

Road Load Simulation Testing for Improved Assessment of Powertrain Noise and Vibration

2011-01-0924

Published
04/12/2011Mark A. Gehringer and Eric J. Defenderfer
General Motors Company

Copyright © 2011 SAE International

doi:10.4271/2011-01-0924

ABSTRACT

This paper describes the development of an improved method for Noise and Vibration (N&V) chassis dynamometer testing using Road Load Simulation (RLS). Powertrain-induced noise and vibration testing on a chassis dynamometer has commonly been conducted using fixed loads or simplistic load versus speed approximations. Simple speed control and load control dyno test conditions are largely sufficient to provide representative noise and vibration performance assessment when the powertrain and its controls are insensitive to differences between the actual road load and the dyno load. With the recent growth of advanced engine control systems and hybrid powertrains, more representative road load simulation is required to ensure proper operation of the increasingly sophisticated and diverse powertrain and chassis control systems. Proper exercise of these control systems often determines the quality of the noise and vibration data. An example of this is provided for a full pedal acceleration test to measure interior sound pressure level. Noise data are acquired using a simple steady state speed control dyno test, and RLS real time run-up test. Sound pressure variation trends in the data from each test method are examined and the major source of variation is attributed to thermally-induced engine spark control changes caused by extended test duration under full engine load. Data from the RLS test method show greatly reduced run-to-run variation, when the number of consecutive test runs is limited to prevent thermally-induced spark retard. These results show that the improved RLS full pedal acceleration test more accurately represents the on-road performance, and results in a more robust powertrain noise assessment on the chassis dyno. Although the results presented include primarily sound pressure measurements, the advantages of the RLS dyno test method are also applicable to powertrain-induced vibration measurements.

INTRODUCTION

N&V CHASSIS DYNAMOMETER TESTING

The use of specialized N&V chassis dynamometer testing to measure powertrain-induced noise and vibration has become commonplace for both vehicle manufacturers and major suppliers. Dynamometer testing has several inherent advantages over on-road testing. On a dynamometer, the environmental factors such as ambient temperature and humidity can be controlled much more closely than on the road. In addition, the load and speed conditions applied to the vehicle can also be precisely controlled via the dynamometer rolls. Due to the controlled test conditions afforded by chassis dynamometer testing, it is generally expected that test data acquired on the dyno are more precise than on-road data. This expected higher precision of chassis dyno data does not always exist in practice, as will be shown. Significant run-to-run variation is sometimes observed in dynamometer testing, and one of the contributors to the observed N&V data variation is thermally-induced powertrain performance variation.

DYNAMOMETER CONTROL MODES

To understand the background of current N&V dynamometer testing practices, some dynamometer control history is useful. Prior to the implementation of modern digital dynamometer control systems, two basic control modes were often used to manually adjust the dynamometer conditions to gather data across a vehicle operating performance range of interest. These two control modes were often referred to as Speed Control and Load Control. Under Speed Control, the dynamometer speed was manually controlled either at a fixed speed or at a manually ramped speed for run-up or rundowns. Under this condition, the load was controlled by manipulating

the vehicle accelerator pedal. Under Load Control, the dynamometer was controlled to provide a fixed tractive force at the roll surface. Under this condition, the dynamometer roll speed was controlled by manipulating the vehicle accelerator pedal. For either control method, the accelerator pedal was generally manipulated using a remote electromechanical actuator controller or a human operator in the vehicle. Using these two simple control modes, it was possible to match any single point combination of vehicle load and speed that could be attained on the road, provided the load and speed were known at the operating point of interest. These manual dynamometer control methods were also capable of simulating limited dynamic conditions, provided only one of the key parameters, load or speed, was changing. While these simple control modes were useful to match static or slowly changing load-speed combinations, they did not have the ability to match the rapidly changing load-speed characteristics of typical on-road driving.

ROAD LOAD SIMULATION

With the arrival of modern digital dynamometer control systems came the ability to prescribe rapidly changing load-speed combinations under automatic control. This enables the use of mathematical functions to simulate the on-road load-speed relationship on the dyno. Specifically, many commercial dyno control systems have the ability to use a pre-programmed equation to control the load-speed relationship. The equation commonly used to specify the load-speed relationship is often referred to as the Road Load Simulation (RLS) equation, and is usually written in the following form:

$$F = A + Bv + Cv^2 + ma + mg \sin \alpha \quad (1)$$

The detailed development of the RLS equation will not be presented here, as it has been in common use for many years for emissions and fuel economy testing, and has been covered in detail by Chapin [1] and others. Using the RLS equation on a chassis dyno, it is possible to accurately simulate the major speed-dependent and independent forces acting on a vehicle on the road. The coefficient A represents the constant forces acting on the vehicle, most notably speed-independent tire rolling resistance. Coefficient B represents vehicle losses that vary linearly with speed, which have generally been attributed to bearings and other speed-dependent driveline losses. Coefficient C represents forces that vary quadratically with speed, including aerodynamic drag and speed-dependent tire losses. It should be noted that measurements of many vehicles have shown that coefficient B is usually very small. For this reason, coefficient B has often been taken as zero by many estimators using coast down techniques due to the fact that its small value is subject to measurement uncertainty. This was the basis of the two-parameter estimating assumption in SAE J1263 [2], as explained by Chapin[1].

The ma term in the RLS equation represents the inertial force due to acceleration of the vehicle mass. The final term $mg \sin \alpha$ represents the grade load.

Although RLS has been extensively used to simulate road load on emissions and fuel economy dynos, its use on N&V dynos has not been nearly as extensive, as reported by Jorro et al. [3]. Perhaps part of the reason for this is the persistence of N&V test procedures based on the previously common manual dyno control modes. Another reason for the continued usage of constant load and speed based N&V chassis dyno tests is that some engine and transmission dynamometer tests (including some N&V tests) are commonly conducted under constant load or constant speed, and the vehicle tests can then be easily related back to powertrain subsystem noise tests. As will be shown, the RLS dyno control mode has clear advantages for N&V testing when compared to older speed control and load control modes.

SUBJECTIVE ROAD TESTING

One of the important standard road test conditions for powertrain induced noise is full pedal acceleration. This test condition is commonly referred to as wide open throttle (WOT) acceleration, although this terminology is no longer always technically correct when referring to accelerator pedal driven tests because of electronic throttle control. Under this test condition, a vehicle is driven at a relatively slow steady state road speed, then the accelerator pedal is rapidly depressed to maximum position and the vehicle is allowed to accelerate freely until some target ending speed is reached. For automatic transmission vehicles, such as those tested for this study, normal shifts may be included, depending on the vehicle speed range of the test. One common subjective noise evaluation test is referred to as the "WOT 10-85 test" as it covers the speed range of 10 mph (16 kph) to 85 mph (137 kph) under full pedal acceleration.

Subjective evaluation of two vehicles studied under full pedal acceleration at the outset of this work indicated that one vehicle was noticeably quieter by approximately one to two subjective rating points on a ten point scale. However, when the interior sound pressure levels of the same two vehicles were measured objectively on a chassis dynamometer under full pedal conditions, the objective sound pressure level data did not indicate a significant difference. This apparent difference between the on-road subjective rating and the objective data from the chassis dynamometer prompted a detailed study of the dynamometer test method as it related to the vehicle noise performance.

FULL PEDAL ACCELERATION NOISE TEST IMPROVEMENT USING RLS

N&V DYNAMOMETER TESTING USING SPEED CONTROL

For automatic transmission equipped vehicles, one objective metric that has been used for full pedal powertrain noise on the chassis dyno is the A-weighted overall sound pressure level at the maximum engine speed reached just before the transmission upshifts out of “passing gear”. Passing gear is defined as the transmission gear that results when the accelerator is rapidly depressed on road, given a steady state entry speed of 70 kph. The chassis dynamometer test previously used to measure the noise under this operating condition was conducted using a dynamometer control mode equivalent to the manual speed control. To prepare for the measurement with the vehicle on the dyno, the operator manually established a roll speed of equivalent to the passing gear shift point speed observed on the road. With the dyno set to maintain that speed, the accelerator pedal was fully depressed and the interior sound pressure was measured at steady state speed and full pedal for 30 seconds. The average sound pressure level from the 30 second run was reported as a single number metric representing the passing gear shift point sound pressure level of the vehicle. Using this method, data was acquired for the two vehicles previously evaluated subjectively on road. For the subjective rating, a 10 point reference scale was used, with a louder rating corresponding to a lower score. A comparison of the subjective rating and dyno data is shown in [Table 1](#).

Table 1. On-Road Subjective Evaluation Ratings and Objective Dyno Data from the Steady State Passing Gear Shift Point Test

	Subjective Noise Rating	Dyno Test Overall SPL (dB relative to Vehicle A)
Vehicle A	8	0
Vehicle B	6	1

The data in [Table 1](#) show a measured difference of only 1 dB sound pressure level in the dyno test, yet Vehicle A was rated two subjective rating points quieter than Vehicle B. Experience has shown that a sound pressure difference of approximately 6 dB typically correlates with a subjective rating difference of two points for most subjective evaluators. As a follow up to the results in [Table 1](#), critical listening of binaural on-road sound recordings was conducted and objective sound pressure level measurements were made from on-road recordings. The results of these follow up studies confirmed that the on-road difference in sound pressure level at the passing gear shift point was significantly greater than what was being measured on the dyno. These

follow up measurements also established that Vehicle A produced nearly the same shift point sound pressure level on the dyno and the road, when tested using the steady state speed control dyno test. Vehicle B produced approximately 4 dB(A) higher overall sound pressure at the passing gear shift point when tested on-road as compared to the dyno when tested using steady state speed control.

Based on this information, additional dyno testing was conducted on Vehicle B. One obvious difference between the dyno operating condition being used to measure the passing gear shift point condition and the on-road condition was that the steady state speed control dyno measurement is the average of sound pressure level over a much longer time period (30 seconds) than the instantaneous shift point occurrence on road. This provided an important clue to the nature of the difference between the dyno and road measurements. With Vehicle B on the dyno, instantaneous overall sound pressure measurements were made in 0.5 second intervals during the 30-second run. This was repeated for 3 consecutive 30-second runs, as a 3-run test series is common practice to establish stable operating temperature of the vehicle and check repeatability. Data from these runs are shown in [Figure 1](#).

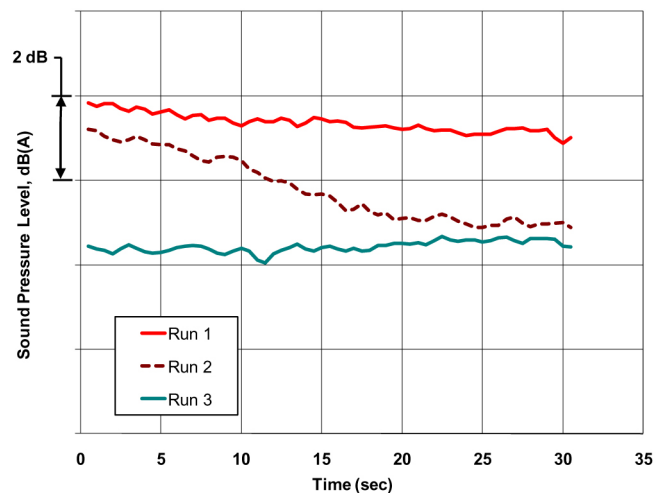


Figure 1. Vehicle B Steady State Speed Control Passing Gear Dyno Test Data for 3 Consecutive Runs

From [Figure 1](#) it is evident that the general trend is decreasing sound pressure level with time, with most of the change occurring over the course of the first two runs. From beginning to end of Run1, there is approximately 1 dB decrease, followed by a decrease of approximately 2 dB during Run 2, and a further decrease of about 0.5 dB between the end of Run 2 and Run 3. The total decrease in measured sound pressure level is approximately 3.5 dB over the 3 runs in this data set. Thus the steady state speed control dyno test clearly produced a decreasing trend in sound pressure level both within the 30-second run averaging time period of each