AUTOMOTIVE APPLICATION

Brake Noise Testing

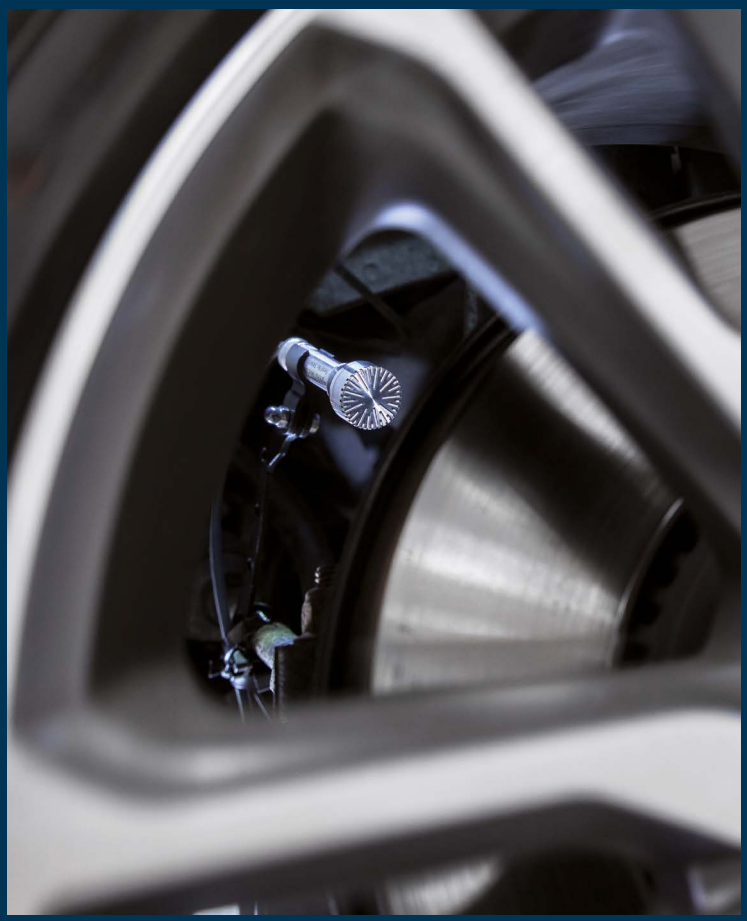
ACOUSTIC SENSORS FOR PREMIUM NVH DATA

GRAS Sound & Vibration

Brake Noise Testing

Brake noise is a chassis-related noise and a big problem for car manufacturers. The noise is caused by friction-induced vibrations, which make the brake system radiate noise. This will in turn cause a lot of irritation and disturbance to the car owner and any person near the vehicle when it occurs. The brake noise can lead to poor results in surveys of customer satisfaction and high warranty costs. Therefore, the development of brake systems with minimum noise issues are highly prioritized in the automotive industry. Brake noise is a very complex problem and the research in this area is in continuous progress.

On top of that, the electrification of vehicles requires new brake design as well as increased focus on noise since the auditory masking from the engine disappears. However, the traditional braking systems will be used to a lesser extent in an electrical vehicle. There is a regeneration process during deceleration used to provide battery charging which in many cases will be sufficient to control the vehicle speed without using the brake pedal.



The usual development process to avoid brake noise is divided into several steps that start when the requirements for brake performance have been defined:

- ✓ Concept selection
- ✓ Design review, best practice checks
- ✓ Computer-aided engineering (CAE) noise predictions
- ✓ Component testing, modal analysis
  - Verification of modes for all brake components, especially pads and rotor
  - CAE correlation
- ✓ System test, brake squeal
- ✓ Vehicle test (started after approval of the system test)

The brake dynamometer squeal test and the wheelhouse test include testing with microphones. The noise characteristics from the most common brake type, i.e. the disc brake, are the following:

- ✓ Low frequency (often broadband) noise between 100 – 1,000 Hz, referred to as scraping, grinding, grunt, groan, moan or judder depending on character.
- ✓ Medium to high-frequency tonal noise between 1 – 5 kHz. This is a friction-induced noise typically caused by coupled modes between pads and rotor causing out-of-plane vibrations. The squeal starts at specific conditions of brake pressure, rotor temperature and environment.
- ✓ High-frequency tonal noise, brake squeal or sometimes referred to as squeak above 5 kHz. This is also a friction-induced noise, but with exciting in-plane resonances of the brake rotor.

ACOUSTIC TEST TYPES WITHIN BRAKE NOISE TESTING

Brake dynamometer squeal noise test
Brake dynamometer squeal noise test is well defined and proved to make sure that the brakes will be in the best possible state when it comes to brake squeal before starting the vehicle testing.

It is performed in a noise, vibration and harsness (NVH) brake dynamometer according to SAE J2521. Brake squeal is defined to be between 1 – 17 kHz.

The brake dynamometer squeal noise test is done as per the following procedure:

- The complete brake system is mounted in a fixture containing a vehicle corner, i.e. ¼ of the full chassis with suspension.
- Several thousands of brake conditions are tested, among others at different wheel speed, brake pressure, rotor temperature, various environmental conditions and brake wear to mention a few.
- A measurement microphone records the brake squeal.
- Accelerometers register vibrations for correlation to the noise.
- 3D laser vibrometer or acoustic cameras are sometimes used for root cause investigations.
- In the case of brake squeal noise exceeding acceptable levels, this test can be used for testing a range of different brake components. This includes modifications of the brake pads, the lining material composition, pad design, adding shims, mass loading and damping or modification of the rotor or caliper, including mass loading of the caliper.

Wheelhouse test
The final important testing is the road test. This is done at precisely defined test locations and test conditions for long periods to capture all, important driving, environmental and brake conditions. The noise is recorded inside the vehicle and in the wheelhouse simultaneously with numerous other parameters like brake vibrations, brake pressure, brake temperature, driving conditions, deceleration and, finally, the important subjective impressions.

The test needs to be repeated for many vehicles and for long mileages at all seasons, especially during wintertime. An OEM would for example use 25 cars equipped with four microphones in the wheelhouse, a reference microphone at the driver's ear, and at least four accelerometers for driving the dedicated test cycles for 50,000 km (30,000 miles). Besides testing on different road conditions, this also includes other tests such as soaking in cooling facilities, driving on splash tracks before braking and other special tests. This allows the NVH engineer to capture brake noise results across all possible external conditions.

CHALLENGES COMMON TO BRAKE NOISE TESTING

The major challenge for brake noise testing is to be able to reproduce the numerous driving conditions that can cause the noise. For example, brake squeal during city traffic, or creep groan during parking. When this happens, during any of the thousands of brake applies, the noise must be recorded at the best possible quality.

Brake dynamometer squeal noise test
Brake squeal will be presented in a similar way as for the wheelhouse test in the NVH brake dynamometer. That is statistical information for noise between 1 kHz and 17 kHz combined with the corresponding conditions. All other low-frequency noise will be classified subjectively, and the microphones and accelerometers provide data to evaluate, if it is the front or rear brakes that are causing the noise. Then further root cause analysis is performed.

There is a need for a very robust microphone for these tests, which can handle the harsh environmental conditions with large temperature and humidity variations as well as brake dust. A test is set to run automatically, and the test time is often around 24 hours, so reliability is critical. Calibration verification is always performed before and after testing, so this must be easy to undertake.

Wheelhouse test
The wheelhouse test is performed with measurement microphones placed directly in the wheelhouse. This is a very demanding environment where the microphones are exposed to dust, water, salt and impacts from gravel. Also, it is important to install the microphones in a way that make them withstand long mileage driving and allows easy and reliable calibration. When installing microphone holders and cables, it is important not to introduce any rattling noise and to ensure that the installation of microphones at the driver's ear is done safely.

SELECTING THE RIGHT MICROPHONE

Brake dynamometer squeal noise test
The SAE J2521 standard recommends a ½" free-field microphone with windshield. The microphone should be able to handle temperature variations and brake dust. For noise source identification, use intensity microphones or array microphones configured according to the relevant equipment needs.

The 146AE ½" CCP Free-field Microphone Set can be used when testing brake noise on the dynamometer. The ruggedized protection grid and overall construction of the 146AE will help the microphone overcome the challenges in temperature variation and brake dust encountered when measuring brake noise on the dynamometer.

The AM0069 Spherical Windscreen for ½" Microphones can be mounted on the 146AE free-field microphone in situations where the microphone is exposed to wind flow.

The AL0004 Small, Lightweight Microphone Tripod can be used in combination with the AL0008 ½" Microphone Holder or the RA0093 ½" 5-click Microphone Holder to place the different microphone positions around both chassis and shaft dynamometers. The AL0008 also requires the use of the AL0005 Swivel Head.

The 42AG Multifunction Sound Calibrator can be used for daily sensitivity verification with the included adapter.

RECOMMENDED MICROPHONES AND CALIBRATORS

Brake Dynamometer Squeal Noise Test		
Test cell	**146AE**	½" CCP Free-field Microphone Set
	AL0004	Small, Lightweight Microphone Tripod
	AL0005	Swivel Head
	AL0008	½" Microphone Holder, POM
	AM0069	Spherical Windscreen for ½" Microphones
	RA0093	½" 5-click Microphone Holder, Stainless Steel
	RA0504	GoPro Adapter
Calibration	**42AG**	Multifunction Sound Calibrator, Class 1

Wheelhouse test
The recommended microphone inside the vehicle is a ½" free-field or random-incidence microphone as defined by company standards. For the wheelhouse measurements, there is a need for an extremely ruggedized measurement microphone with good performance. It should be able to endure long-term measurements at extremely tough

conditions, different environmental conditions and exposure to dust, water, salt and gravel.

Our 147EB CCP X-Rugged Microphone Set is the first obvious choice with its three layers of protection against water, dust and oil specially designed to be mounted inside the wheelhouse for long-term brake noise measurements very close to the source (even in the toughest environmental conditions). When mounted in the wheelhouse, the 147EB needs to be installed with watertight cables like the AA0121 5 m Waterproof BNC-BNC Cable to prevent the loss of valuable data due to water-damaged equipment.

The 146AE microphone set is another possibility. For brake noise measurements in the vehicle, the 146AE can also be used as a random-incidence microphone with the help of the RA0357 Random-incidence Corrector for 146AE. The RA0504 GoPro Adapter will help to ensure quick and easy positioning of the 146AE microphone inside the car. The adaptor is also applicable for mounting of any other ½" measurement microphone and can be used on the wide variety of GoPro tripods, mounts and clamps available on the market.

The possibility of easy verification of calibration will minimize test time and enable repeatable measurement results. The 42AG calibrator can be used for daily sensitivity verification.

RECOMMENDED MICROPHONES AND CALIBRATORS

Wheelhouse Test		
Wheel-house	**147EB**	CCP X-Rugged Microphone Set
	AA0121	5 m Waterproof BNC-BNC Cable (other lengths available)
In vehicle	**146AE**	½" CCP Free-field Microphone Set
	RA0357	Random-incidence Corrector for 146AE
	RA0504	GoPro Adapter
Calibration	**42AG**	Multifunction Sound Calibrator, Class 1

Troubleshooting

When troubleshooting, measuring or locating sound sources using techniques like beamforming, near-field acoustic holography (NAH) or acoustic cameras, array microphones are a viable option. This could include microphones like the 40PH and the 40PL CCP Free-field Array Microphones which are cost-effective, free-

field acoustic sensors designed to be mounted on large or small array modules like the PR0002 Array Module for analysis of sound fields. The 42AG calibrator can be used for calibration of array microphones as well.

A sound intensity probe like the 50GI-RP CCP Rugged Intensity Probe can also be used for sound source location, especially useful when testing in noisy environments and for areas difficult to access with microphone arrays. The 51AB Phase Calibrator according to IEC 61043 can be used for level and phase calibration of the intensity probes.

RECOMMENDED MICROPHONES AND CALIBRATORS

Troubleshooting		
Test cell	**40PH**	CCP Free-field Array Microphone
	40PL	CCP Free-field Array Microphone, High Pressure
	50GI-RP	CCP Rugged Intensity Probe
	R0002	Array Module
Calibration	**42AG**	Multifunction Sound Calibrator, Class 1
	51AB	Phase Calibrator according to IEC 61043

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LI0225-05-2021

About GRAS Sound & Vibration

GRAS is a worldwide leader in the sound and vibration industry. We develop and manufacture state-of-the-art measurement microphones to industries where acoustic measuring accuracy and repeatability is of utmost importance in R&D, QA and production. This includes applications and solutions for customers within the fields of aerospace, automotive, audiology, and consumer electronics. GRAS microphones are designed to live up to the high quality, durability and accuracy that our customers have come to expect and trust.

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