Performance

In the absence of a customer-specified criterion, the following minimum Noise Reduction is the design objective. The construction methods that have been outlined should easily achieve this level of performance with the minimization of the potential flanking paths.

Octave Band Hz.	63	125	250	500	1K	2K	4K	8K	16K	20K
Noise Reduction, dB	15	25	28	30	32	35	35	36	38	40

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Providing a Free Field Environment

A free field environment can be defined in a few ways. In the simplest sense, such an environment is the equivalent of that found out of doors. In the case of braking systems this would be a hard reflecting plane with a completely open environment above it - in other words, the open road.

To achieve an absorption coefficient of 99.9 percent from 500 to 20,000 Hz would require specialized sound absorbing wedges approximately 6 inches deep. This is not practical in many of the enclosures we build. Instead, the design goal is to produce a sound environment better than that found within the vehicle fender well with reflections from sheet metal, engine, tires, and other vehicle components. To meet this criterion, it is necessary to achieve a sound absorption coefficient of 80 percent or higher from 500 to 20,000 Hz.

1. Sound Absorption Materials

Sound absorption materials are placed on all the inner surfaces of the enclosure except the floor. This includes the ceiling and the inside surface of all doors. There are commercially available materials that will provide sufficient absorption.

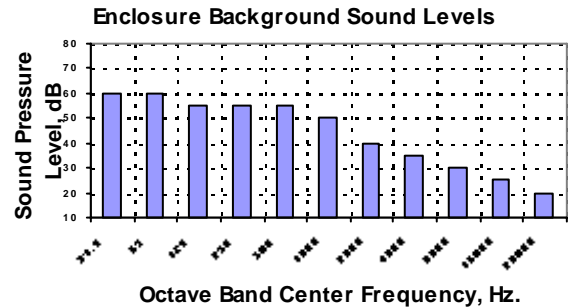
2. Interaction Between Sound Absorption and Transmission Loss

One of the additional benefits of installing sound absorption materials on the interior surfaces of the enclosure is that it improves the Noise Reduction performance of the enclosure. The absorption material provides two benefits. First, it reduces the interior sound levels by absorbing and dissipating sound energy. In addition, mounting the materials on the enclosure surfaces provides a small increase in damping that helps to attenuate sound transmission.

Thus, the Noise Reduction construction methods described above and the sound absorption treatment described here are part of the complete system of a sound enclosure. That is why at Link they are done together.

3. Interior Sound Levels

By combining both Noise Reduction and Sound Absorption treatments, an acceptably low interior-background sound level can be achieved which will permit accurate measurements of all brake noise issues from 500 to 20,000 Hz. A typical spectrum that should be achieved is shown in the next table.



Vibration Isolation

The final function that the enclosure performs is to isolate the measurement system from the vibration of other sources. Vibration isolation is achieved by providing high loss connections between the enclosure and other parts of the dynamometer and the room within which it is located. At high frequencies this loss at the connection point can be achieved by the use of damping materials where energy is actually dissipated by the connection link. At lower frequencies, below 500 Hz., isolation can be achieved by creating an impedance mismatch that causes vibrational energy to be reflected back toward the source instead of driving the enclosure.

The first rule in providing vibration isolation is that there is no direct connection between the enclosure and the rest of the dynamometer. The drive shaft connects to the dynamometer and the reaction torque from the brake is connected to the subframe and not the enclosure. All other connections to the dynamometer are avoided.

The enclosure is mounted on isolators separate from the rest of the dynamometer. In addition, these isolators prevent the dynamometer from causing problems with other measurements being carried out in the building and prevent energy from other units in the building causing measurement problems in the sound enclosure.

Please contact us to learn how we can help you with test system development and engineering services related to NVH.

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