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# **Sensitivity of Contact Electronic Throttle Control Sensor to Control System Variation**

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# Sensitivity of Contact Electronic Throttle Control Sensor to Control System Variation

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## ABSTRACT

The purpose of this paper is to improve the understanding of the advantages of a non-contact electronic throttle control (ETC) air control valve position sensor over the potentiometer technology of contacting position sensors. The non-contact position sensing offers the industry an opportunity to take advantage of an improved ability to assess reliability of the product and utilize accelerated testing techniques with improved robustness to control system perturbations. Specifically; eliminating the contact wear failure mechanism reduces the complexity, and duration of ETC air control valve life testing and increases the robustness of the ETC system to noise factors from the control system variation.

## INTRODUCTION

Two types of issues are frequently encountered with the use of contact sensor technology for ETC systems. The first issue includes anticipated real problems that are not detected during the development of the ETC/sensor (type 1 error). The second issue deals with false test failures related to poor test correlations which raise issues that are not related to field operation (type 2 error).

One source of these errors is control system variation in bench testing systems. Typical contact sensor ETC air control valve testing may not properly account for all the factors that affect contact sensor durability. The tribology and wear debris management issues in contact sensor design produce significant sensitivity to test methods and strategies (controlled and uncontrolled variables). This paper describes the relationship of the ETC air control valve test cycling profile to perturbations of the closed loop control signal, and the correlation errors, which can produce electrical signal noise issues. The ETC air control valve supplier must

have a clear understanding of the vehicle control system to insure product robustness.

The contact position sensors used on ETC air control valves have generally shown themselves to be capable of providing acceptable performance over the life of the vehicle. Detailed ETC cycling profile tests have been developed by various manufacturers to assess the durability of the ETC air control valve and within the air control valve the contact position sensors' ability to resist wear. The demonstration of the differences between the industry ETC bench cycling profiles and a perturbed closed loop control system were the basis of this study to highlight the advantage of a non-contact ETC air control valve sensor's improved ability to assess and demonstrate robustness to control system variation.

## DISCUSSION

### ETC OVERVIEW

The use of electronic throttle control (ETC) systems is becoming standard on vehicle systems to allow advanced powertrain control, meet and improve emissions, and improve driveability. An ETC system architecture consists of a pedal module to translate the drive input to an electrical signal for the engine control module and an ETC air control valve. The ETC air control valve is typically referred to as an ETC or ETB (electric or electronic throttle body). We will use the ETC terminology throughout this paper for the air control valve portion of the ETC system. For specified areas where we are referring to the ETC as the entire system we will utilize the terminology of 'ETC system'.

The ETC receives the command electrical signal from the engine control module and moves the throttle valve to allow airflow into the internal combustion engine. The ETC provides feedback of

its relative position as measured by the throttle position sensor (TPS) from the throttle to the engine control module (ECM). (A diagram of a typical ETC system is shown in Figure 1.)

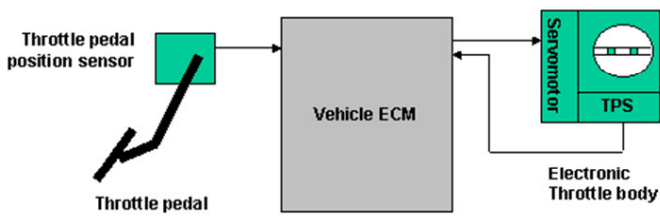


Figure 1

The ETC has two main functions. The first is to regulate the airflow into the engine. This airflow control contributes to the regulation of the engine speed and power. The second function is to indicate the throttle valve relative position for closed loop system control and diagnostics. This paper focuses on this relative position measurement function.

A typical ETC system has greater demands on the relative position signal from the TPS and the quality of the signal than previous mechanical systems. In order to provide the required closed loop functionality the TPS signal is checked continually for reliability by the system. This criticality has created greater challenges for TPS performance (particularly in the contacting sensor where noise on the sensor electrical signal is inevitable).

## THROTTLE POSITION SENSOR CONSTRUCTION

The ETC typically utilizes dual position sensors to communicate the relative position of the throttle to the engine control module for closed loop position control. For most ETC there are two redundant position sensors used to enable diagnostic capability between the sensors. The correlation and tracking of these two signals can be used to detect possible failures in the system, wiring, electrical connections, or component issues. Electrical noise on the sensor signal is frequently the root cause of correlation failures.

The current throttle position sensors used on many vehicles consist of a thick-film resistive potentiometer with a moving contact that provides

an output signal proportional to the throttle shaft position. (See figure 2 for a typical representation.)

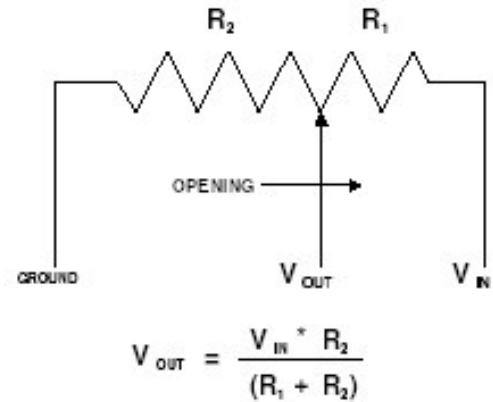


Figure 2

The electrical input is applied between the ends of the resistive strip track forming an electrical gradient along the length of the track. A collector (or lead) track of minimal resistance runs approximately parallel to the resistor track. A multiple finger 'wiper' contacts both the resistive strip track and collector track to transmit the ratiometric signal position from the resistive strip track to the output circuit. (See Figure 3)

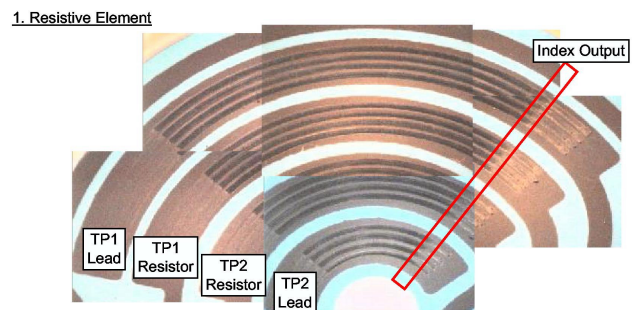


Figure 3

The wiper is connected via a rotor to the throttle shaft. The output voltage level of the sensor is converted in the engine controller to be used for ETC position closed loop control, diagnostics and as an input for engine control.

## CONTACT SENSOR WEAR FAILURE MECHANISM

With this variable resistor technology, the wear of the wiper-to-track sliding interface is typically the limiting failure mode for long life sensor reliability. As wear occurs at this sliding interface, debris can be trapped between the wiper and the tracks. This significantly increases contact resistance, producing changes in voltage (noise) on the output signal. This noise on one of the sensors is detected in the correlation between sensor 1 and sensor 2 diagnostics. The OBD2 diagnostic for ETC TPS correlation is typically known as P2135. (See Figure 4.)

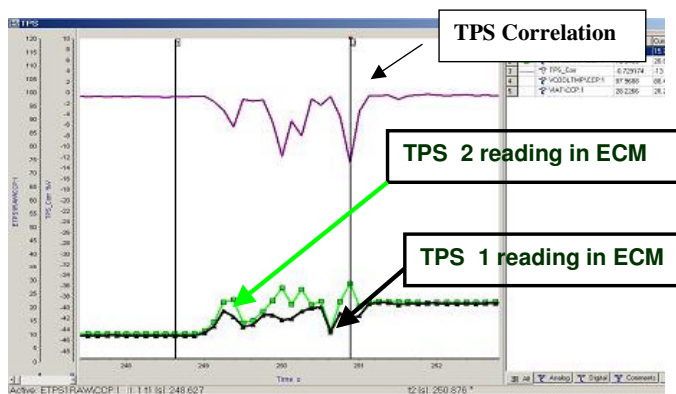


Figure 4

Two methods are commonly used to address the electrical noise caused by debris between the wiper and track. These methods are debris avoidance and debris management. Debris avoidance attempts to balance hardness, friction, and pressure between the points in contact to maximize the time to the start of debris formation on the sensor surface. Once the debris is formed the sensor is likely to begin to produce noise on the electrical outputs. The second method is debris management. Debris management attempts to keep the debris created during the wearing of the wiper and track surfaces from becoming trapped between the wiper and tracks. This strategy optimizes hardness, contact force, geometry, and lubrication to prevent electrical noise. As debris levels increase the balance degrades and the likelihood of noise increases.

Both methods have been shown to be effective in delaying failure due to noise until beyond design life goals, but experience has shown that maintaining this design life standard pushes the limits of production process capability and test reliability (execution and correlation).

## ETC AIR CONTROL VALVE BENCH TESTING

The vehicle OEMs have standard ETC cycling profiles to evaluate ETC durability. Contact sensor durability is evaluated within these cycles. (see figures 5,6,7)

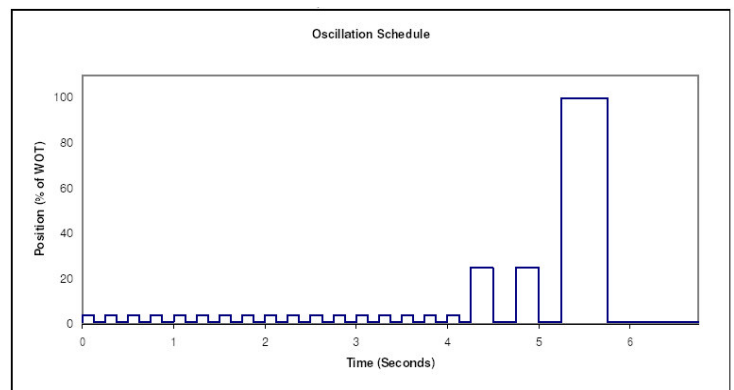


Figure 5

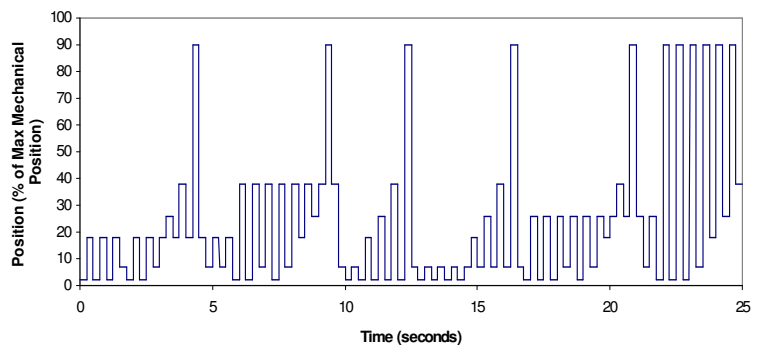


Figure 6

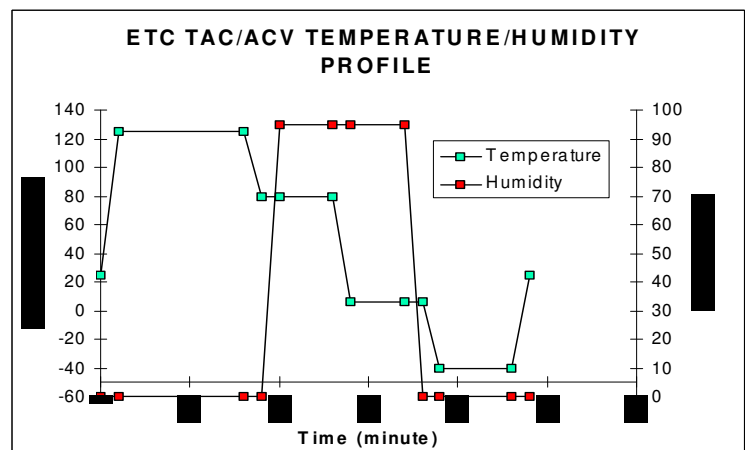


Figure 7

Figures 5 & 6 are two of many ETC cycle profiles. Cycle profiles typically have a mixture of small ETC maneuvers to simulate idle control, medium range maneuvers to simulate typical drive positions and wide open throttle cycles. Between figure 5 and 6 the numbers of these maneuvers differ as a percentage of the total number of cycles. Additional ETC cycling tests have been added by some vehicle OEM's for heavy acceleration events; constant throttle position control; ignition key cycling events; and un-powered returns from wide open throttle to attempt to represent all worst case applications and throttle maneuvers. These ETC cycle profiles were developed to correlate to worst-case ETC control system usage. The exact failure modes that these cycle profiles were correlated to at the system level may not be representative of TPS wear failure modes. A worst-case ETC system cycling profile may not produce the worst case ETC TPS wear. The details of these cycling profiles can have a significant effect on the wear of the sensor and the ability to correlate bench testing of ETC (inclusive of TPS wear) to field performance.

For example, the cycle profiles as illustrated have square waveforms that can cause high accelerations. The commanded waveform may produce unanticipated resonance in the actual motion at the limits of closed loop position control system performance (under-damped control). In the sensor all accelerations (particularly changes in direction) produce heat and stress at the wiper/track interface. A sinusoidal cycle has a completely different wear characteristic than a square waveform due to the average velocities and number of accelerations & decelerations. The accelerations and velocities within the contact sensor greatly affect the tribology of the wiper-to-track interface surface. As the accelerations of the control system increase, the ability of the wiper to move debris decreases as the wiper tends to move over the debris rather than sweep the material to the end of the track. This relationship is one of several complex interactions which make test correlation and repeatability so difficult. The common problems with all of these interactions are difficulties in measurement and control limitations.

These bench cycling tests as executed by ETC suppliers can produce differing results for contact sensor wear, since each ETC supplier has differing test cycling stations to execute the specified ETC cycling profiles. Also under-damped oscillations within the test stand controls can occur as the ETC reaches it's controlled position or over-damped control systems can under-simulate velocities or oscillations experienced in field usage.

Total degrees traveled, number of turn-arounds, accelerations, and average velocity of the TPS are additional measures used by ETC and sensor manufacturers to attempt to quantify the cycle profile severity and compare results across applications. These measures while helpful in highlighting differences between ETC cycling profiles do not provide insight into sensitivity of ETC testing to control system perturbations.

## BASELINE BENCH TESTING

ETC Component testing was conducted by Delphi using the industry multiple standard cycling profiles (as shown in Figures 4-6) with temperature and humidity exposure during all cycling. Testing was conducted with step time and transition time typical of industry specifications. ETCs were tested to multiple lifetimes (3.0+ lives) with no issues involving TPS correlation to demonstrate robustness of the contact sensor to ETC industry cycling profiles. (see figure 8 for end of test data)

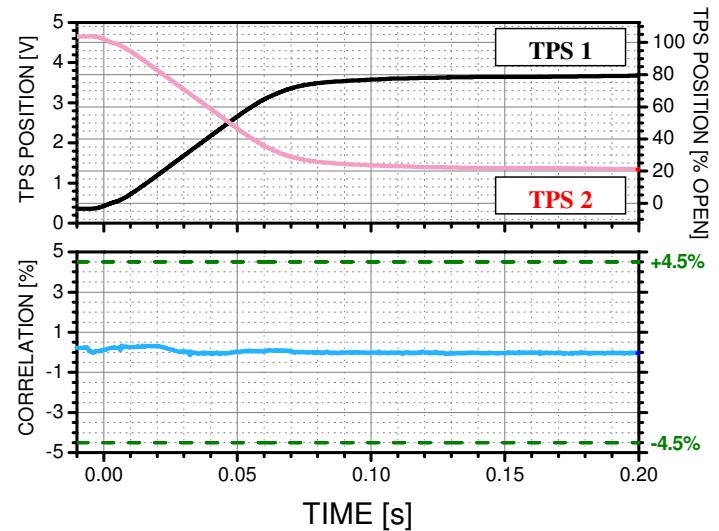


Figure 8

This component testing demonstrated a reliability of 97% with 70% confidence with Beta of 2 based on success testing completed. (See Figure 9)



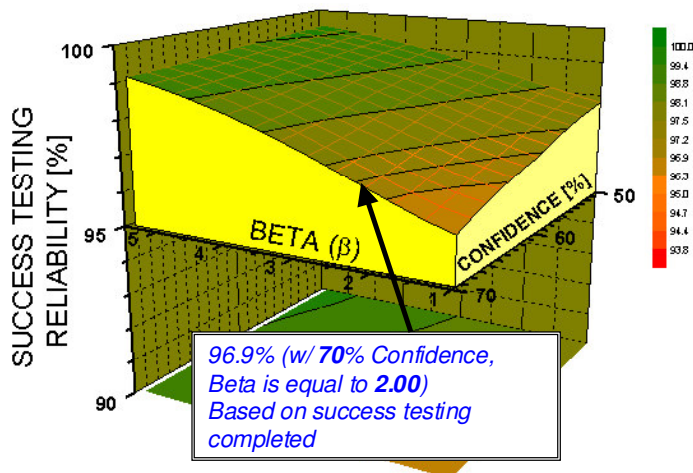


Figure 9

## MODIFIED BENCH TESTING

This bench testing was compared to modified bench testing to assess the robustness of the contact sensor to control system perturbations.

The modified testing used a reasonable control perturbation imposed on the feedback system. The control system perturbation increased the aggressiveness of the ETC control system to attempt to drive the ETC to an exact position. This aggressive system produced a low level oscillation superimposed on the base feedback control system. (See Figure 10). The TPS signals shown follow the desired (or commanded) control of the ETC control system. Within the ETC these oscillations result in an increase in the reversals and accelerations in the contact sensor.

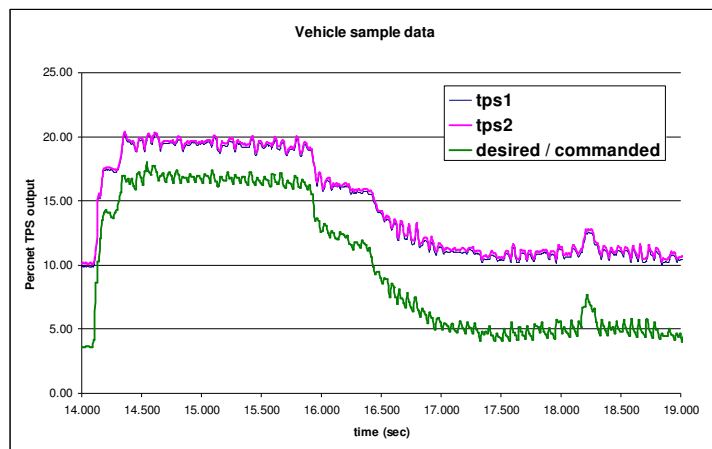


Figure 10

This oscillation overlay has been noted on previous control systems and was used as a comparison base line because of the likelihood of this occurring

due to control system gains, system noise, battery voltage variation, and other real world effects. This modification represents the subtle variables that significantly affect the failure mechanism of wear on the contact sensor.

Testing was completed with the oscillation overlay and showed a significant increase in noise and correlation errors on the ETC. ETC contact TPS noise would appear beginning at approximately 0.3 lives of cycling. As noise appeared on the sensor signals the control system aggressiveness would drive the system to a higher amplitude oscillation further accelerating wear on the contacting surfaces. (see figure 11 for end of test sensor correlation errors).

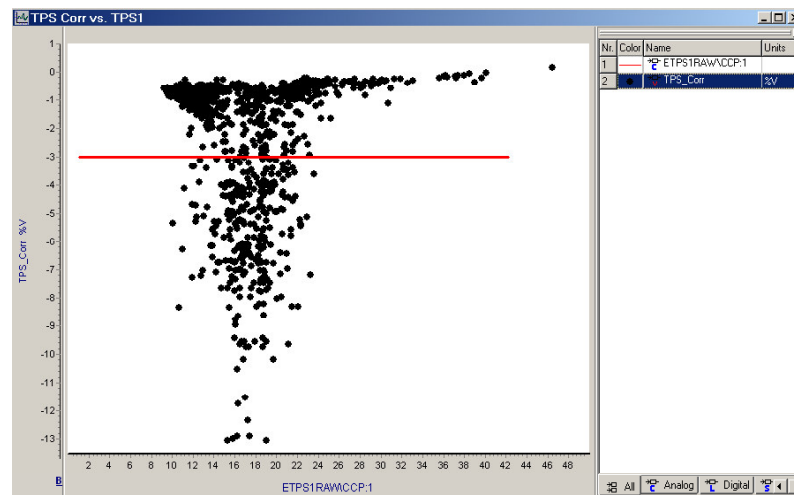


Figure 11

The results of the testing demonstrated the lack of correlation that may exist between the standard ETC bench testing cycling profiles and modified drive profiles with small perturbations in the feedback control system. By introducing a more aggressive control system we were able to demonstrate that small changes to ETC controls can have a significant durability effect on ETC contact sensor performance. This study demonstrated a durability decrease from 3.0+ lives to 0.3 lives.

While contact ETC sensors have demonstrated multiple lifetime durability, given extended usage wear (debris) between the contacting brush and resistive strip will occur. With a control system that has oscillations the mechanism of wear is accelerated. This sensitivity to control system variation could be addressed with more detailed specifications on the ETC bench testing (acceleration, velocity, ...). Unfortunately, additional controls could change the correlation of the ETC bench cycling profiles to the other failure

mechanisms being evaluated during bench testing (gear, motor, bearing durability). The sensitivity to control system variation is more effectively addressed by the utilization of non-contact sensor technology to eliminate the failure mode.

Proper design and analysis of non-contact technology eliminates cycle related failure modes and the previously mentioned sensitivities and correlation problems. This risk elimination helps offset risk and cost associated with the introduction of new technology in the ETC system by allowing better correlation of failure mechanisms and decreased bench validation testing. For many programs (i.e. extended durability applications such as medium and heavy duty truck applications) new non-contact sensor technology may represent lower overall risk and cost considering the extended ETC cycling bench testing and correlation issues with extremely long life contact ETC sensor wear.

## **CONCLUSION**

This study illustrates the complex interactions of contact sensor testing to control system variation. The elimination of the complex wear failure mechanisms of a contacting sensor represents a robustness advantage that the non-contact sensor technology has to improve test confidence. Specifically, eliminating the contact wear failure mode reduces the complexity, duration and uncertainty for ETC bench cycling testing. The failure mechanisms of the contact sensor involve inevitable wear and noise on the sensor electrical signal that are not clearly correlated across control systems changes.

The introduction of this new technology of non-contact position sensing offers the industry an opportunity to take advantage of improved ability to assess reliability of the product. With the elimination of the wear failure mechanisms, ETC bench testing can be simplified resulting in higher confidence testing.

## **CONTACT**

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## **DEFINITIONS, ACRONYMS, ABBREVIATIONS**

**ECM:** Engine Control Module

**ETB:** Electronic or Electric throttle body

**ETC:** Electronic throttle control

**OBD2:** On-board diagnostics

**TPS:** Throttle Position Sensor