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Testing and Analysis of Toyota and Lexus Vehicles and Components for Concerns Related to Unintended Acceleration

Exponent

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Acronyms and Abbreviations

CEL	check engine light
DTC	diagnostic trouble code
ECM	engine control module
ECU	electronic control unit
ETCS-i	Electronic Throttle Control System With Intelligence
TMC	Toyota Motor Corporation
VIN	vehicle identification number

Executive Summary

Exponent was retained in December 2009 to assist Toyota Motor Corporation (TMC) in its efforts to understand customer reports and claims of unintended acceleration in vehicles using their ETCS-i (Electronic Throttle Control System-intelligent) system. TMC did not limit the scope or budget of Exponent's investigation. This report summarizes some of the testing that has been performed. Exponent's testing and analysis is ongoing.

Exponent obtained six Toyota and Lexus vehicles containing various versions of the ETCS-i system, and one Honda vehicle to use as a peer comparison. Exponent selected and purchased these vehicles on the open market based on our evaluations of the rates of reported claims of unintended acceleration calculated from analyses of the NHTSA complaint database. Exponent also obtained more than 100 new and used ETCS-i and pre-ETCS-i components (throttle bodies, accelerator pedals, engine control modules [ECMs]), as well as similar components used by other vehicle manufacturers.

Exponent initiated an independent evaluation of the performance of the vehicles and the individual components under a variety of normal and abnormal conditions. The evaluation was performed by a team that included both engineers and technicians with specialized knowledge in mechanical, electrical, and automotive engineering. The evaluation included: a) measuring characteristics of individual components, b) characterization of the sensitivity of the system to aberrations and noise imposed on individual components, c) driving tests with anomalies imposed on the ETCS-i system, d) comparisons of actual performance to performance as published in service manuals and guides, e) comparisons of different generations and manufacturers of Toyota and Lexus parts, and f) comparisons of competitive manufacturers' parts with those used in Toyota and Lexus vehicles.

Throughout the evaluation and testing conducted to date, the ETCS-i components and whole vehicles behaved in a manner consistent with published performance characteristics. Exponent has so far been unable to induce, through electrical disturbances to the system, either unintended acceleration or behavior that might be a precursor to such an event, despite concerted efforts toward this goal.

Testing and Analysis of Toyota and Lexus Vehicles and Components for Concerns Related to Unintended Acceleration

Introduction

This report documents the scope, and summarizes the findings to date, of Exponent's testing and evaluation of the ETCS-i system used in Toyota and Lexus vehicles for concerns related to unintended acceleration. The first section describes the vehicles and components that were obtained for this study. The second section describes studies and measurements of individual components. The third section describes the test procedures and results from perturbations and disruptions imposed on the ETCS-i systems of different Toyota and Lexus vehicles. The final section summarizes the conclusions that Exponent has formed to date on the ETCS-i system as implemented in the vehicles it has tested.

Vehicles and Components Obtained for Study

Exponent purchased seven vehicles for its study. A listing of the vehicles used in the study is shown in Table 1. These vehicles were selected because they represented a cross-section of models and model years, including vehicles with elevated and lower rates of complaints of unintended acceleration.

Table 1. Listing of vehicles purchased for testing

Make	Model	Model Year	Vehicle Identification Number (VIN)
Toyota	Camry	2002	4T1BE30K32U594362
Toyota	Camry	2007	JTNBE46KX73061175
Toyota	FJ Cruiser	2007	JTEZU11F570012218
Toyota	Sienna	2008	5TDZK23C38S211978
Lexus	IS 250	2006	JTHBK262065014899
Lexus	IS 350	2006	JTHBE262062001692
Honda	Accord EX	2008	1HGCP36818A015878

In addition, Exponent purchased more than 100 parts for study. These parts included new and used (from salvage yards) accelerator pedals, throttle bodies, and ECUs from Toyota and Lexus vehicles as well as vehicles from other manufacturers. Exponent also acquired non-ETCS-i parts from earlier years of Toyota vehicles. A listing of the parts acquired for this study is provided in Appendix A.

Studies and Measurements on Individual Components

Individual components were studied to identify the geometries and technologies used for different models and model years. In addition, electrical measurements were completed on individual components, as well as components installed on the study vehicles. Some of the significant findings are presented here.

Electronic Throttle Control System

The diagram shown in Figure 1 shows the functional layout of the ETCS-i system in Toyota and Lexus vehicles. The accelerator pedal position is sensed by two redundant sensors, with the outputs labeled as VPA1 and VPA2. These signals are read by the engine control module (ECM). The ECM also receives signals from two redundant throttle position sensors, VTA1 and VTA2. Based on these signals and other vehicle state parameters, the ECM sends current to the throttle control motor to control the position of the throttle plate.

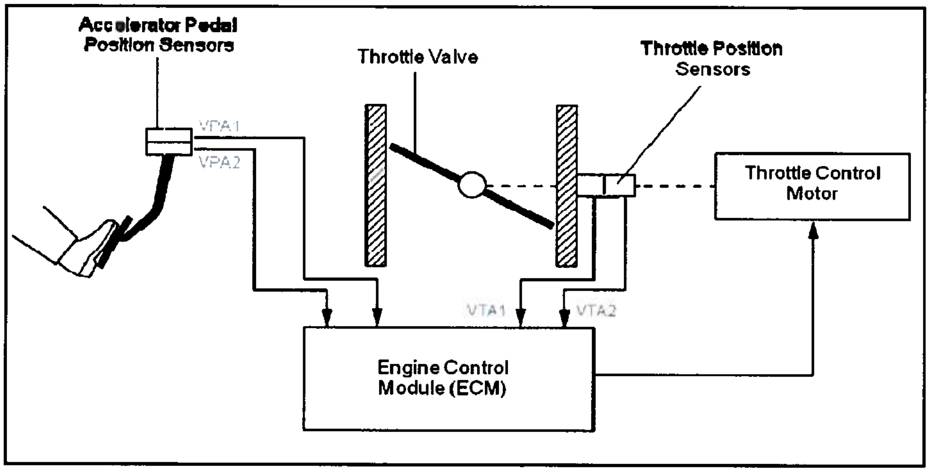


Figure 1. Functional diagram of electronic throttle control system in Toyota and Lexus vehicles

Accelerator Pedals

Before the advent of the ETCS-i system, Toyota, like other manufacturers, had a cable directly connecting the accelerator pedal to the valve on the throttle plate. Figure 2 is a photograph of a pre-ETCS-i pedal and cable.

Figure 2. Pedal from a pre-ETCS-i Toyota Tundra

In Toyota's ETCS-i system, the pedal has the two position sensors integrated into the pedal assembly. An example of such a pedal assembly is shown in Figure 3. Earlier pedals in the ETCS-i system used two potentiometers (variable resistors) to measure pedal position. Later pedals used Hall effect sensors to measure pedal position. The Hall effect sensors detect changes in the magnetic field resulting from the movement of magnets affixed to the pedal. Two different designs of pedals using Hall effect sensors are used by Toyota; one design is made by CTS and the other design is made by Denso.

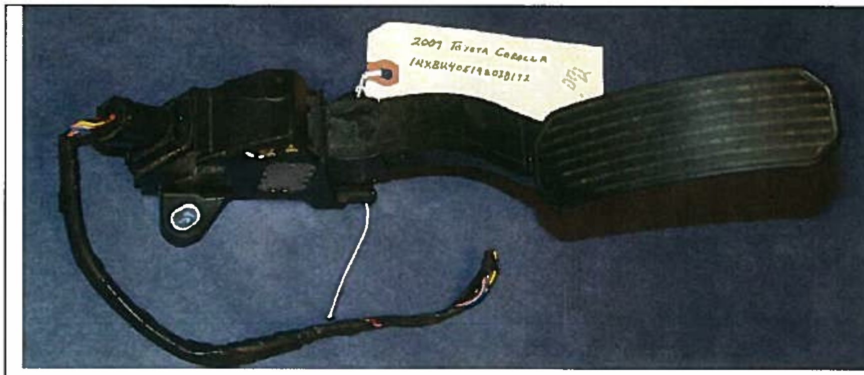


Figure 3. Accelerator pedal manufactured by CTS for an ETCS-i equipped 2009 Toyota Corolla

To gain a greater understanding of Toyota's electronic throttle control system, Exponent characterized individual components of the system, and also tested the entire systems in vehicles, as will be discussed later. Exponent began by characterizing accelerator pedal position sensors. Figure 4 shows the voltage outputs from the two pedal position sensors, named VPA1 and VPA2, as a function of accelerator pedal displacement angle, for eight different Toyota and Lexus accelerator pedals. The two signals contain information about the position of the pedal; VPA2 is higher than VPA1.

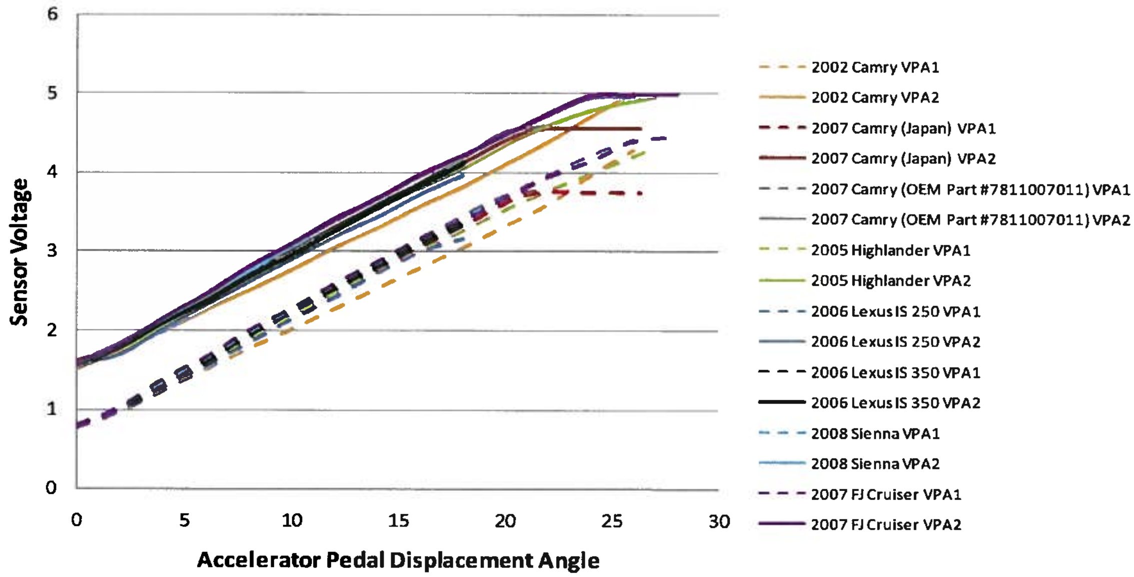


Figure 4. Accelerator pedal sensor voltages as a function of pedal angle for various Toyota and Lexus pedals

Exponent also examined pedals from other manufacturers. For example, Figure 5 shows VPA1 and VPA2 for a 2009 Honda CRV. The functionality was found to be very similar to that of the Toyota and Lexus pedals.

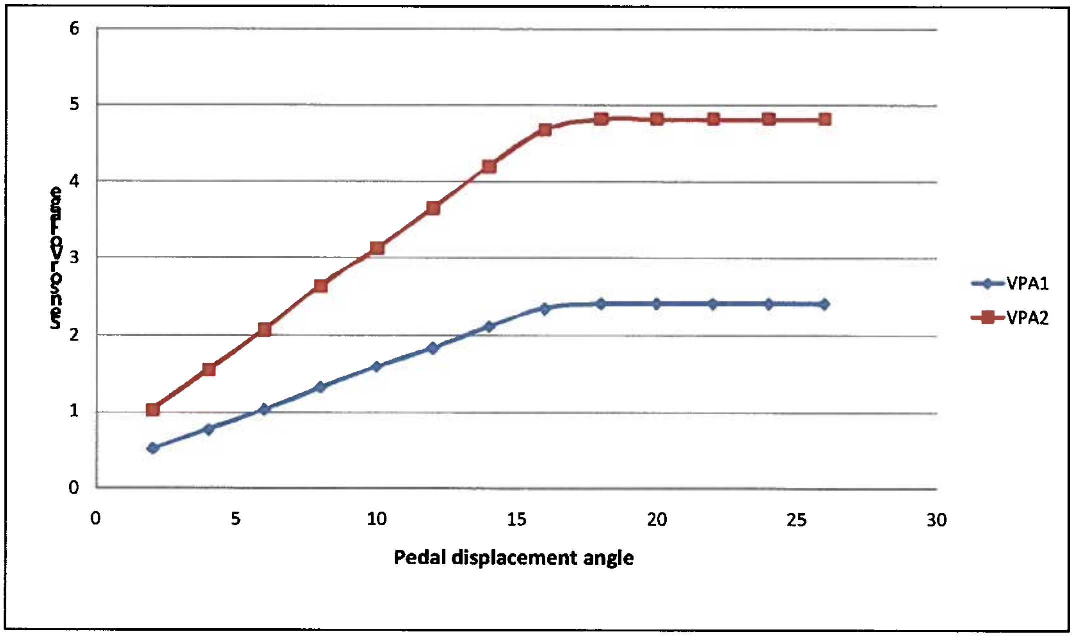


Figure 5. Accelerator pedal sensor voltages as a function of pedal angle for a 2009 Honda CRV.

Throttle Bodies

Before the introduction of the ETCS-i system, Toyota, like other manufacturers, had a throttle body where the throttle valve position was directly controlled by a cable that was pulled by the accelerator pedal. A photograph of a typical pre-ETCS-i pedal and cable is shown in Figure 6. This design of throttle body has a throttle position sensor. The throttle position sensor sends the throttle valve opening angle to the ECM, which uses this information, along with other data, to determine fuel injection, spark timing, and other parameters. The ECM in this engine design has no control over the position of the throttle valve.

Figure 6. Pre-ETCS-i throttle body

In the ETCS-i system, the throttle body has the two throttle position sensors and a motor integrated into the throttle body assembly. An example of such a throttle body assembly is shown in Figure 7. The throttle position sensors are located under the black housing, and the motor is inside the housing, perpendicular to the valve bore. When the throttle valve motor is not energized, the throttle body valve is forced into its most closed position by two powerful internal springs.

Figure 7. Throttle body from an ETCS-i vehicle

Exponent characterized the voltage output of the throttle position sensors for different no-load engine speeds. Figure 8 shows the results of these measurements for six vehicles, where the two sensor outputs are labeled VTA1 and VTA2.

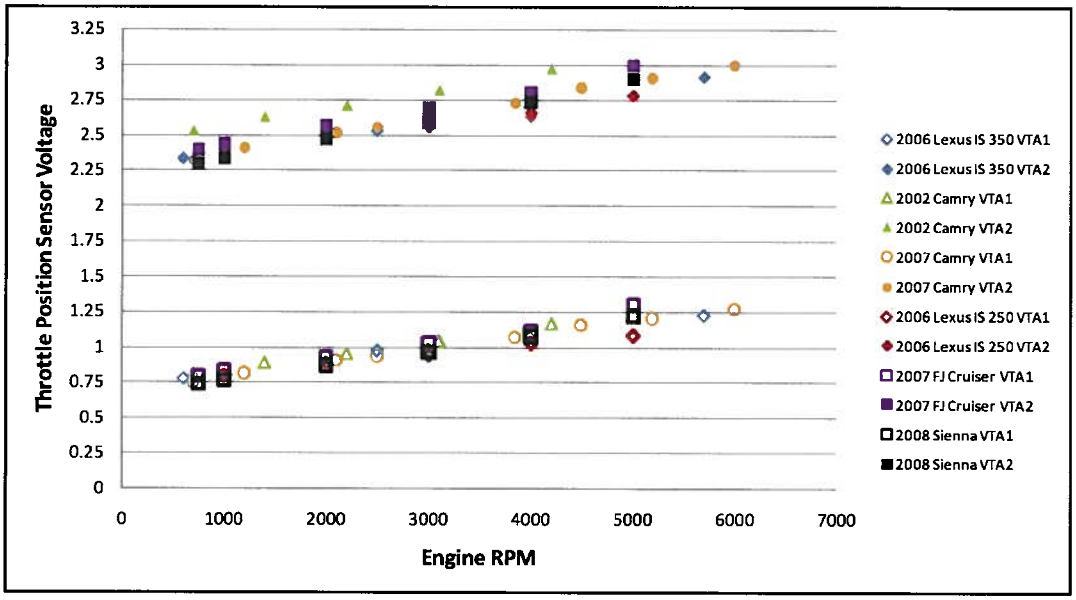


Figure 8. Throttle position sensor voltages as a function of no-load engine speed for various Toyota and Lexus vehicles.

Peer Vehicle Component Technology

Exponent also reviewed the technologies used in position sensing in competitors' throttle bodies and accelerator pedals. A summary comparing some of these designs is provided in Appendix B. Other manufacturers have used potentiometers and Hall effect sensors in their throttle valve and accelerator position sensors, though no manufacturer in our survey has used two different sensing technologies within any accelerator pedal or throttle body.

Summary

The components that were studied behaved as described in the technical manuals for Toyota and Lexus vehicles. No anomalous behavior was detected in any of the component tests.

Sensitivities to Anomalies and Perturbations

The accelerator pedal and throttle body both contain redundant position sensors that enable the ECM to detect faults in sensor operation. Having understood the functionality of the sensors, Exponent next examined the sensitivity of the ECM to perturbations in one or both sensors, including the ability of the ECM to diagnose faults. Exponent performed these tests in running vehicles by holding a single position signal constant, while varying the other position signal until the ECM detected a fault. Faults, when detected, would illuminate the check engine light (CEL) and set a diagnostic trouble code (DTC). For example, Figure 9 is from a 2002 Toyota Camry, and shows how much the voltage of VPA2 varied, with the VPA1 voltage signal held constant, before a fault was detected by the ECM. Under normal operation, the ECM uses VPA1 to determine pedal position and VPA2 to determine whether VPA1 is a valid signal. Therefore, when Exponent varied VPA2 while holding VPA1 constant, the engine speed was not sensitive to changes in VPA2. The engine speed did vary depending on engine loads (fans and auxiliary equipment).

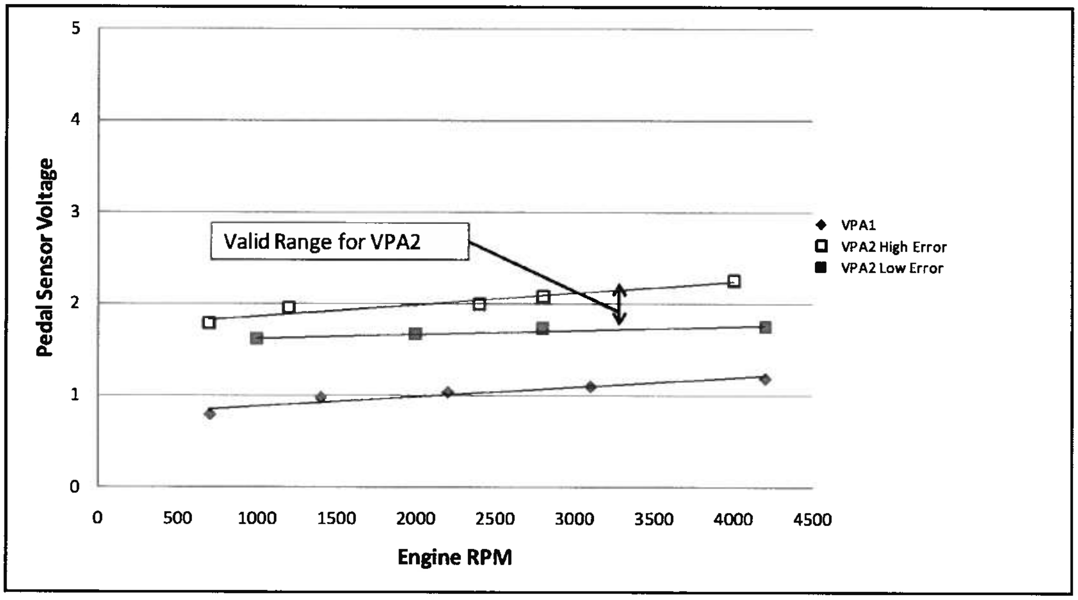


Figure 9. Determination of the valid sensor value range for VPA2 in a 2002 Toyota Camry.

Similar tests were repeated in other vehicles, the results of which are shown in Figure 10. This graph plots the upper and lower limits of the difference between VPA1 and VPA2 signals, before the vehicles' ECMs detected a fault. The voltage differences varied somewhat between vehicles, an indication that ECMs may not have been programmed identically in this regard.

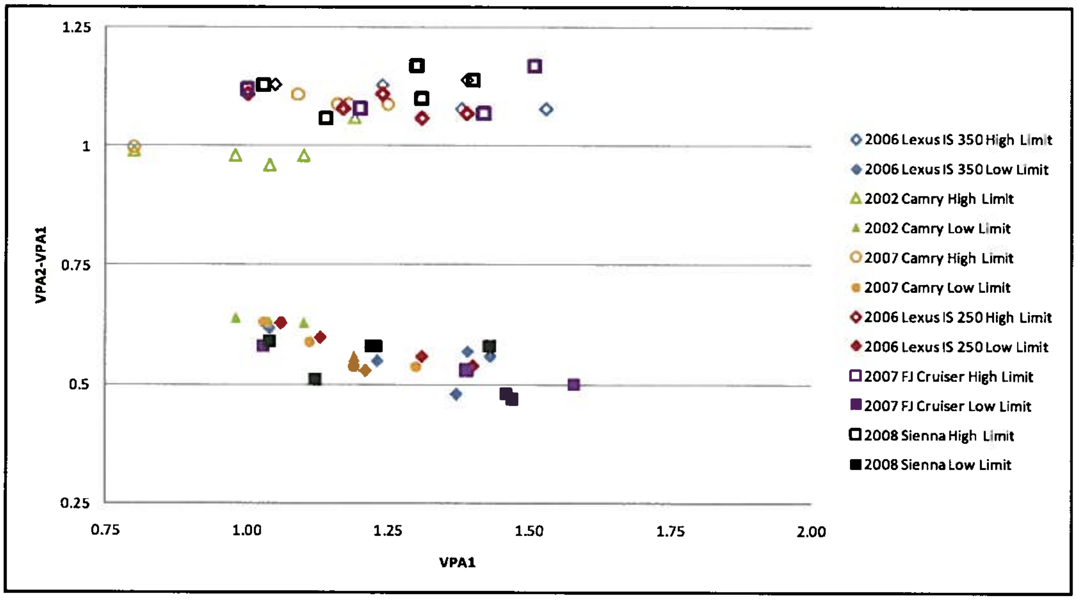


Figure 10. Comparison of VPA2 error limits for various Toyota and Lexus vehicles

Investigation of Vehicle Response to Failure Modes

Exponent completed a series of tests that imposed a variety of failure modes on the electronic throttle control systems in several Toyota and Lexus vehicles. The purpose of this testing was to attempt to create a fault in the system that would cause the vehicle to accelerate without input from the accelerator pedal.

Testing Setup

In order to impose failure modes on the electronic throttle control system, Exponent intercepted the signals being sent to and from the accelerator pedal and the throttle body. These signals were altered and then sent to the ECM. The goal of this testing was to modify these sensor output signals and induce an unintended acceleration event.

Figure 11 shows an accelerator pedal and the location of the accelerator pedal wiring harness connector on the pedal. The pedal wiring harness was disconnected at this connector so that the signals passing through the wiring harness, including VPA1 and VPA2, could be altered and sent to the ECM.

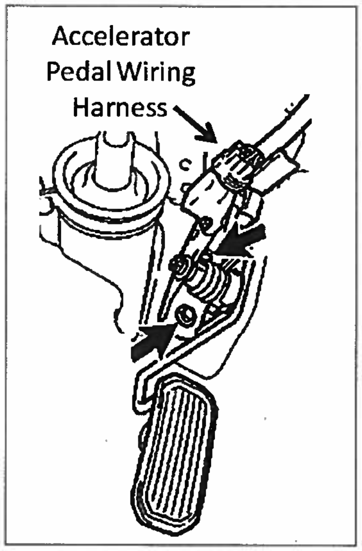


Figure 11. Accelerator pedal and accelerator pedal wiring harness

Figure 12 shows a throttle body and the throttle body wiring harness connector. At this connector the signals being sent to and from the throttle body were intercepted and altered. Specifically, Exponent modified VTA1 and VTA2, and also simulated faults in the throttle control motor by placing resistors in series and in parallel with the motor.

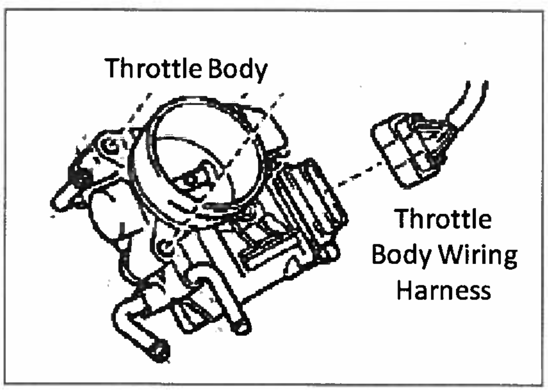


Figure 12. Throttle body and throttle body wiring harness

In addition to creating sensor faults and altering the electrical characteristics of the throttle control motor, Exponent also created a mechanical fault in the throttle body by jamming the throttle plate so that it could not fully close. This was done by using a bent wire inserted into the throttle body, as shown in Figure 13.

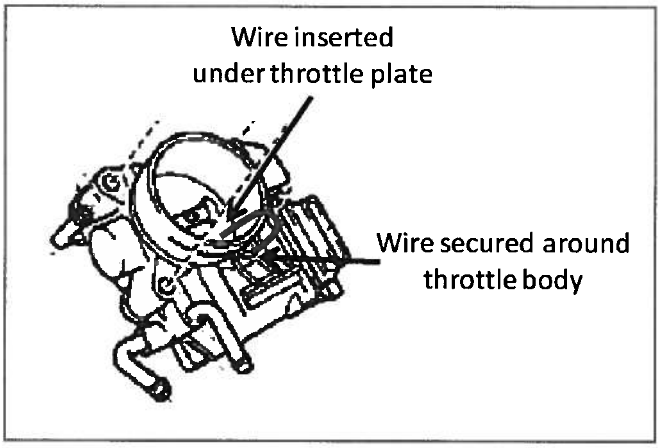


Figure 13. Wire inserted in throttle body to prevent throttle valve from fully closing

Test Protocol

Each test began with the vehicle cleared of any existing diagnostic trouble codes (DTCs) and ensuring the CEL was off. Depending on the test being performed, either the throttle body or pedal wiring was intercepted. The vehicle was then started and operated normally until the fault was inserted. Exponent then made observations of any unintended acceleration, change in the vehicle behavior, DTCs, or CEL.

The following tests were performed:

- Short VTA1 signal to ground
- Short VTA2 signal to ground
- Open circuit on VTA1
- Open circuit on VTA2
- Decrease VTA1 signal voltage
- Decrease VTA2 signal voltage
- Increase VTA1 signal voltage

- Increase VTA2 signal voltage
- Short VPA1 signal to ground
- Short VPA2 signal to ground
- Open circuit on VPA1
- Open circuit on VPA2
- Decrease VPA1 signal voltage
- Decrease VPA2 signal voltage
- Increase VPA1 signal voltage
- Increase VPA2 signal voltage
- Add resistance in parallel with the throttle control motor
- Add resistance in series with the throttle control motor
- Mechanically prevent the throttle plate from fully closing.

Test Results

The testing was first performed on stationary vehicles with the gear selector in park and the vehicle secured with wheel stops. The tests were then performed on moving vehicles. During the testing, all vehicles operated as designed; Exponent was unable to induce unintended acceleration, or even create any situations that could lead to unintended acceleration.

Every failure mode attempted was detected by the ECM, resulting in a CEL and a DTC being recorded. For all electrically simulated failures, the vehicle entered a limp mode where available engine power was significantly reduced. The engine operation during limp mode varied slightly depending on the specific type of fault detected. When the throttle plate was mechanically stuck open, the engine completely shut off.

All of the DTC codes stored after the simulated failures had to be cleared using a scanning tool before the CEL turned off and the vehicle resumed normal operation. In addition, some failure modes required waiting before restarting the vehicle, and in some vehicles the stuck throttle plate required that the battery be temporarily disconnected before the vehicle would resume normal operation.

Summary

During extensive testing on multiple vehicles, where different electrical and mechanical perturbations were imposed on the components comprising the ETCS-i system, Exponent did not observe any instances of unintended acceleration or any circumstances that might lead to unintended acceleration. To the contrary, imposing these perturbations resulted in a significant drop in power rather than an increase. In all cases, when a fault was imposed, the vehicle entered a fail-safe mode consistent with descriptions provided in the technical manuals for Toyota and Lexus vehicles.

Conclusions

This report summarizes the results of some of the testing that has been performed by Exponent. Exponent's testing and analysis is ongoing.

Exponent was unable to induce unintended acceleration in any of the ETCS-i equipped Toyota and Lexus vehicles it tested. The testing included a wide variety of perturbations and anomalies imposed on the electrical signals to and from the throttle body and accelerator pedal. In all cases, the vehicle either behaved normally or entered a fail-safe mode where engine power was significantly reduced or shut off.

The ECM responds to commands sent by the accelerator pedal. It cannot, however, detect the difference between a foot pressing on the pedal, a pedal that is being pressed by a floor mat, or a pedal that is binding.

When Exponent induced failures of the position sensors in the accelerator pedals or throttle bodies, or caused significant shifts in the calibrations of these sensors, these changes were detectable by the ECM.

About Exponent

Exponent is an engineering and scientific consulting firm providing solutions to complex problems. Exponent's multidisciplinary organization of scientists, physicians, engineers, and business consultants brings together more than 90 technical disciplines to address complicated issues facing industry and government today.

Over the past 40+ years Exponent (formerly Failure Analysis Associates) has conducted more than 50,000 investigations in areas such as fires and explosions, human performance, electrical engineering, civil/structural engineering, product or process risk assessment, and biomechanics. Some of the better-known projects include the collapse of the Kansas City Hyatt Regency walkway, the bombing of the Alfred P. Murrah building in Oklahoma City, the explosion of the Piper Alpha oil platform, and the attack on the World Trade Center. More recently the firm has developed military products designed to help save soldiers' lives; performed research related to health exposures and the environment; and volunteered its expertise to aid in search, rescue and structural engineering efforts for both natural and man-made disasters.

Exponent is certified to ISO 9001 and is authorized by the General Services Administration (GSA) to provide professional engineering services. Exponent has more than 850 employees including more than 600 degreed technical professionals, of which 350 have earned a doctorate degree. The firm operates out of 19 offices in the U.S. as well as 5 locations overseas.

Additional information regarding Exponent can be found on its website at www.exponent.com.

Appendix A

Listing of Parts Obtained for This Study

Part #	Part	MY	Make	Model	VIN
P1	Accelerator Pedal Assembly	2007	Toyota	Camry	
P10	Accelerator Pedal Assembly	2002-2008	Mercedes	E-Series	
P100	Accelerator Pedal Assembly	2008	Toyota	Camry	4TBK46K28U058243
P101	Accelerator Pedal Assembly	2008	Toyota	Camry	4TBF46K68U250708
P102	Accelerator Pedal Assembly	2008	Toyota	Camry	4T1BE46K28U768914
P103	Accelerator Pedal Assembly	2001	Toyota	Camry	4TBG26KX1U830108
P104	Accelerator Pedal Assembly	1998	Toyota	Camry	JTZBG22K2W0109432
P11	Accelerator Pedal Assembly	2002-2008	Mercedes	E-Series	
P12	Accelerator Pedal Assembly	2005-2010	Chrysler	Chrysler-LX bodies (Charger)	
P13	Accelerator Pedal Assembly	2006	Ford	F-150	
P14	Accelerator Pedal Assembly	2007	Ford	Mustang	
P15	Accelerator Pedal Assembly	2002	Toyota	Camry	JTDBE32K020126517
P16	Accelerator Pedal Assembly	2006	Chrysler	300	
P17	Accelerator Pedal Assembly	2006	Toyota	Tacoma	
P18	Accelerator Pedal Assembly		Honda		
P19	Accelerator Pedal Assembly		Honda		
P2	Accelerator Pedal Assembly	1998	Toyota	Camry	4T1BG22K9WU313141
P20	Accelerator Pedal Assembly		Honda		
P22	Accelerator Pedal Assembly	2006	Chevy	Impala	
P23	Accelerator Pedal Assembly	2004	Nissan	Quest	

Part #	Part	MY	Make	Model	VIN
P24	Accelerator Pedal Assembly		General Motors	General Motors	
P25	Accelerator Pedal Assembly	2005	Nissan	Quest	
P26	Accelerator Pedal Assembly	2006	Ford	F-150	1FTPW12576KD49083
P27	Accelerator Pedal Assembly	2007	Toyota	Sienna	5TDZK23C87S040157
P28	Accelerator Pedal Assembly	2000	Toyota	Tundra	5TBBT481XYS102606
P3	Accelerator Pedal Assembly	2005	Toyota	Highlander	JTEEP21A150107176
P30	Accelerator Pedal Assembly	2005	Nissan	Quest	5N1BV28U05N138320
P32	Accelerator Pedal Assembly	2005	Chevy	Suburban	
P33	Accelerator Pedal Assembly	2006	Ford	F-150	1FTRX14W66NA44085
P35	Accelerator Pedal Assembly	2002-2004	Ford	Super Duty Truck	
P36	Accelerator Pedal Assembly	2006	Honda	Pilot	5FNYF28456B043747
P37	Accelerator Pedal Assembly	2003	BMW	325i	
P38	Pedal	2000	Toyota	Tundra	5TBJN321XXS075089
P4	Accelerator Pedal Assembly	2002	Toyota	Camry	
P40	Accelerator Pedal Assembly	2002	Toyota	Corolla	1NXBR12EX2Z624764
P41	Accelerator Pedal Assembly	2000	Toyota	Tundra	5TBBT4411YS077570
P42	Accelerator Pedal Assembly	2001	Toyota	Camry	4T1BG22K11U860820
P46	Accelerator Pedal Assembly		Nissan		Unknown
P5	Accelerator Pedal Assembly	2002	Toyota	Camry	
P52	Accelerator Pedal Assembly		BMW		

Part #	Part	MY	Make	Model	VIN
P53	Accelerator Pedal Assembly		BMW		
P54	Accelerator Pedal Assembly	2006	Chevy	Impala	2G1WD58C26924118
P55	Accelerator Pedal Assembly	2007	Ford	Mustang	1ZVFT80NX75325065
P56	Accelerator Pedal Assembly	2006	Chrysler	300	2C3KA43RX6H484551
P57	Accelerator Pedal Assembly	2006	Toyota	Camry	4T1BE32K86U133385
P58	Accelerator Pedal Assembly	2004	Toyota	Camry	4T1BE32K04U814752
P59	Accelerator Pedal Assembly	2005	Honda	Pilot	5FNYF18525B043349
P6	Accelerator Pedal Assembly	2000	Toyota	Camry	JT2BG22KXY0516739
P60	Accelerator Pedal Assembly	2006	Chevy	Impala	2G1WT58K369138837
P61	Accelerator Pedal Assembly	2006	Honda	CRV	SHSRD78846U43P964
P62	Accelerator Pedal Assembly	2007	Honda	CRV	JHLRE48517C095650
P65	Accelerator Pedal Assembly	2007	Toyota	Sienna	5TDZK23C87S040157
P66	Accelerator Pedal Assembly	2006	Toyota	Camry	4T1BA30K46U088962
P67	Accelerator Pedal Assembly	2004	Toyota	Camry	4T1BA32K94U028587
P68	Accelerator Pedal Assembly	2005	Chevy	Tahoe	1GNEK13TX5R249914
P69	Accelerator Pedal Assembly	2002	Toyota	Tundra	5TBBT44182S258849
P7	Accelerator Pedal Assembly	2002	Toyota	Tundra	5TBBN441025288437
P71	Accelerator Pedal Assembly	2002	Toyota	Camry	4T1BE32K52U619842
P72	Accelerator Pedal Assembly	2003	Toyota	Camry	
P77	Accelerator Pedal Assembly	2004	Nissan	Quest	5N1BV28U04N313017

Part #	Part	MY	Make	Model	VIN
P8	Accelerator Pedal Assembly	2008	BMW	328i	
P82	Accelerator Pedal Assembly	2007	Toyota	Camry	4T1BE46K57U535432
P83	Accelerator Pedal Assembly	2007	Toyota	Camry	4T1BE46K17U357943
P89	Accelerator Pedal Assembly	2002	Toyota	Camry	4T1BE32K12U512044
P9	Accelerator Pedal Assembly	2002	BMW	745i	
P90	Accelerator Pedal Assembly	2007	Toyota	Tundra	5TFLU52137X003335
P91	Accelerator Pedal Assembly	2009	Toyota	Corolla	1NXBU40E39Z015416
P92	Accelerator Pedal Assembly	2009	Toyota	Corolla	1NXBU40E19Z038192
P93	Accelerator Pedal Assembly	2007/2008	Toyota	Tundra/Sequoia	
P94	Accelerator Pedal Assembly	2007	Toyota	Camry	4T1BE46K57U576191
P95	Accelerator Pedal Assembly	2007	Toyota	Camry	4T1BE46K07U528680
P96	Accelerator Pedal Assembly	2007	Toyota	Tundra	5TFLU52197X003582
P97	Accelerator Pedal Assembly	2007	Toyota	Camry	4T1BB46K07U019665
P98	Accelerator Pedal Assembly	2008	Toyota	Camry	4T1BE46K78U240303
P99	Accelerator Pedal Assembly	2007	Toyota	Tundra	5TFLU52127X001561
T1	Throttle body	2007	Toyota	Camry	
T10	Throttle body	2002	Mercedes	E320	
T13	Throttle body	2007	Ford	Mustang	
T14	Throttle body	2006	Ford	F-150	
T16	Throttle body	2006	Chrysler	300	
T17	Throttle body	2006	Toyota	Tacoma	
T2	Throttle Body	1998	Toyota	Camry	4T1BG22K9WU313141
T23	Throttle body	2005	Chevy	Suburban	
T26	Throttle body	2006	Ford	F-150	1FTPW12576KD49083

Part #	Part	MY	Make	Model	VIN
T27	Throttle body	2007	Toyota	Sienna	5TDZK23C87S040157
T28	Throttle body	2000	Toyota	Tundra	5TBBT481XYS102606
T29	Throttle body	2007	Honda	CRV	5J6RE48547L002224
T3	Throttle body	2005	Toyota	Highlander	JTEEP21A150107176
T30	Throttle body	2005	Nissan	Quest	5N1BV28U05N138320
T31	Throttle body	2006	Chevy	Impala	
T32	Throttle body	2005	Chevy	Suburban	
T34	Throttle body	2000	Toyota	Tundra	5TBJN321XYS075089
T35	Throttle body	2002-2004	Ford	Super Duty Truck	
T36	Throttle body	2006	Honda	Pilot	5FNYF28456B043747
T37	Throttle body	2003	BMW	325i	
T39	Throttle body		Toyota	Toyota	
T4	Throttle body	2002	Toyota	Camry	
T40	Throttle body	2002	Toyota	Corolla	1NXBR12EX2Z624764
T43	Throttle body	2006	Honda	Pilot	
T44	Throttle body		Nissan		
T45	Throttle body	2006	Chrysler	300	
T46	Throttle body		Nissan		Unknown
T47	Throttle body	2006	Honda	CRV	
T48	Throttle body		Nissan		
T49	Throttle body	2007	Honda	CRV	
T5	Throttle body	2002	Toyota	Camry	
T50	Throttle body	2006	Chevy	Impala	
T51	Throttle body		BMW		
T52	Throttle body		BMW		
T6	Throttle Body	2002	Toyota	Tundra	5TBBN441025288437
T63	Throttle body	2007	Honda	CRV	JHLRE485X7C052960
T64	Throttle body	2004	Toyota	Camry	
T69	Throttle body	2002	Toyota	Tundra	5TBBT44182S258849
T7	Throttle body	2002	BMW	745i	
T72	Throttle body	2003	Toyota	Camry	
T73	Throttle body	2002	Toyota	Camry	JTDBE32K120135419
T75	Throttle body	2004	Toyota	Tacoma	5TENL42N14Z431885

Part #	Part	MY	Make	Model	VIN
T76	Throttle body	2006	Toyota	Tacoma	5TENX22NS6Z179276
T78	Throttle body	2006	Chrysler	300	2C3LA53G36H114342
T79	Throttle body	2006	Chevy	Impala	2G1WB58K769119477
T8	Throttle body	2008	BMW	328i	
T80	Throttle body	2005	Chevy	Tahoe	1GNEK13T55R108782
T81	Throttle body	2006	Honda	CRV	SHSRD78806U430838
T84	Throttle body	2007	Toyota	Camry	JTNBE46K173087552
T86	Throttle body	2006	Ford	F-150	1FTRX14W76NA01309
T87	Throttle body	2005	Honda	Pilot	5FNYF184X5B010459
T9	Throttle body	2008	Mercedes	E350	
G72	Throttle body gasket	2003	Toyota	Camry	
S1	Throttle position sensor	2002	Toyota	Camry	
S21	Sensor Assembly	2006	Honda	CRV	
E15	Engine control	2002	Toyota	Camry	JTDBE32K020126517
E2	ECM	1998	Toyota	Camry	4T1BG22K9WU313141
E28	ECM	2000	Toyota	Tundra	5TBBT481XYS102606
E3	ECM	2000	Toyota	Camry	JT2BG22KXY0516739
E38	ECM	2000	Toyota	Tundra	5TBJN321XXS075089
E4	ECM	2002	Toyota	Tundra	5TBBN441025288437
E74	ECM	2002	Toyota	Camry	4T1BE30K82U034191
E85	ECM	2007	Toyota	Camry	4T1BE46K47U041370
C100	Pedal Cable	2008	Toyota	Camry	4TBK46K28U058243
C101	Pedal Cable	2008	Toyota	Camry	4TBF46K68U250708
C102	Pedal Cable	2008	Toyota	Camry	4T1BE46K28U768914
C16	Pedal Cable	2006	Chrysler	300	
C17	Pedal Cable	2006	Toyota	Tacoma	
C19	Wire, Throttle		Honda		
C20	Wire, Throttle		Honda		
C21	Harness		General Motors	General Motors	
C26	Pedal Cable	2006	Ford	F-150	1FTPW12576KD49083
C27	Pedal Cable	2007	Toyota	Sienna	5TDZK23C87S040157

Part #	Part	MY	Make	Model	VIN
C28	Wire, Throttle	2000	Toyota	Tundra	5TBBT481XYS102606
C28	Pedal Cable	2000	Toyota	Tundra	5TBBT481XYS102606
C30	Pedal Cable	2005	Nissan	Quest	5N1BV28U05N138320
C36	Cable	2006	Honda	Pilot	5FNYF28456B043747
C41	Cable	2000	Toyota	Tundra	5TBBT4411YS077570
C42	Cable	2001	Toyota	Camry	4T1BG22K11U860820
C58	Pedal Cable	2004	Toyota	Camry	4T1BE32K04U814752
C62	Pedal Cable	2007	Honda	CRV	JHLRE48517C095650
C66	Pedal Cable	2006	Toyota	Camry	4T1BA30K46U088962
C67	Pedal Cable	2004	Toyota	Camry	4T1BA32K94U028587
C68	Pedal Cable	2005	Chevy	Tahoe	1GNEK13TX5R249914
C70	Pedal Cable	2002	Toyota	Camry	4T1BE32K82U159920
C71	Pedal Cable	2002	Toyota	Camry	4T1BE32K52U619842
C79	Cable	2006	Chevy	Impala	2G1WB58K769119477
C81	Cable	2006	Honda	CRV	SHSRD78806U430838
C82	Pedal cable	2007	Toyota	Camry	4T1BE46K57U535432
C83	Pedal Cable	2007	Toyota	Camry	4T1BE46K17U357943
C84	Cable	2007	Toyota	Camry	JTNBE46K173087552
C86	Cable	2006	Ford	F-150	1FTRX14W76NA01309
C89	Pedal Cable	2002	Toyota	Camry	4T1BE32K12U512044
C94	Pedal Cable	2007	Toyota	Camry	4T1BE46K57U576191
C95	Pedal Cable	2007	Toyota	Camry	4T1BE46K07U528680
C96	Pedal Cable	2007	Toyota	Tundra	5TFLU52197X003582
C97	Pedal Cable	2007	Toyota	Camry	4T1BB46K07U019665
C98	Pedal Cable	2008	Toyota	Camry	4T1BE46K78U240303
C99	Pedal Cable	2007	Toyota	Tundra	5TFLU52127X001561
CR103	Cruise Control Actuator	2001	Toyota	Camry	4TBG26KX1U830108
CR104	Cruise Control Actuator	1998	Toyota	Camry	JTZBG22K2W0109432
H88	Connector Housing	2007	Toyota	Camry	
H93	Connector Housing	2007	Toyota	Tundra	
	ECM Connectors	2001	Toyota	Camry	4T1BG22K11U860820

Part #	Part	MY	Make	Model	VIN
B68	Brake pedal Assembly	2005	Chevy	Tahoe	1GNEK13TX5R249914

Appendix B

Comparison of Accelerator and Throttle Position-sensing Designs

Comparison of Accelerator and Throttle Position-sensing Designs

Overview

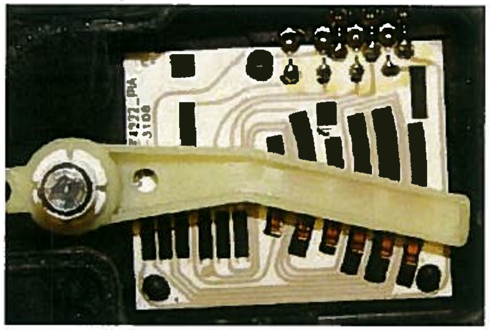
Overview

- Total of 18 different accelerator pedals and throttle bodies from 8 different manufacturers were inspected.
- Three different technologies were found:
  - Hall effect sensors
  - Potentiometers (resistive sensors)
  - Inductive sensors
- None of the inspected accelerator pedals or throttle bodies utilize more than one type of sensor technology.

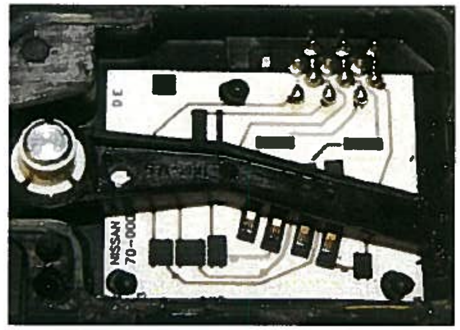
Hall Effect Sensors and Magnets

Toyota Tacoma 2006 Pedal (P17)	Mercedes E-series 2002 - 2008 Pedal (P10)	Honda Odyssey 2005-2006– Throttle (T43)	Honda CR-V 2007 Pedal (P18)	Toyota– Pedal	Toyota Camry 2007 Pedal (P1)

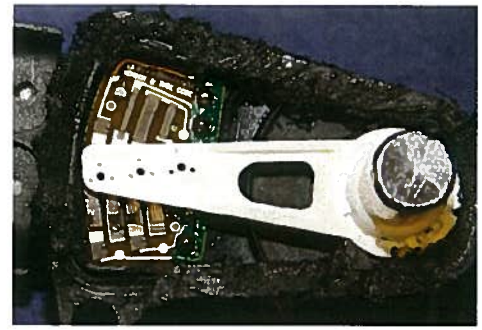
Potentiometer sensors



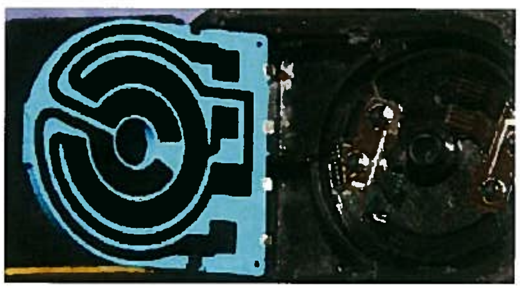
Ford F150 2006
Pedal (P33)



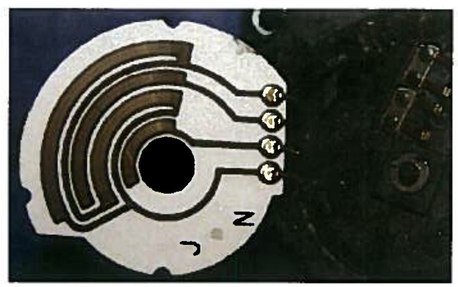
Nissan Quest 2005
Pedal (P25)



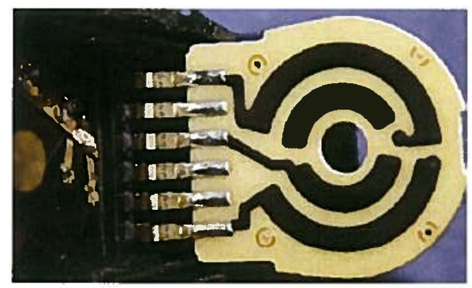
Chevrolet Impala 2006
Pedal (P22)



Ford F150 2006
Throttle (T14)

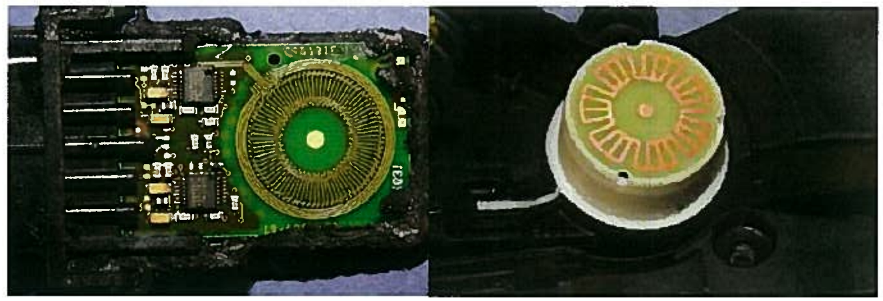


Nissan - Throttle
(T44)

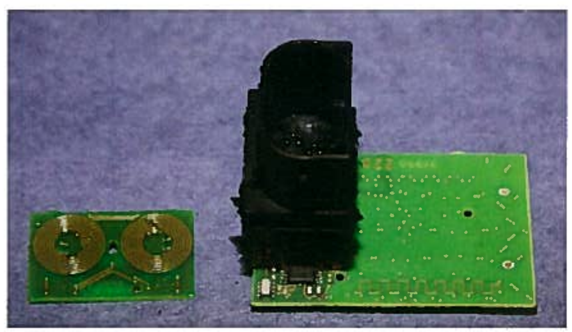


Toyota Camry 2002
Pedal (P4)

Inductive Sensors

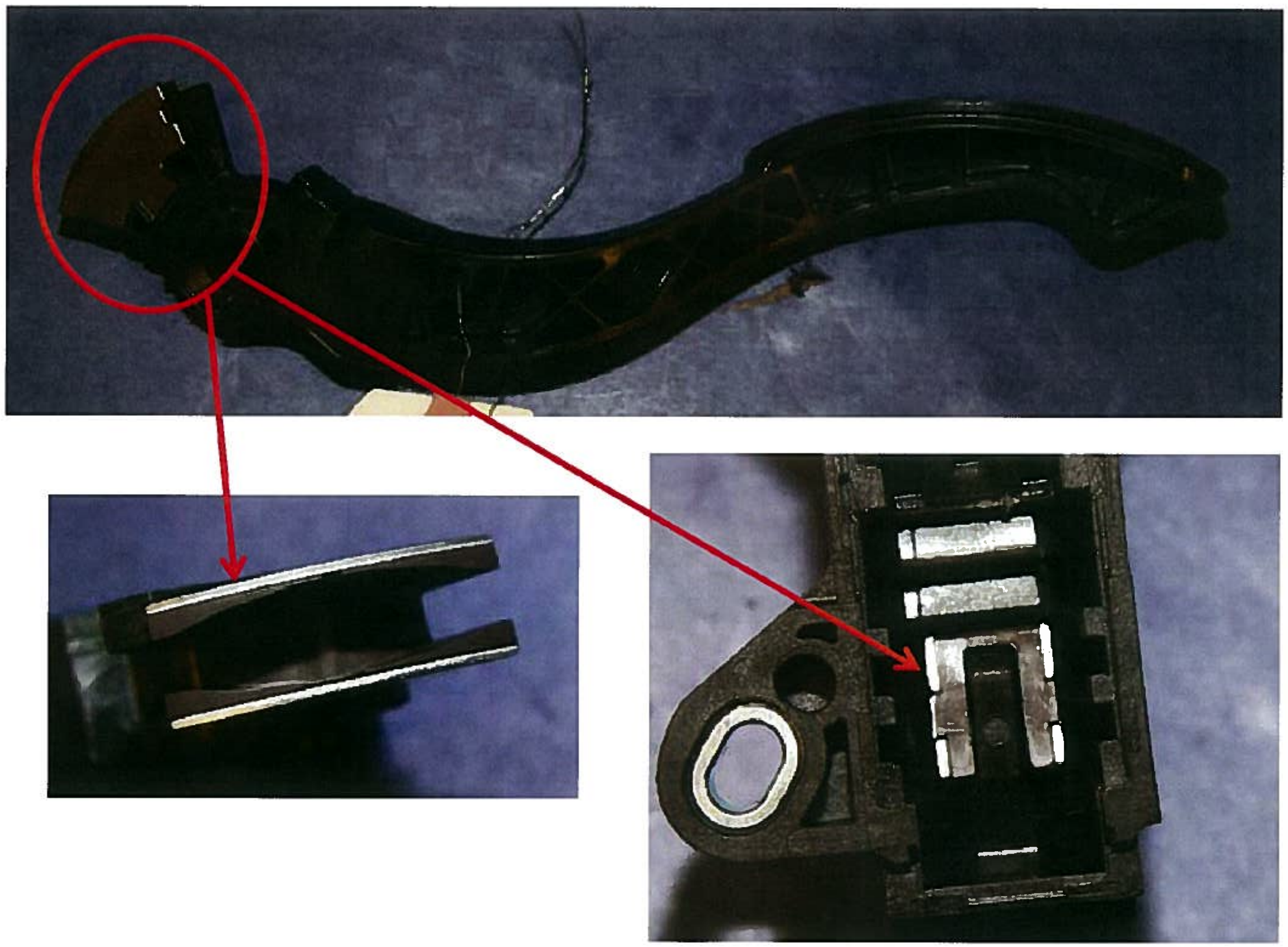


Chrysler – Pedal (P16, P12)



BMW – Pedal
(P53)

Toyota Camry 2007 Pedal Sensor and Magnet



Appendix C

Test Protocol

Test Protocol For Electronic Throttle Control Systems in Toyota and Lexus Vehicles

Date: ____________________

Vehicle Details:
Make: ____________________ Model: ____________________ Model Year: ____________________

VIN: ____

Test Materials

These tests involve altering the signals passed from the throttle body or accelerator pedal position sensor to the engine control module (ECM). The signals from the throttle body are accessed at the connector on the throttle body, as shown in Figure 1.

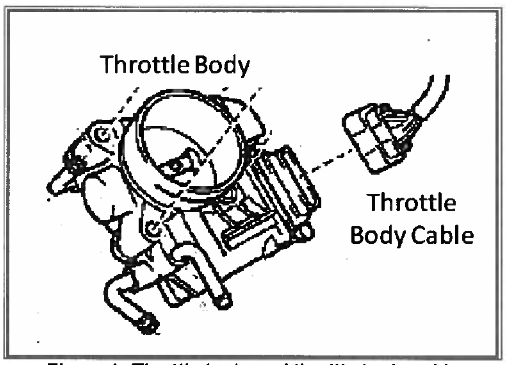


Figure 1 Throttle body and throttle body cable

The signals from the accelerator pedal are accessed at the connector located near the top of the accelerator pedal assembly, as shown in Figure 2.

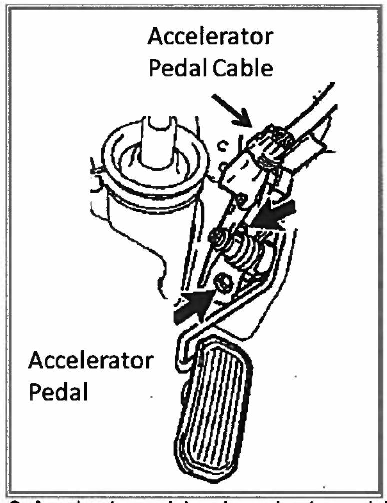


Figure 2 Accelerator pedal and accelerator pedal cable

Both sets of signals are separately modified using a breakout box. This box connects to either the throttle body or accelerator pedal using adapter cables specific to each connector. When attached to the throttle body, this box has the following functionality:

- Pass signals through unchanged
- Using power supplies, add positive or negative voltage to VTA1 and/or VTA2 signals
- Using power supplies, replace VTA1 and/or VTA2 signals with specified voltages
- Short VTA1 and/or VTA2 to ground
- Open circuit on VTA1 and/or VTA2
- Pass voltage supplied to throttle position motor through unchanged
- Insert resistance in series with the voltage supplied to the throttle position motor
- Insert resistance in parallel with the voltage supplied to the throttle position motor
- Always pass 5V and ground through unchanged

The wiring schematic for this breakout box is shown below in Figure 3.

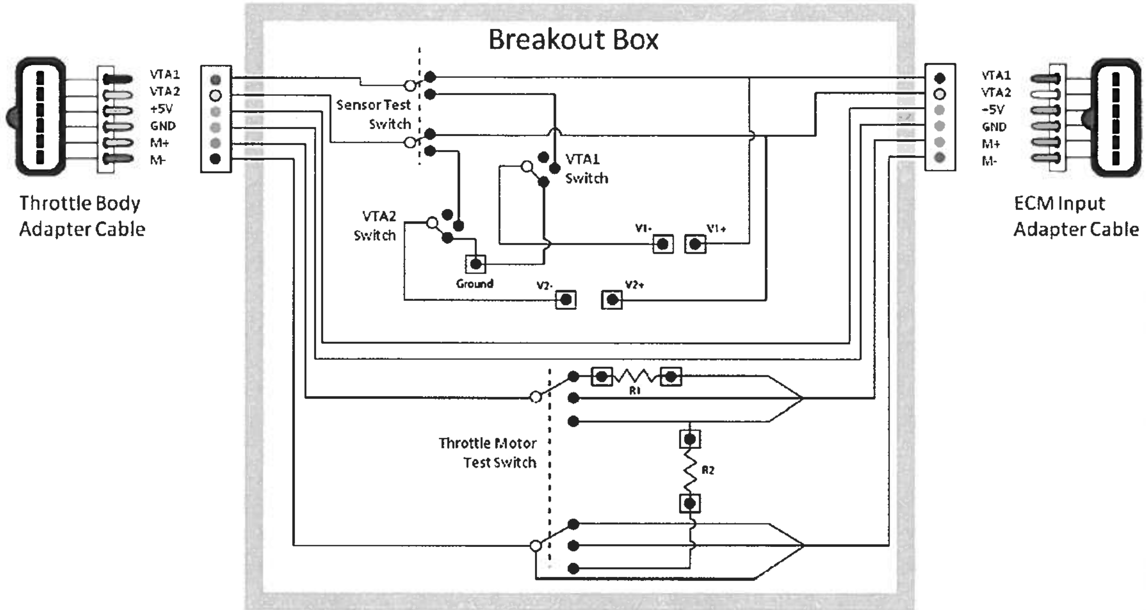


Figure 3 Breakout box and adapter cables configured for use with signals from the throttle body

When attached to the accelerator pedal, this box has the following functionality:

- Pass signals through unchanged
- Using power supplies, add positive or negative voltage to VPA1 and/or VPA2 signals
- Using power supplies, replace VPA1 and/or VPA2 signals with specified voltages
- Short VPA1 and/or VPA2 to ground
- Open circuit on VPA1 and/or VPA2
- Always pass 5V and ground through unchanged

When attached to the accelerator pedal, the throttle motor test switch circuitry is not used and the wiring schematic for the breakout box is as shown below in Figure 4.

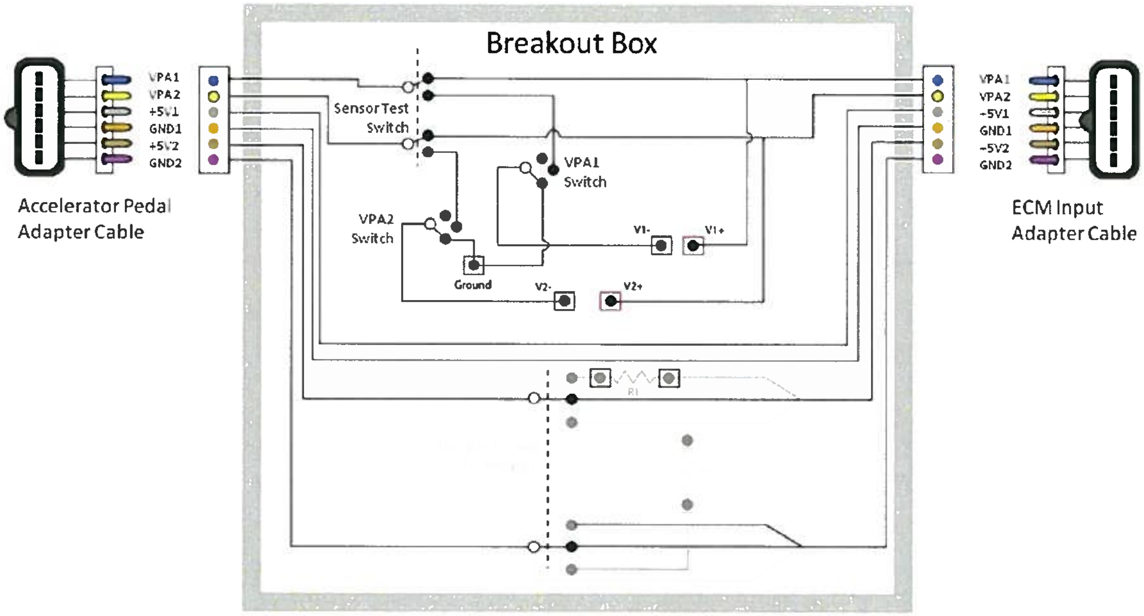


Figure 4 Breakout box and adapter cables configured for use with signals from the accelerator pedal

The breakout box modifies signals using inputs V1-, V1+, V2-, and V2+. These inputs can either be connected to the positive and negative terminals of power supplies, or connected together (V1- to V1+ and V2- to V2+) using standard banana connectors. Ground is attached to vehicle ground.

When configured for normal vehicle operation, the breakout box passes all signals through unchanged.

- The sensor test switch is set to pass signals through unchanged (up position)
- The throttle motor test switch is set to pass signals through unchanged (middle position)
- The VTA1/VPA1 and VTA2/VPA2 switches can be in either position, as they are not in use when the sensor switch is set to pass signals through unchanged.
- The V1 and V2 control inputs may be connected to power supplies or shorted, as they are not in use when the sensor switch is set to pass signals through unchanged.

Test Preparation

- Place vehicle in park, with parking brake applied. Vehicle should be secured with wheel stops or properly positioned on a dynamometer.
- Depending on the test being performed, disconnect either the throttle body or pedal wiring harness and attach breakout box using appropriate adapter cables.
- Prior to each test, clear any diagnostic trouble codes (DTCs), turn off the engine and restart the vehicle. Then turn off the vehicle again prior to starting the next test.
- If the vehicle will not start following a test, the battery may have to be disconnected then reconnected to clear all fault codes.
- After each test, make note of any DTCs or CEL.

Test 1: VTA1 Signal Short to Ground

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to ground (switch in down position).
- Connect V1- to V1+ with a jumper cable.
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 2: VTA2 Signal Short to Ground

Procedure

- Connect breakout box to throttle body cable.
- Set VTA2 switch to ground (switch in down position).
- Connect V2- to V2+ with a jumper cable.
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 3: VTA1 Signal Open Circuit

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to open circuit (switch in up position).
- Connect V1- to V1+ with a jumper cable.
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 4: VTA2 Signal Open Circuit

Procedure

- Connect breakout box to throttle body cable.
- Set VTA2 switch to open circuit (switch in up position).
- Connect V2- to V2+ with a jumper cable.
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 5: Decrease VTA1 Signal Voltage

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to power supply negative lead and V1+ to power supply positive lead.
- Set power supply to desired voltage decrease (e.g. -0.5V DC).
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 6: Decrease VTA2 Signal Voltage

Procedure

- Connect breakout box to throttle body cable.
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to power supply negative lead and V2+ to power supply positive lead.
- Set power supply to desired voltage decrease (e.g. -0.5V DC).
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 7: Increase VTA1 Signal Voltage

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to power supply negative lead and V1+ to power supply positive lead.
- Set power supply to desired voltage increase (e.g. +1.0 V DC).
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 8: Increase VTA2 Signal Voltage

Procedure

- Connect breakout box to throttle body cable.
- Set VTA2 switch to pass signal through (switch in middle position).
- Connect V2- to power supply negative lead and V2+ to power supply positive lead.
- Set power supply to desired voltage increase (e.g. +1.0 V DC).
- Set VTA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running, turn sensor test switch on (down position).

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 9: Throttle Motor Circuit Failure—High Current

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to pass signal through (switch in up position).
- Connect V1- to V1+ with a jumper cable.
- Set VTA2 switch to pass signal through (switch in up position).
- Connect V2- to V2+ with a jumper cable.
- Set sensor test switch to pass signals through unchanged (switch in up position).
- Set motor to pass current through unchanged (switch in middle position).
- Install R2 jumper (0.25 Ω) to purple connectors.
- Start the engine.
- Set motor test switch such that R2 is in parallel with the throttle motor (switch in down position).
- Modulate throttle.

Expected Result

☐ Check engine light on
☐ DTC: ____________
Comments____

Test 10: Throttle Motor Circuit Failure—Low Current

Procedure

- Connect breakout box to throttle body cable.
- Set VTA1 switch to pass signal through (switch in up position).
- Connect V1- to V1+ with a jumper cable.
- Set VTA2 switch to pass signal through (switch in up position).
- Connect V2- to V2+ with a jumper cable.
- Set sensor test switch to pass signals through unchanged (switch in up position).
- Set motor to pass current through unchanged (switch in middle position).
- Install R1 jumper (500 Ω) to blue connectors.
- Start the engine.
- Set motor test switch such that R1 is in series with the throttle motor (switch in up position).
- Modulate throttle.

Expected Result

☐ Check engine light on
☐ DTC: ____________
Comments____

Test 11: Throttle Valve Stuck

Procedure

- The breakout box is not used for this test.
- With the vehicle off, disconnect the throttle body from the air intake.
- Rotate the throttle plate open and insert one end of a wire under the throttle plate so as to prevent the throttle from fully closing. See Figure 5. The throttle plate should be open approximately 5 mm at the largest opening point.

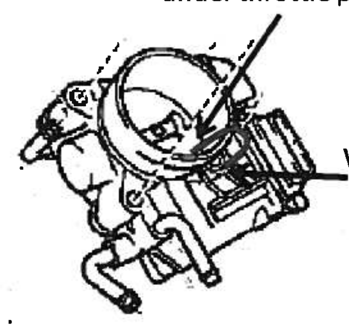


Figure 5. Wire inserted in throttle body to prevent throttle from fully closing.

- Bend the other end of the wire around the outside the throttle body so as to secure the wire. *Make sure that the wire is secure, so that it will not be inducted into the engine once the engine is started.*
- After securing the wire, reattach the air intake.
- Start the engine.
- Modulate throttle.

Results

☐ Engine stalls
☐ Check engine light on
☐ DTC: ____________
Comments____

Test 12: VPA1 Signal Short to Ground

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA1 switch to ground (switch in down position).
- Connect V1- to V1+ with a jumper cable.
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 13: VPA2 Signal Short to Ground

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA2 switch to ground (switch in down position).
- Connect V2- to V2+ with a jumper cable.
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 14: VPA1 Signal Open Circuit

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA1 switch to open circuit (switch in up position).
- Connect V1- to V1+ with a jumper cable.
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 15: VPA2 Signal Open Circuit

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA2 switch to open circuit (switch in up position).
- Connect V2- to V2+ with a jumper cable
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 16: Decrease VPA1 Signal Voltage

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to power supply negative lead and V1+ to power supply positive lead.
- Set power supply to desired voltage decrease (e.g. -0.5V DC).
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 17: Decrease VPA2 Signal Voltage

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to power supply negative lead and V2+ to power supply positive lead.
- Set power supply to desired voltage decrease (e.g. -0.5V DC).
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ___________
Comments____

Test 18: Increase VPA1 Signal Voltage

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to power supply negative lead and V1+ to power supply positive lead.
- Set power supply to desired voltage increase (e.g. +1.0 V DC).
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to V2+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____

Test 19: Increase VPA2 Signal Voltage

Procedure

- Connect breakout box to accelerator pedal cable.
- Set VPA2 switch to pass signal through (switch in middle position).
- Connect V2- to power supply negative lead and V2+ to power supply positive lead.
- Set power supply to desired voltage increase (e.g. +1.0 V DC).
- Set VPA1 switch to pass signal through (switch in middle position).
- Connect V1- to V1+ with a jumper cable.
- Start vehicle with breakout box in the normal vehicle configuration (sensor and motor test switches set to pass signals through unchanged).
- While vehicle is running at idle, turn sensor test switch on (down position).
- Modulate throttle.

Results

☐ Check engine light on
☐ Engine in power limited mode
☐ DTC: ____________
Comments____