

FMVSS126 Electronic Stability Control Sine With Dwell Incomplete Vehicle Type 2 Analysis

2011-01-0956

Published
04/12/2011

Nathan Picot, Bryan Miller, Michael D. Rizzo and Thomas A. Klingler
General Motors Company

Copyright © 2011 SAE International

doi:[10.4271/2011-01-0956](https://doi.org/10.4271/2011-01-0956)

ABSTRACT

Incomplete vehicles are partially manufactured by an Original Equipment Manufacturer (OEM) and subsequently sold to and completed by a final-stage manufacturer. Section S8.8, Final-Stage Manufacturers and Alterers, of Federal Motor Vehicle Safety Standard (FMVSS) 126 states “Vehicle that are manufactured in two or more stages or that are altered (within the meaning of 49 CFR 567.7) after having been previously certified in accordance with Part 567 of this chapter, are not subject to the requirements of S8.1 through S8.5. Instead, all vehicles produced by these manufacturers on or after September 1, 2012, must comply with this standard.” The FMVSS 126 compliance of the completed vehicle can be certified in three ways: by the OEM provided no alterations are made to identified components (TYPE 1), conditionally by the OEM provided the final-stage manufacturer follows specific guidelines (TYPE 2), or by the final-stage manufacturer (TYPE 3). An engineering solution to provide TYPE 2 certification boundaries for FMVSS 126 compliance to final-stage manufacturers of incomplete vehicles was found using a combination of physical tests and Hardware-in-the-Loop (HIL) simulations. The requirements to comply with FMVSS 135 (Hydraulic Brake Systems) and FMVSS301 (Fuel System Integrity MPV's, Trucks, and Buses) were used to limit the scope of the investigation. FMVSS 301 compliance restricts the maximum unloaded vehicle curb weight, providing a vehicle weight boundary condition other than the maximum gross vehicle weight. FMVSS 135 provides longitudinal and vertical restrictions on center of gravity location for the completed vehicle. HIL tests were performed to guide targeted physical tests. The HIL results were then correlated to the physical tests. The correlated model was then used to determine pass/fail center of gravity locations for each of the incomplete vehicle model configurations. TYPE 2 FMVSS 126 compliance was

achieved by restricting the lateral, longitudinal, and vertical location of the completed vehicle's center of gravity.

INTRODUCTION

Starting on September 1st, 2012, all vehicles sold in the United States must comply with FMVSS 126, Electronic Stability Control Systems (ESC) [1]. The OEM is required to self-certify compliance with FMVSS 126. While completed vehicles sold by the OEM can be certified through the use of physical or HIL testing before sale to the public, incomplete vehicles first sold by the OEM to a final-stage manufacturer for completion and subsequent sale to the public present an engineering challenge. Section S8.8, Final-Stage Manufacturers and Alterers, of FMVSS 126 states “Vehicle that are manufactured in two or more stages or that are altered (within the meaning of 49 CFR 567.7) after having been previously certified in accordance with Part 567 of this chapter, are not subject to the requirements of S8.1 through S8.5. Instead, all vehicles produced by these manufacturers on or after September 1, 2012, must comply with this standard.” This paper focuses on the vehicle performance requirements listed in FMVSS 126 that are measured during an open-loop dynamic maneuver called sine with dwell. The sine with dwell maneuver will be described in the following section of this paper. The performance of the vehicle during the sine with dwell maneuver is heavily influenced by the vehicle's mass characteristics, suspension, tires, brake system, and the performance of the ESC controller. The calibration used in the ESC controller is set at the factory by the OEM without knowledge of the mass, inertia, or center of gravity location of the completed vehicle. This paper outlines the technique used to certify the FMVSS 126 compliance of incomplete vehicles once a calibration has been developed.

Incomplete vehicles are sold with a document that is furnished, as required by the Federal Motor Vehicle Safety Regulations and Canada Motor Vehicle Safety Act, to aid intermediate and final stage manufacturers in their determination of the conformity of the completed vehicle with applicable FMVSS and Canada Motor Vehicle Safety Standards [2]. There are three categories of compliance in the incomplete vehicle document: TYPE 1, TYPE 2, and TYPE 3. TYPE 1 is a statement that the vehicle, when completed, will conform to the standard if no alterations are made in identified components of the incomplete vehicle. TYPE 2 is a statement of specific conditions of final manufacture under which the OEM specifies that the completed vehicle will conform to the standard. TYPE 3 is a statement that conformity with the standard cannot be determined based upon the components supplied on the incomplete vehicle, and that the OEM makes no representation to conformity with the standard. TYPE 1 compliance guidelines are not possible because ESC performance is affected by the mass characteristics of the completed vehicle. TYPE 2 compliance guidelines benefit the final stage manufacturer compared to TYPE 3 because of the cost associated with developing ESC calibrations and testing for FMVSS 126 compliance. A method to find TYPE 2 compliance guidelines for FMVSS 126 was needed. Past experience with FMVSS 135, Hydraulic Brake Systems, has shown that restricting the center of gravity location of the completed vehicle in the longitudinal and vertical directions is sufficient to achieve TYPE 2 compliance if the components listed in the incomplete vehicle document, including the complete brake hardware, are not modified. Figure 1 shows the trapezoid used to define the FMVSS 135 center of gravity location boundaries. Because the sine with dwell maneuver uses the steering wheel and builds lateral acceleration, the basic concept of restricting the center of gravity location was expanded to include the lateral direction.

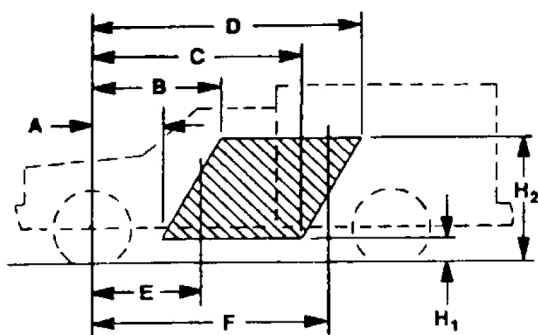


Figure 1. FMVSS 135 TYPE 2 Compliance Center of Gravity Trapezoid from the Incomplete Vehicle Document [2].

A combination of physical and HIL testing was used to define TYPE 2 compliance guidelines by restricting the center of gravity location of the completed vehicle. Outside of the

scope of this paper, a robust ESC calibration was developed for the incomplete vehicle using ballasted physical vehicles. Both a two-wheel drive (2WD) and four-wheel drive (4WD) version of the incomplete vehicle were considered. The calibration was developed with loads that were roughly symmetrical in the lateral direction. HIL testing was used to determine the bandwidth of the calibration. Tests were first run with the HIL bench to guide the construction of a suitable physical test rig. The physical test rig was ballasted to several different center of gravity locations that were used to establish a baseline for HIL correlation. HIL tests with the correlated model were used to define the final boundaries. Over 1,000 sine with dwell tests were performed on the HIL bench, something that would have been cost and time prohibitive with physical testing.

METHOD

SINE WITH DWELL TEST PROCEDURE

The sine with dwell maneuver is performed by applying an open-loop 0.7 Hz sine wave with a 3/4 cycle 500 millisecond dwell to the steering wheel [1]. The test is performed when the vehicle is equipped with new tires and ballasted with 168 kg over curb weight, including the driver and instrumentation. The maneuver is performed at an initial speed of 80 kph without the accelerator pedal or brake pedal applied. The peak Steering Wheel Angle (SWA) used in the test is calculated from the SWA that develops 0.3 g's of lateral acceleration. Several runs are performed, with the amplitude of the SWA sine wave multiplied by scalars that increase to between 540 and 600 degrees of total SWA peak to peak. The scalars start at 1.5 and monotonically increase by 0.5 each run. During the maneuver, the lateral displacement of the vehicle center of gravity at 1.07 seconds after the initial steer-in is measured as well as the yaw velocity ratio at 1.0 second and 1.75 seconds after the steering event completes is measured. The yaw velocity ratio is the ratio of the peak yaw velocity to the current yaw velocity. FMVSS 126 requires that the lateral displacement be greater than 1.829 m, the 1.0 second yaw velocity ratio be less than 0.35, and the 1.75 second yaw velocity ratio be less than 0.2. There is also a requirement that no two wheels tip-up, or lift off the ground, at the same time.

PHYSICAL TESTING

Physical testing was performed on the Vehicle Dynamics Test Area at the Milford Proving Ground. The vehicle was instrumented to record several data-channels including lateral acceleration, yaw velocity, vehicle speed, wheel speeds, and SWA. The vehicle was equipped with a robot that actuates the steering wheel with the correct open-loop steering profile. The vehicle was also equipped with a body structure that allowed ballast weights to be mounted at several points. The mounting points were chosen to allow the total vehicle center

of gravity to be moved to several different locations that were shown to be extremes by preliminary HIL testing.

HARDWARE IN THE LOOP (HIL) TESTING

HIL testing was performed using an Opal-RT real-time simulator and a hardware buck. The simulator was used to run a CarSim 7.1b vehicle model in real-time and to interface with the physical brake hardware. The complete brake hardware, including the vacuum booster, master cylinder, Electronic Brake Control Module (EBCM), the front brake calipers, the front brake rotors, the rear brake wheel cylinders, the rear brake drums, and the connecting brake lines, was integrated into the simulator. The vehicle dynamics, tire dynamics, and driver inputs were modeled in the CarSim environment. The tire model was developed from data obtained on the force and moment machine located at CalSpan, an independent testing company located in Buffalo, NY. The vehicle dynamics model was developed using data obtained from a MTS kinematics and compliance measurement machine. The vehicle used for measurement was equipped with the same suspension as the test vehicle, but was in fact a different test property. The simulator communicated with the EBCM through the EBCM's standard electrical interface. Pressure transducers, located near the wheel cylinders, were used to feed back the brake system's response to the simulated driver inputs and vehicle dynamics. Ballasting was accomplished by adding mass and inertia to baseline measurements taken with both the unaltered incomplete vehicle and the incomplete vehicle equipped with the ballast mounting rig.

ANALYTICAL AND FMVSS CONSTRAINTS

The builder is first restricted to using stock brake components, suspension components, and tires. Changing these components would affect ESC performance. Changing them would also require the builder to revalidate FMVSS 301 compliance, FMVSS 135 compliance, and other FMVSS requirements. Without these requirements, TYPE 2 compliance guidelines would not be possible.

Rather than arbitrarily trying to certify every possible center of gravity location, practical limitations were applied to what vehicle center of gravity location could be achieved by final-stage manufacturers. FMVSS 301 and FMVSS 135 requirements were used as a starting point for analysis as they place restrictions on mass, vehicle center of gravity location, and the type and size of service body attached to the incomplete vehicle. The pertinent FMVSS 301 requirements found in the incomplete vehicle document are summarized in [Table 5](#) found in the [Appendix](#). Both FMVSS 135 and FMVSS 301 contain explicit center of gravity location boundaries. The center of gravity location boundaries used in

the FMVSS 135 trapezoid, shown in [Figure 1](#), are listed in [Table 1](#). Note that the table values are referenced to the front axle centerline and the surface on which the vehicle sits. The FMVSS 135 trapezoid proved to be less restrictive than the final FMVSS 126 requirements, but still proved to be a useful guideline for FMVSS 126 TYPE 2 compliance. The guideline for FMVSS 301 compliance is actually the most restrictive requirement on the vertical direction, but the final-stage manufacturer is able to independently certify FMVSS 301 compliance for higher center of gravity locations if needed.

Table 1. FMVSS 135 TYPE2 Compliance Center of Gravity Trapezoid Coordinate Locations.

Coordinates of Allowable CG Variation at FMVSS 135 Unladen, Curb Weight + 181.4kg (cm)							
H ₁	H ₂	A	B	C	D	E	F
30.5	121.9	46.4	114.1	188.7	256.4	46.4	256.4

FMVSS 301 places requirements on the maximum curb weight of the vehicle and the maximum height and width of the service body added to the bed area. The FMVSS 301 maximum curb weight of 1961 kg was significantly lower than the Gross Vehicle Weight rating of 2404 kg and proved to be a key enabler in reducing the complexity of the experiment set. A completed vehicle curb weight of 1961 kg was used when finding the analytical boundaries because, for a given laterally-asymmetrical service body, the largest mass possible leads to the largest lateral offset in vehicle center of gravity possible. Similarly, the mass and center of gravity characteristics 2WD incomplete vehicle were used as a starting point because the additional mass of the 4WD powertrain is primarily located along the vehicle's centerline. The completed vehicle mass and center of gravity locations listed in this document do not include the additional 168 kg driver and equipment load required for sine with dwell testing.

The TYPE 2 center of gravity location was restricted along the lateral axis by a combination of practical limitations, FMVSS 301 guidelines, and HIL test results. The FMVSS 301 service body width requirement places a restriction on the maximum lateral offset of the center of gravity of the service body. The maximum width is 203.2 cm, which was considered reasonable because it is 23 cm wider than the production completed vehicle. A service body with a lateral center of gravity near ± 101.6 cm is not possible because the service body must be attached to the same points as a conventional truck bed would be on a complete vehicle. It must also provide similar structural rigidity to comply with FMVSS 301. The frame rails have a width at their centerlines of 110 cm, so, if symmetry is assumed and the service body is attached to both frame rails, the maximum lateral offset of the service body is ± 23.3 cm. A less conservative estimate of the maximum lateral center of gravity offset that can be built can be found by assuming the center of gravity of the service