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Design and Construction of a Four-Wheel Drive Noise and Vibration Chassis Dynamometer

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ABSTRACT

As vehicle development cycles become more condensed, it is necessary to perform testing as expeditiously as possible. One way to accomplish this is to perform tests previously performed over the road in a controlled laboratory environment. The Noise and Vibration engineering consulting group, a division of Roush Industries, Inc. has recently commissioned a four-wheel drive chassis dynamometer located in a hemi-anechoic test cell in order to provide manufacturers and tier suppliers a faster alternative to over the road noise and vibration vehicle level testing.

As a consulting company that supports a wide variety of vehicle development needs, many unique challenges had to be overcome throughout the design and construction process. This paper identifies these challenges and presents a methodology for designing and constructing a facility to meet the broad purpose of supporting the noise and vibration testing requirements of the automotive industry.

INTRODUCTION

The noise and vibration engineering consulting group, a division of Roush Industries, Inc. has recently added a four-wheel drive NVH chassis dynamometer to their laboratories in Livonia, MI.

Balancing performance requirements, financial targets and timing goals can be a challenging task; though, through focusing efforts and encouraging cooperation with and between contractors, unique solutions can be identified.

A noise and vibration testing facility is unique in that every system must be considered not only for its own purpose, but also for the potential effects one system can have on the noise and vibration characteristics of the facility as a whole. While contractors are typically experts in their field, clear communication of the noise and vibration ramifications their system can have on the facility as a whole is imperative to ensure noise and vibration targets are met. Working with contractors throughout the design and construction phases ensures that the end result will not only meet the present design criteria, but will also be viable as vehicle testing and noise and vibration testing strategies change as the facility ages.

DESIGN CRITERIA

An imperative first step to planning a new facility or an addition to a current facility is to clearly define the purpose and the goals of how the facility will be utilized upon completion. These requirements should remain fluid throughout construction, increasing the useful life of the facility. However, while the goals may change, having a clear understanding of how the facility will be used, along with enough forethought to accommodate both anticipated and unanticipated changes, will allow everyone to work together throughout the design and construction process. Having everyone on the same page also decreases the decision time when the team is presented with design and construction options.

One of the first steps toward planning this facility was to decide on the best location. A location analysis was performed comparing the advantages and disadvantages of available location options. Once the location was identified, the team worked with an architect and facility planner in order to determine if construction of the chassis dynamometer cell inside an existing building would be feasible and / or preferential to adding on to an existing facility. The decision was made that the best option would be to add a pre-engineered metal building to an existing structure, reducing shoring costs and facility down time during construction and providing more design flexibility.

Another early consideration was to define how the facility would be used, both internally and by users outside the company. Significant effort was put into understanding the current needs of our customers and attempting to anticipate future needs. This was done primarily through conversing with as many potential facility users as possible, as well as current users of similar facilities. Having a deep understanding of current facility shortfalls and user challenges allowed the design team to consider challenges up-front and reduce the need to make changes to the facility after construction had begun in order to accommodate unforeseen circumstances. To satisfy this requirement, a master list of general requirements and performance goals was generated and was used and updated throughout duration of the project. This list was distributed to everyone, internal and external, who was involved. As suppliers presented different options, the costs were weighed against the master requirement list and if the options were not identified as a requirement, the option was declined. This allowed the team to maintain a focused budget and served as a tool to focus expenses only to activities that would support facility requirements. Additionally, this allowed the team to plan for future changes early to reduce future expenses incurred when facility upgrades become necessary. These requirements were divided into the four workspaces the new facility would encompass. Each of these workspaces is listed below and discussed in further detail.

TEST CHAMBER

The focus of this facility was placed on the test chamber. Acoustic and HVAC performance during testing is critical for testing and operation. Vehicle / test setup and teardown are also critical in order to increase operational efficiency. Stringent acoustic and cooling requirements were placed on the test chamber early in the design process and were primary considerations throughout the entire construction process. Table 1 contains a small subset of the design criteria relating to the dynamometer system and test chamber.

Table 1 – Specifications Excerpt

Dynamometer System	
Operating Sound Level, 1m above, 1.5m behind	< 50 dB(A) at 60 MPH
Restraint System	Basic Straps attached to chamber floor at corners
Road Shell Provisions	10° holes for fish-line
Impact Bar Provisions	90° tapped ¼ x 20
Test Chamber	
Cut off Frequency	100 Hz
Background Noise Level (non-operating)	< 25 dB(A) or NC 20
Penetrations into Chamber	2 x 4" sleeves with caps
Lighting Level	Min – 50 foot candles @ 30" above floor

To achieve these criteria the test chamber was isolated from the surrounding building utilizing an independent foundation and no structural connections. Ducts were acoustically treated and duct silencers were utilized to prevent noise contamination. To achieve TL targets, the exterior walls of the chamber were constructed using sand filled concrete blocks. Absorption targets were achieved by installing 3' deep acoustic wedges on the interior walls. To ensure sufficient cooling capacity without introducing flow noise, the HVAC and Acoustic teams worked closely to design a system with ducts appropriately sized to allow sufficient delivery of air volume while reducing the flow rate to reduce noise contamination within the chamber. Flow controls were also added both to the inlet air entering the chamber and to the vehicle exhaust removal system in order to allow flow to be increased or decreased as required by a specific test specimen. This control allows sufficient cooling flow and exhaust elimination for extreme cases, while eliminating flow noise generated by the systems during less extreme testing.

Additional acoustic considerations of the chamber include the use of CCTV cameras to allow the dynamometer operator to view the test without the need of a window between the test chamber and control room. Eliminating a viewing window reduces the potential for contamination of acoustic measurements as a result of noise reflection from the source.

It was also recognized that the ability to make component changes to the vehicle in the cell, without changing vehicle retention, allows A to B comparison tests to be performed more accurately by eliminating installation variables. To accommodate this requirement, several features were added to the test chamber, such as: sufficient lighting, removable center floor (allowing access to the underside of the vehicle), and compressed air inside the chamber. These features allow spot cooling capabilities using vortex coolers on vehicle components that may require additional cooling during or between tests.

CONTROL ROOM

A significant amount of time was spent understanding the activities that would take place in the control room, and design specifications were added to facilitate these activities. Specific attention was given to desk layout to promote communication between the dynamometer operator and the personnel involved in data acquisition. Other requirements revolved around controlling HVAC parameters, the ability to view the vehicle during testing, and the ability to comfortably house several people who may be involved in a test. Internet connectivity was included, along with a dedicated work space and some storage space to accommodate people working away from their primary place of employment. The result is a control room that is quiet enough to listen to data and has ample desk space to allow several people to work at once, collectively or independently.

BASEMENT – ROLLER AND MOTOR ROOMS

The two primary goals for the basement were 1) decrease the amount of noise penetrating the floor into the control room and test chamber; and 2) have enough room for easy access to the underside of the vehicle.

The first step toward the introduction of noise from the basement into the test chamber was to install the primary noise sources, which are the dynamometer motors and hydrostatic lubrication pumps, in a separate room from the dynamometer rollers.

Recognizing the amount of noise generated by the motors and blowers, several measures were implemented to reduce the amount of noise entering the roller room. The motor room and roller room are separated by poured concrete wall. The motor to roller shaft pass throughs are acoustically treated to eliminate noise penetration through the wall. The walls of the roller room were also acoustically treated to increase the acoustic absorption of the space and reduce noise penetration into the test chamber.

To isolate machine vibration, both the dynamometer motors and rollers are mounted on inertia masses that have a decoupling material installed around the mass, isolating the masses from the earth and the surrounding structure. To determine the amount of isolation required to decouple the masses, seismic measurements were made prior to the start of construction. Upon completion of the seismic measurements, it was determined that a decoupling foam-rubber would be sufficient. This provided a cost saving opportunity, as this method is much less costly than mechanical spring or air bag isolation methods.

PROJECT COORDINATION

Successful competition of this project required tremendous coordination and cooperation from several teams of people. The primary team at Roush consisted of four people. The majority of the construction was performed by a contractor, utilizing smaller teams of sub-contractors. The hemi-anechoic test chamber and HVAC system were performed by two additional teams. One key to success was keeping everyone involved appraised of the most current plans, challenges and solutions. Roush worked with contractors and had contractors work together early in the design process and often throughout the construction phase to ensure system integration, performance, and construction efficiency. This approach allowed the individual companies to coordinate efforts in order to reduce construction time and complexity. Each system within the facility was integrated to ensure both operational and acoustic performance. Providing opportunities for everyone involved to work and plan together proved to be extremely beneficial both during the design and construction phases.

Each contractor made at least one person available to attend weekly update meetings. This ensured that design changes or problems encountered during construction could be communicated to the entire team, and as changes were made, negative consequences downstream could be avoided. Additionally, this allowed a forum for people to present ideas on how to approach challenging situations and propose solutions.

CONCLUSION

By taking a team approach to the design and construction of a unique facility and involving everyone early in the process, Roush was able to achieve facility completion in less than seven months, which many of the contractors had initially thought impossible. In addition to meeting timing targets, the performance goals of the facility identified in Table 1 were all either met or exceeded. Figure 1 is a subset of the acoustic certification of the test chamber showing that the NC 20 target was well exceeded with nearly an NC 10 rating. The frequency cutoff target of 100 Hz was also exceeded, with an actual frequency cutoff of 80 Hz. A subset of these data is included as Figure 2.

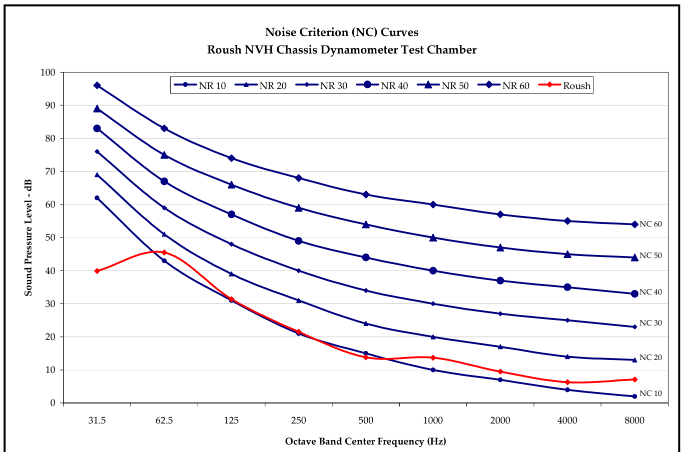

Figure 1

The NVH chassis dynamometer at Roush's facility is a facility that can be used for many automotive NVH tests. The four-wheel drive dynamometer is rated at 300 horse power per axle, with independent motors and controls for the front and rear axles. The wheelbase is adjustable from 79 to 170 inches (200 – 431 cm) and the rollers can support up to 6000 pounds (2721 kg) per axle. The ability to simulate road conditions as well as controls for speed and force make the system appropriate for testing nearly every vehicle system and accommodates gasoline, diesel, and hybrid drive systems.

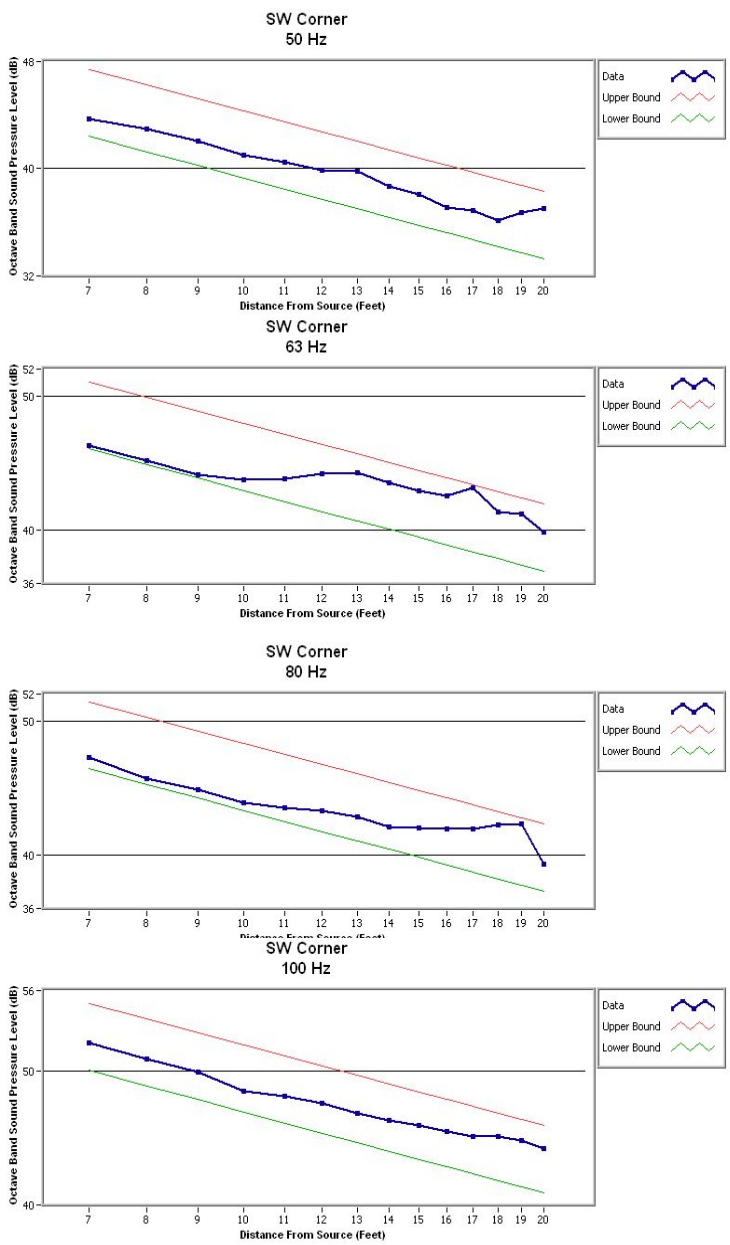

Figure 2 – Cut-Off Frequency Data Subset