

KEYS TO SUCCESSFUL ENGINE NVH TESTING



ABSTRACT

Many factors are driving the need for automotive manufacturers to implement more stringent noise, vibration and harshness (NVH) testing. Consumer tolerance for any perceived noise is minimal. The slightest unexpected engine noise can lead to a costly warranty claim. Other factors such as longer warranty periods and increasing engine complexity compound the NVH challenge for manufacturers. These manufacturers must earn customer satisfaction and minimize the risk of a large warranty exposure by implementing systems to drastically reduce engine NVH defects.

This document discusses some of the basics of engine NVH testing in a production environment.

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KEYS TO SUCCESSFUL ENGINE NVH TESTING

1. DEFINITION OF ENGINE NVH TESTING

Noise, vibration and harshness (NVH) is one of the sensory inputs from a vehicle to the driver. Noise is audible, vibration can be felt, and harshness refers to the qualitative assessment of noise and vibration. Noise consists of any unwanted sound. Not all sounds coming from the engine are bad, for example a pleasing humming sound from the engine of a sports car can be an attractive feature.

2. DRIVING FACTORS FOR ENGINE NVH TESTING

There are 3 major forces driving the demand for NVH testing of engines during manufacturing;

Increased complexity of powertrain technology has lead to engines that generate more NVH

Advances in engine and powertrain technology such as turbo-chargers, light weight materials and complex intake systems can all contribute to potentially noisier engines.

Decreased noise levels in vehicle interiors magnify any engine NVH

Over the past three decades, vehicle manufacturers have made significant progress in reducing the noise levels inside a vehicle through means such as placing dampening materials inside door panels and increasing the thickness of window glass. These enhancements have resulted in drivers expecting a much quieter ride, not only in higher-end luxury vehicles but in the lower-end entry level as well.

Expanded warranty coverage leaves engine manufacturers exposed to claims for a longer period of time

Any unexpected noise or vibration emanating from the engine such as buzzes, squeaks or rattles can have an adverse effect on the customer's perception of the engine and the vehicle in general. The noise or vibration may not influence the actual engine performance but the customer may still perceive the engine to be somehow defective. Ultimately the customer may make a warranty claim. In most cases these claims are settled in order to maintain customer satisfaction. These types of warranty claims contribute to the \$22.6B in warranty costs that vehicle manufacturers¹ face on an annual basis.

An additional benefit of engine NVH testing is that it can find certain defects that may not be detected by traditional testing methodologies. For example, engine timing problems may not be caught during upstream testing and although timing problems do not typically exhibit noise they still can be caught with engine NVH testing (see "Order Spectral Analysis" on p.3 for more details on how this can be done).

Noise and vibration measurements have been used for a long time as a quality appraisal tool on the engine production line. The challenge for engine manufacturers is to understand the level of noise, vibration and harshness that is within consumer tolerance and expectations then translate this subjective limit to an objective measurement for testing purposes. In the past, most engine manufacturers have relied on the experience of their production personnel to identify defective engines based on the sound that they emit during hot test. The speed, accuracy and objective nature of an instrument system is far superior to even

¹ AMR Research. "Today's Vehicle Quality Improvements Lie Within Yesterday's Warranty Issues". February 12, 2004.

the most trained ear. Emerging NVH test systems are capable of the measurement, analysis, classification and diagnosis of complex sensory inputs from engines to provide accurate and real-time quality judgements.

3. WEAKNESSES OF TRADITIONAL NVH TESTING MECHANISMS

The subjective nature of production personnel testing for NVH and the use of inappropriate test measurement techniques means that defective engines may pass to the vehicle operations plant or worse they may make it to the end customer and result in costly warranty claims. Ineffective testing techniques may also hamper productivity when good engines are misdiagnosed and sent to the repair bay.

Some test systems lack comprehensive classification systems and/or communicative diagnosis capability. The diagnosis element of a classification system can be used to facilitate efficient repair bay management, root cause traceability, and continuous improvement processes. Some faults may only be apparent at certain engine speeds. To detect these defects the engine test cycle must be conducted in a comprehensive way, using careful speed control and the capture of a large amount of data. This data may be difficult to manipulate, and require a lengthy analysis process.

Another common weakness of traditional engine NVH testing is that the same systems used for testing in the laboratory during the engine design stage are being used in the production environment. These systems are not robust or built for high-volume operation and result in continuous failures when deployed in manufacturing environments. Laboratory type systems are also built for engineers and do not have the ease of use required for plant floor operators. When selecting an engine NVH system for high-volume engine production, it is imperative for the system to be robust, production floor ready and easy to use.

4. NVH TESTING TECHNIQUES

NVH test systems consist of sensors, a measurement system, a classification system and the result – a pass or fail judgement.

Sensors

There are two types of sensors – contact and non-contact. Sensor selection depends on cost constraints, the environment where testing will be done and the specific defects that need to be detected.

Typical *non-contact* sensors such as a microphone or laser velocimeter are not connected to the product under test. Although they may have advantages for certain applications, they may not be adequate in some production environments. For example, a microphone is not industrially robust and requires frequent calibration. Background noise can also cause inconsistencies in results.

A *contact* sensor such as a piezoelectric accelerometer is attached to the engine, and has certain advantages such as relative immunity from background noise, and robustness. Contact sensors also tend to be less expensive than non-contact sensors.

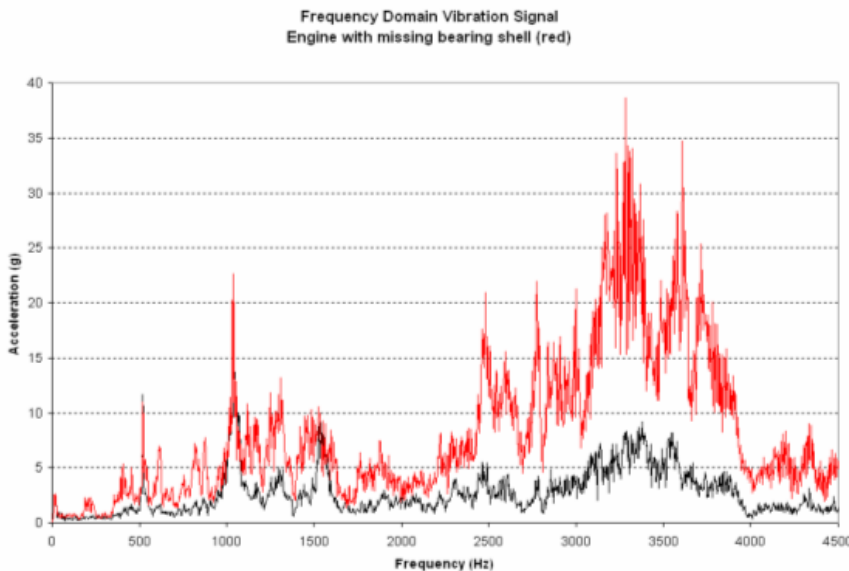
Measurement System

The measurement system takes the signal from the sensors and manipulates it into meaningful data. The noise or vibration signature of the engine can be extracted, and features from the signature can be analyzed. The signature may be processed from time domain to frequency domain by use of a Fast Fourier Transform (FFT). Additional useful information is gained if the time domain is converted to angle domain by using a crank position sensor, providing an order spectral analysis.

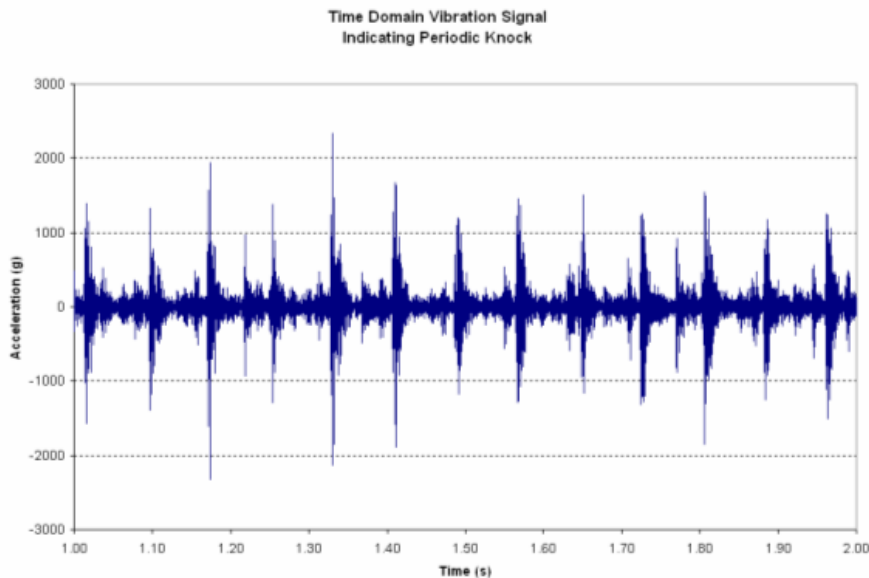
Various processing techniques should be used:

- **Time Domain Analysis** is particularly useful for transient event detection. Time domain analysis is optimal when looking for defects that would cause knocks and clicks on a mechanism at a known time during the test cycle. An example of this scenario would be testing the starter motor assembly function, which always happens at the same time during the test.
- **Frequency Domain Analysis** is the most common tool used to detect and diagnose defects. The FFT analysis is used for analysis of signatures with a repetitive pattern, and can also be used to detect the excitation of a natural frequency. Frequency domain analysis is a powerful tool for the diagnosis of engine defects such as faulty fuel systems, defective ignition systems and assembly faults such as missing bearings. These defects are generally associated with low frequency excitations, and are relatively immune to changes in test speed.
- **Order Spectral Analysis** is used to analyze defects relating to the speed of the engine. This technique helps to resolve the problem of accurate tracking of higher frequency content and repetitive signals such as noisy camshafts and gear drives that could be lost or misread by slight changes in running speed. The “order tracked” or “order normalised” signature may be used for other analysis associated with high frequency excitations dependant upon the engine configuration.

The following diagrams are examples of engine test waveforms where classification can be used to diagnose the source of the defect.



A missing bearing shell will result in knocking of the cylinder block during each revolution of the crank shaft. The black waveform indicates the response measured on the engine block caused by the rotating crank, while the red waveform represents the increased response from the structure created by the knocking.



Excessive valve clearance will result in a periodic knock. Because the knock will occur during each revolution of the cam shaft, the spikes indicating the defect correlate to the cam shaft speed. The location of the deviance from a normal waveform helps diagnose the cause of the test failure.

Classification

The above processing techniques may be logically attributable to specific engine features. By attributing the optimal processing technique to given engine feature, an excitation map can be defined to classify defects. The classification system consists of a method of assessing signatures into “normal” and “abnormal” categories. This evaluation must be made virtually in real time during production and provide the engineer some form of diagnosis if a signature is determined to be abnormal. The classification system can be programmed using engineering standards, results from road tests or even by converting subjective listening jury measurements into an objective measure to define pass / fail criteria. An advanced engine NVH test system should have the ability to statistically ‘learn’ acceptable threshold levels by capturing the knowledge of an expert panel and transforming this into test limits. In other words, the test system should be able to ‘learn’ what experts consider to be good or bad engine NVH and pass or fail engines accordingly. When an engine is failed, the system should provide a diagnosis of the reason for the failure. This classification will reduce the required repair time for the failed part.

Result

The pass/fail result should be passed to a birth history system for storage and further analysis or to a repair bay manager to facilitate effective repairs. Results can be saved as simple Pass/Fail indicators or as a full signature.

5. OPTIMISING TEST SYSTEM SETTINGS

Armed with valuable understanding of the manufacturing process and comprehensive test results, manufacturers will be equipped with the insight they need to optimize their NVH test system. The understanding of defect root cause may lead to upstream testing to isolate defects as early in production as possible. For example, if Pareto analysis reveals that missing bearings are the most common defect detected by engine NVH testing at hot test, then a process change can be introduced upstream to eliminate the defect from occurring and a new test can be implemented to catch the problem before it reaches hot test. Identifying engine defects or process abnormalities at the earliest possible production stage can result in substantial savings (please see Sciometric’s “In-Process Test Blueprint of Engine Manufacturing” for more details).

Test optimisation can:

- Reduce test cycle time
- Reduce false rejects
- Reduce test process failures
- Maximise sensor life expectancy
- Exploit advanced processing techniques for other non-NVH defects

An effective engine NVH test system should come with an integrated SPC (Statistical Process Control) module to allow optimisation of the test system by statistical updating of the classification system. There will be natural changes to the test parameters during a production run, and these may be tracked and monitored using statistical analysis. This mechanism may be used to facilitate a continuous improvement process.

6. EMERGING NVH TECHNOLOGY

Recent advances in waveform analysis allow both time and frequency domain data to be displayed and analysed in an efficient manner. This is useful for detecting defects such as, sticking wastegates and problems with other control devices. Creation of proprietary algorithms for specific defect mapping is possible given the range of engineering software available to the NVH engineer. Complex mathematical manipulation of waveforms can provide engineers with enhanced insight into process and quality weaknesses.

The decreasing cost of sensors such as laser velocimeters is encouraging the use of non-contact sensor arrays for engine NVH measurement. Non-contact sensors have the advantage of providing versatility and robustness, while being suitable for both production and laboratory use. Engineers can use a laboratory measurement sensor in a production environment, saving time in the feasibility and pilot phase of deploying an engine NVH solution.

7. PRODUCT QUALITY MANAGEMENT

A comprehensive engine NVH testing solution should include a system to archive test results by serial number and store the actual waveforms measured during testing. Storing complete waveforms equips the manufacturer with actionable information. For example, if required, specific engines could be isolated for recall without having to issue a costly and damaging general recall. Defects and deficiencies can also be traced to the level of individual stations, operators, shifts, and components. This capability facilitates rapid identification and resolution of process and product problems before significant costs for repair and rework are incurred. Finally, storing complete waveforms allows the engine manufacturer to quantitatively demonstrate to vehicle operations plants their commitment to the quality process, ensuring that engines have been manufactured and tested according to specifications.

8. KEYS TO SUCCESSFUL NVH TESTING

The keys to successful NVH testing are process, people and practise! The process of testing engines for their noise, vibration and harshness can be split into phases;

- ***Test requirement planning, including costs, timing and responsibilities:*** The planning phase should include cost and timing studies, with good prior knowledge of the engine design, and potential defects. Reference to the engine manufacturing failure mode cause and effect analysis will facilitate the planning of measurement verification.
- ***Feasibility and test experiment verification:*** The feasibility study should make careful study of critical test aspects such as sensor selection and utilization, signal processing and analysis routines.
- ***Pre-production line validation:*** The pilot phase and the feasibility study may in certain applications be made concurrently with the feasibility study. This phase will validate the measurement process and the classification system, allowing any issues to be resolved prior to implementation on the live line.
- ***Production testing:*** Should provide accurate and consistent test results and facilitate continuous process and quality improvement.

9. BENEFITS OF ACCURATE ENGINE NVH TESTING

Effective engine NVH testing will allow manufacturers to:

- Reduce costs by detecting NVH issues during production where repairs are less complex and less costly than when discovered by vehicle operations, dealers or end customers.
- Minimize the impact of quality spills by isolating specific units with specific NVH problems.
- Improve their production process using root cause understanding.
- Improve the sound quality of their engines.
- Improve customer satisfaction and industry reputation.



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For more information on how you can catch more engine NVH defects and improve your engine quality call 1-877-581-0112 or email nvh@sciometric.com.

About Sciometric® Instruments

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