



Hydraulic Brake Boost System Performance

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The purpose of this standard is to determine the performance of a vehicle equipped with a hydraulic brake boost system. This standard may be used for development or validation of requirements within the GM Vehicle Technical Specification (VTS) and for regional regulations.

Three (3) different technical conditions of hydraulic brake boost systems are considered: connected booster and valid vacuum sensor (normal system), connected booster and invalid sensor (normal vacuum and faulted sensor) and depleted brake booster and invalid vacuum sensor (zero vacuum and faulted sensor).

1.2 Applicability. This standard is applicable for vehicles with antilock brake system/electronic stability control (ABS/ESC) with the addition of hydraulic brake boost valve added function.

1.3 Remarks. Not applicable.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

FMVSS 135

2.2 GM Standards/Specifications.

None

2.3 Additional References.

- ETAS INCA data acquisition system (DAS), available from:
http://www.etas.com/en/products/inca_software_products.php
- Subsystem Technical Specification (SSTS)
- Vehicle Technical Specification (VTS)

3 Resources

3.1 Facilities.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label. See Appendix A, Data Sheet A1.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.1.3 Garage equipped for test vehicle build and instrumentation installation.

3.1.4 Dry asphalt test surfaces are located at North/South (N/S) Straightaway of Milford Proving Grounds (MPG) or on Vehicle Dynamics Test Area (VDTA) or equivalent.

3.2 Equipment.

3.2.1 Brake pedal force transducer 0 N to 2000 N $\pm$ 10 N. See Appendix B, Figure B1.

3.2.2 Longitudinal velocity sensor.

3.2.3 Longitudinal accelerometer at vehicle's center of gravity ($\pm 1.25g$).

3.2.4 Brake booster vacuum pressure regulator located between the vacuum brake booster and the vacuum source.

3.2.5 Brake vacuum pressure transducer located between the vacuum brake booster and the regulator, (± 200 kPa) to monitor vacuum pressure.

3.2.6 Brake pad temperature thermocouples at each corner or external thermocouples (0 °C to 1000 °C).

3.2.7 Brake pressure sensors located at each corner and at master cylinder.

3.2.8 Electronic Brake Command Module (EBCM) pump motor on/off switch.

3.2.9 Data acquisition system (DAS) (i.e., ETAS INCA (see 2.3)) capable of collecting data channels at 100 Hz sample rate.

3.2.10 In the DAS, set up a visual representation of the brake pedal force/second such that the driver can see the rate at which the brake pedal is being pressed, see Appendix A, Figure A1.

Note: All instrumentation is to be calibrated as required. Record instrumentation details (serial number) and date of calibration in the test record.

3.3 Test Vehicle/Test Piece. See Section 4.

3.4 Test Time.

Instrumentation/De-instrumentation time: 2 days

Calendar time: 5 hours

Test time: 8 hours

Coordination time: 3 days

3.5 Test Required Information. Possible sources are:

- Vehicle Technical Specification (VTS)
- Regional regulations

3.6 Personnel/Skills. Experienced chassis test technician for vehicle instrumentation. Vehicle program chassis controls engineer to conduct test.

4 Procedure

4.1 Preparation.

4.1.1 Build or verify the test vehicle brake apply system. Record vehicle and brake system information in the test record (see Appendix A, Data Sheets A2 and A3). The vehicle to be tested must be in safe operating condition for maneuvering levels approaching the limit of vehicle performance. Condition of tire, brake and suspension components should be inspected carefully. All vehicle safety equipment must be in proper operating condition.

4.1.2 Information about the vehicle and the brake system should be stored with the test data.

4.1.3 Perform burnish snubs in accordance with FMVSS 135 test specifications or equivalent. Install new tires before burnishing.

4.1.4 Install Instrumentation. All instrumentation must be securely fastened to the vehicle due to the nature of test maneuver. Instrumentation should be located on the passenger seat. See 3.2.1 thru 3.2.10 for sensor and DAS requirements. Verify that all instrumentation is functioning properly. Calibrate instrumentation as necessary.

4.1.5 Ballast the vehicle to curb weight, meaning the mass of the vehicle in running order including fuel, fluids, driver plus 75 kg for measuring equipment.

4.1.6 Inflate tires to manufacturer's recommended pressure or per test engineer's instructions.

4.2 Conditions.

4.2.1 Environmental Conditions. Wind speed should be less than 16 kph.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions.

4.3.1 Brake pad temperatures shall be less than 150 °C during test runs.

4.3.2 All tests shall be performed on same portion of test surface as a method to reduce test variation caused by changes in road surface friction.

4.3.3 Validate Normal Hydraulic Brake Boost (HBB) System Performance with Connected Booster Vacuum and Valid Vacuum Sensor Test. See also Appendix C, Figures C1 thru C5.

4.3.4 Find the baseline of the brake booster performance of the vehicle by measuring vehicle deceleration vs. pedal apply force. Start with nominal booster vacuum pressure (80 kPa to 90 kPa) by idling vehicle for 10 s and do not depress the brake pedal. Check to ensure that the signal [BrkBstVac] is valid as it should be for this portion of the test.

4.3.5 Accelerate vehicle on dry asphalt to the test speed of 120 kph $\pm$ 2 kph and hold test speed for at least 10 s with vehicle traveling in a straight line.

4.3.6 Trigger DAS for data collection.

4.3.7 Use the brake pedal force transducer to set an apply rate of approximately 50 N/s and apply between 400 N and 600 N of pedal force and hold to a vehicle speed of zero.

4.3.8 Stop DAS.

4.3.9 Repeat steps 4.3.4 thru 4.3.8 with the EBCM pump turned off to measure the non-HBB assisted deceleration vs. pedal apply force. Test speed at 120 kph $\pm$ 2 kph. Note that for runs made with the EBCM pump "off", the vehicle could rotate under braking for the higher vacuum level test runs. Therefore, those runs should be done on the VDTA.

4.3.10 Plot vehicle deceleration, brake pedal force, booster vacuum, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force per 5.1.1 and 5.1.2. Compare HBB assist "on" vs. HBB assist "off". Verify the HBB assisted deceleration does not exceed the non-HBB assisted deceleration by more than 0.3g at 400 N as a function of brake pedal force. Compare brake corner pressure vs. time curves to verify that additional corner pressure is being applied for the HBB system "on" vs. the HBB system "off".

4.3.11 Repeat steps 4.3.4 thru 4.3.10 for booster vacuum levels of 0, 10, 20, 40 and 60 kPa and brake pedal apply rates of approximately 50 N/s and 200 N/s. Adjust brake pedal applies rates by using the brake pedal force transducer. Check to ensure that the signal [BrkBstVac] is valid for all runs. Determine the vacuum level for engine start/stop to not allow the engine to be shut off or force the engine to be restarted. Reference Engine Start/Stop Subsystem Technical Specification (SSTS) 7.2.1.5.3. Brake Booster Vacuum 45 kPa or 7 psi (i.e., calibration [KeASSR_p_AStopBrkVacMin]). It is recommended for HBB to not function at vacuum levels exceeding the engine start/stop threshold 45 kPa or 7 psi (i.e., calibration [KeASSR_p_AStopBrkVacMin]). Verify the "Service Brake System" Driver Information Center (DIC) message occurs when vacuum is at 0 kPa for 30 s with the engine running. The EBCM Diagnostic Trouble Code (DTC) is C0299.

4.3.12 Plot vehicle deceleration, brake pedal force, booster vacuum, master cylinder brake pressure and brake corner pressures in the time domain. Plot deceleration vs. pedal force per 5.1.3. For each vacuum level, compare vehicle deceleration vs. brake pedal force curves to verify HBB assist does not increase vehicle deceleration by more than 0.3g at 400 N brake pedal force with preference of linear increase of vehicle deceleration from knee point in deceleration/pedal force curve (booster run out) to 400 N compared to HBB assist "off". In all cases with HBB assist "on", the vehicle shall achieve at least 0.5g deceleration at 400 N.

Note: At higher vacuum levels, HBB may not be required to activate in order to achieve the required 0.5g deceleration at 400 N brake pedal force. Verify the HBB assisted deceleration does not exceed the non-HBB assisted deceleration by more than 0.3g as a function of brake pedal force.

4.3.13 Verify Unwanted Brake Activation Does Not Occur with Stop/Start System Engaged. With the vehicle at a stop and the engine not running (ignition on), verify HBB does not activate for booster vacuum levels of 0, 30, and 50 kPa. With the vehicle at a stop and engine start/stop feature has shut the engine off, continuously pump the brake pedal to deplete the booster. Verify HBB does not activate and engine start/stop restarts the engine when vacuum falls below 45 kPa or 7 psi (i.e., calibration [KeASSR_p_AStopBrkVacMin]).

4.3.14 Verify Unwanted Brake Activation Does Not Occur when Performing a Three (3) Point, 180 degree Turning Maneuver. With normal engine vacuum, perform a three (3) point 180 degree turning maneuver. Stop

vehicle in one (1) direction. Accelerate vehicle to opposite side of road while turning left. Stop vehicle. Shift into reverse and back up vehicle to align in lane and then stop. Shift forward and accelerate to complete maneuver. The HBB system should not activate (brake pedal disturbance and/or brake modulator noise) during this maneuver. If an activation does occur, then HBB should be recalibrated to operate at a lower vacuum level.

4.3.15 Validate Normal HBB System Performance with Normal Booster Vacuum and Invalid (Disconnected) Vacuum Sensor Test. Validate functional safety metric at normal brake booster vacuum to limit HBB assist "on" to no more than 0.3g vehicle deceleration increase above vehicle deceleration with HBB assist "off".

4.3.16 With the ignition "off", disconnect the vacuum sensor.

4.3.17 Start engine and wait till nominal brake booster vacuum is established. EBCM shall "assume" a calibrated vacuum level since the vacuum sensor signal is invalid. After engine is started, verify that the "Service brake system" DIC message illuminates on the vehicle instrument panel before proceeding to the next step.

4.3.18 Accelerate vehicle on dry asphalt to the test speed of 120 kph $\pm$ 2 kph and hold test speed for at least 10 s with vehicle traveling in a straight line.

4.3.19 Trigger data acquisition system for data collection.

4.3.20 Apply brake pedal at an apply rate of approximately 50 N/s between 400 N and 600 N of pedal force and to a vehicle speed of zero.

4.3.21 Stop DAS.

4.3.22 Plot vehicle deceleration, brake pedal force, booster vacuum, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force per 5.1.4.

4.3.23 Compare with plots obtained for baseline brake performance with the EBCM pump turned "on" (i.e., HBB system "on") from 4.3.4.

4.3.24 Compare vehicle performance (vehicle deceleration vs. brake pedal force) of HBB assist "on" with nominal brake booster vacuum and with invalid vacuum sensor to vehicle performance of HBB assist "on" with nominal brake booster vacuum and valid vacuum sensor. Verify HBB assist "on" with nominal brake booster vacuum and invalid vacuum sensor does not exceed HBB assist "on" with nominal brake booster vacuum and valid vacuum sensor by more than 0.3g as a function of brake pedal force.

4.3.25 Validate HBB System Performance with Zero Booster Vacuum and Invalid (Disconnected) Vacuum Sensor Test. Validate the overall vehicle deceleration level (overall vehicle deceleration = base brake deceleration + HBB additional deceleration) exceeds 0.5g at 400 N brake pedal force. The HBB assist shall assume a vacuum level due to the booster vacuum sensor signal being invalid.

4.3.26 Set the booster vacuum level to 0 kPa.

4.3.27 With the ignition "off", disconnect the vacuum sensor.

4.3.28 With engine running, fully depress the brake pedal ten (10) times to fully deplete the vacuum booster. Verify "Service Brake System" DIC message illuminated on the vehicle instrument panel.

4.3.29 Accelerate vehicle on dry asphalt to the test speed of 120 kph $\pm$ 2 kph and hold test speed for at least 10 s with vehicle traveling in a straight line.

4.3.30 Trigger DAS for data collection.

4.3.31 Apply brake pedal at an apply rate of approximately 50 N/s between 400 N and 600 N of pedal force and to a vehicle speed of zero.

4.3.32 Stop DAS.

4.3.33 Plot vehicle deceleration, brake pedal force, booster vacuum, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force per 5.1.6.

4.3.34 Examine vehicle deceleration vs. brake pedal force curves to verify HBB assist provides a linear increase of vehicle deceleration from the knee point (booster run out) in the vehicle deceleration vs. brake pedal force curve to 0.5g at 400 N brake pedal force.

4.3.35 Repeat 4.3.28 thru 4.3.34 with the ignition turned to accessory and engine shut "off" before applying the brake pedal.

4.3.36 Plot vehicle deceleration, brake pedal force, booster vacuum, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force per 5.1.6.

4.3.37 Verify HBB functions the same way as with the ignition turned “on” and with the engine running.

5 Data

Data is to be reviewed by responsible engineer to resolve any issues surfacing during vehicle testing.

5.1 Calculations. Plot the following conditions.

5.1.1 Normal system: connected booster, connected vacuum sensor and EBCM pump motor powered. The initial speed of 120 kph $\pm$ 2 kph for the brake pedal apply (ramp) rate of approximately 100 N/s and a maximum pedal force of between 400 N and 600 N. Plot vehicle deceleration vs. pedal force and vehicle deceleration, brake pedal force, booster vacuum, booster vacuum validity, master cylinder brake pressure and brake corner pressures in the time domain.

5.1.2 Normal system: connected booster, connected vacuum sensor and EBCM pump motor power removed. The initial speed of 120 kph $\pm$ 2 kph for the brake pedal apply (ramp) rate of approximately 100 N/s and a maximum pedal force of between 400 N and 600 N. Plot vehicle deceleration vs. pedal force and vehicle deceleration, brake pedal force, booster vacuum, booster vacuum validity, master cylinder brake pressure and brake corner pressures in the time domain.

5.1.3 Normal system: connected booster, connected vacuum sensor and EBCM pump motor powered. Repeat the preceding full power tests (5.1.1 and 5.1.2) at pedal apply rates of approximately 100 N/s and 50 N/s with a maximum pedal force of reduced booster vacuum levels of 0, 10, 20, 40 and 60 kPa with EBCM powered. Plot vehicle deceleration vs. pedal force and vehicle deceleration, brake pedal force, booster vacuum, booster vacuum validity, master cylinder brake pressure and brake corner pressures in the time domain.

5.1.4 Failed system: connected booster, disconnected vacuum sensor. The initial speed of 120 kph $\pm$ 2 kph for the brake pedal apply (ramp) rate of approximately 100 N/s and a maximum pedal force of between 400 N and 600 N. Plot vehicle deceleration, brake pedal force, booster vacuum, booster vacuum validity, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force.

5.1.5 Failed system: connected booster and connected vacuum sensor. The initial speed of 120 kph $\pm$ 2 kph for the brake pedal apply (ramp) rate of approximately 100 N/s and a maximum pedal force of between 400 N and 600 N. Plot vehicle deceleration vs. brake pedal force.

5.1.6 Failed system: depleted brake booster, disconnected vacuum sensor and EBCM pump motor powered. Using the initial speed of 120 kph $\pm$ 2 kph for the brake pedal apply (ramp) rate of approximately 100 N/s and 50 N/s and a maximum pedal force of between 400 N and 600 N. Plot vehicle deceleration, brake pedal force, booster vacuum, booster vacuum validity, master cylinder brake pressure and brake corner pressures in the time domain. Plot vehicle deceleration vs. pedal force.

5.2 Interpretation of Results. Not applicable.

5.3 Test Documentation. The vehicle information, test information, test results and data processing details shall be published following GM corporate protocol using the Evaluation Report template and Engineering Document Management system or its successor.

6 Safety

This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

In general, a risk assessment needs to be performed for every driving instruction prior to executing this standard. (**Note:** National law needs to be considered while performing a risk assessment.) The required rating of risk by exposure probability and possible violation will be done in a separate document. Every identified risk must be named inside the risk assessment for the relevant driving instruction in order to announce that risk to employees. Within the risk assessment, the vehicle equipment and different vehicle build stages have to be considered. After performing a risk assessment, non-acceptable risk needs to be mitigated by appropriate countermeasures. Here technical measures are preferred because these are independent from attendant circumstances. In case technical measures are not appropriate, organizational and/or personal measures will apply. This includes training, wearing of Personal Protection Equipment, or arrangement of idle time.