

Optimization of Test Parameters and Analysis Methods for Fuel Tank Slosh Noise

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ABSTRACT

As the interior sound levels in cabin compartments of passenger vehicles continue to get quieter, noises from various sources which previously were not objectionable can become an issue. One such source is the “slosh noise” from liquid movement within fuel tanks.

Vehicle manufacturers, responding to the phenomena, have turned to their suppliers and worked with them to establish robust test and analysis methods to characterize the NVH performance of their fuel storage and delivery systems. Test facilities have recently made great advancements in the capability to measure and characterize “fuel slosh noise” in tanks. However, the industry today lacks standardized procedures to apply to the issue, including defining test parameters and analysis methods (both of which are complex because of the time-domain nature of slosh events).

The purpose of this paper is to identify the current capabilities and discuss optimal parameters of testing component-level fuel slosh noise, and to explore the merits of various NVH analysis methods that can be used to quantify slosh noise.

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INTRODUCTION

The main variables to consider in designing a repeatable and accurate component level test are the test methodology and data processing parameters. These tests are performed at component level not only because of supplier development and target adherence, but also because the data from in-vehicle testing tends to exhibit higher variability in the results and is much less efficient.

A test facility for fuel tank slosh noise should allow not only representative noise and vibration measurement capability, but also visual feedback of how the liquid moves within the test sample. This is critical information for the tank supplier so that they might identify countermeasures to employ, such as planar baffles or inserts to eliminate the wave's propagation.

The test facility should also account for variables that may affect the liquid movement and subsequently noise and vibration response. For example, the acceleration and deceleration rates of the fuel tank should be adjustable and carefully monitored.

The time-domain nature of fuel slosh events creates inherent complications in the processing and presentation of

data. There are many methods of quantifying transient events, but it is necessary to identify the most appropriate for the application of fuel slosh noise. To date, little industry-wide documentation or processing methodology has been established, although many suppliers and OEM's have accepted practices that have been developed internally within their own organizations.

The contents of this paper shall discuss the history and current state of facilities for fuel slosh noise testing as well as the parameters used to replicate in-vehicle testing. Various analysis methods will also be reviewed for their feasibility and potential benefits.

Testing Facilities and Parameters

In the early stages of performing Slosh Noise tests at Testing Services Group, LLC (“TSG”), the test stand consisted of a fifteen foot tower and set of rails upon which a wheeled platform travelled. The platform was pulled by a chain drive belt, which was in turn connected to a counterweight. As the counterweight was raised up through the tower, it “loaded” the platform to its' starting position (see

Figure 1 below). This system was installed in an area of open floor space within the existing laboratory.



Figure 1. Original Fuel Slosh Test Facility

A hydraulic disc braking system was utilized to hold the platform in place after it was moved to its starting position. As soon as the brake was released, the counterweight dropped and the platform was accelerated by the falling counterweight. By employing a braking system that could be controlled remotely, the rate of acceleration, the terminal velocity of the platform and the deceleration rate could be controlled. This method was crude and lack consistency.

This original configuration of the test stand at TSG resulted in a time-consuming and labor-intensive test which brought with it many challenges, including the repeatability of test profiles. The design of the system did not provide for close control of the motion parameters, and therefore substantial time was spent making multiple test runs of the same condition.

Compounding the situation, as the combined mass of the platform and tank system under test changed with varying fill conditions and different fuel tanks, it was necessary to also readjust settings on the test stand braking system. A lot of “trial and error” was required with each new test condition in order to match the target profile, consuming valuable resource time.

Because of where the test stand was installed, background noise in the open area of the laboratory was also problematic. Test runs were frequently invalidated because of extraneous noise from other activities taking place concurrently in the immediate vicinity. Conversely, the slosh noise test disrupted other testing activities by making it necessary to temporarily interrupt them. This created a very inefficient use of facilities and labor.

Redesign of fuel slosh test facility

As interest from vehicle OEM's and suppliers in the test grew, it became apparent that a better means of controlling the velocity profile was needed. At the same time, the decision was made to relocate the activity to a more isolated location away from other tests which were interrupted by fuel slosh testing. In order to minimize ambient sound and clearly identify slosh noise, TSG constructed a hemi-anechoic room for the terminus of the travelling platform.

An engineering design team was formed at TSG and charged with developing the performance parameters for the new system. Over the course of several weeks and with consultation from various suppliers, the following set of target parameters was established:

1. Accelerate a 250 kg payload from a resting position to a velocity of 2.5 m/s (± 0.1 m/s) in less than 2.0 seconds.
2. Bring a 250 kg payload moving at a velocity of 2.5 m/s (± 0.1 m/s) to a complete stop in 0.5 second or less.
3. Total length of track rails 7.0 meters (± 0.2 m)
4. A software control system that provides the operator with the ability to easily create “custom accel/decel” profiles that fall within the constraints of items 1 - 3 above.
5. The “sled” shall be an aluminum plate with overall dimensions of 1.2m $\times$ 1.2m and incorporate integral tie-down points to be used to secure the test specimen.
6. The system, when not in operation, shall not emit any noise energy above the background level in the unoccupied hemi-anechoic termination cell.
7. The system software shall record velocity versus time for every test run with a unique identification.
8. The system shall be capable of operating and performing to the preceding standards within a temperature range of 15C to 30C (± 2 C), in relative humidity levels up to eighty percent (80%) (± 5 %).

The new system was installed and has been a resounding success in nearly every respect. All of the performance parameters established by the design team were achieved and the result is a reliable system that has made it possible to perform dozens of valid test runs in a single day. The repeatability and consistency of the new system are a great improvement over the original. Figure 2 shows the velocity output from the test sled during 4 repeats from the old and new test facilities. Not only is the profile of the velocity greatly improved, but the peak velocity went from a variance of 5% to 0%.

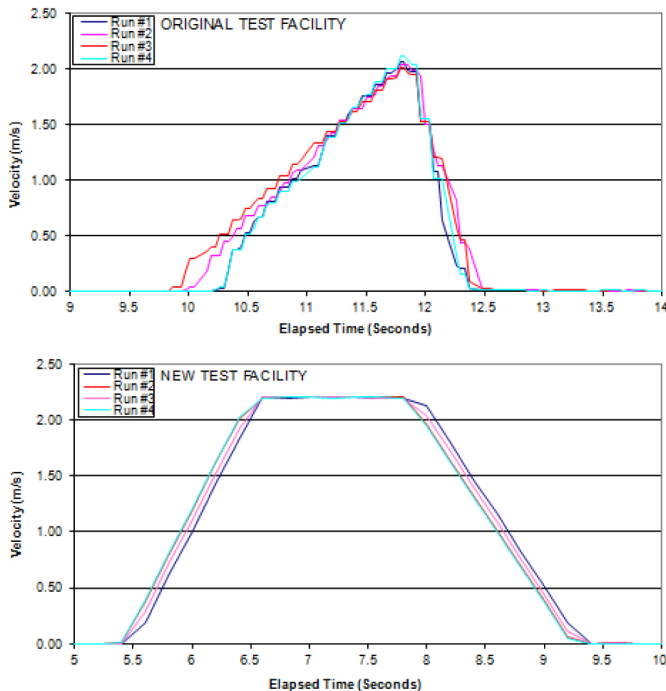


Figure 2. Velocity Profile from old (top) and new (bottom) test facilities - 4 repeats for each.

The new test system operates in a dedicated suite that includes the control room with the drive system and rails (Figure 3), the hemi-anechoic test cell where the platform comes to its stopping point and the data recorded, and an isolated observation room equipped with four simultaneous video feeds and stereo audio feed - allowing clients the ability to safely see and hear the testing being conducted.



Figure 3. Improved Facility - Rails & Sled

A PC-based drivetrain control system allows the engineer to program the desired motion profile for each test. The new “sled” is an aluminum plate, 1.2m × 1.2m, featuring tie down points in order to secure the test part. At the end of the track, the test bed stops inside a hemi-anechoic chamber (Figure 4). This room, when empty, has an overall A-weighted sound pressure level of less than 25 dBA. This provides a sufficient noise floor for the measurement of slosh noise.



Figure 4. Termination Test Cell

The software-control system provides velocity versus time data for each run that is stored for future retrieval. At the customer's request, video imagery from up to four different cameras filming simultaneously can be provided in the event that clear fuel tanks are used for development. These videos can be stored digitally and later burned to a DVD for review. Microphones are placed in the hemi-anechoic chamber to capture the sloshing noise occurring inside the fuel tank system as it comes to a rest. The microphone and video signals can be seen and heard in real time in the observation room which is equipped with a sixty inch plasma flat panel display and stereo speakers (Figure 5). Accelerometers can be mounted on the tank surface to record vibration levels in a parallel NVH acquisition system. These signals can be correlated to the noise data.

The PC-based system features user-programmable set point controls. It is designed to accelerate a 250 kg load from a resting position to a velocity of 2.5 m/s (+/- 0.1 m/s) in less than 2.0 seconds. Additionally, the system is designed to bring this load to a full stop in 0.5 seconds or less. The total travel length of the system is approximately 6 meters. The system controls allow the user to enter not only the acceleration/deceleration rate and the velocity, but also the stopping point of the sled inside the hemi-anechoic room. The variability of the stopping point is less than 1 mm. A wide variety of set points can be used to run the test, which allows