ETC Air Control Valve (ETC-ACV)

Application Manual

DELPHI

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ELECTRONIC THROTTLE CONTROL (ETC) AIR CONTROL VALVE ASSEMBLY APPLICATION MANUAL

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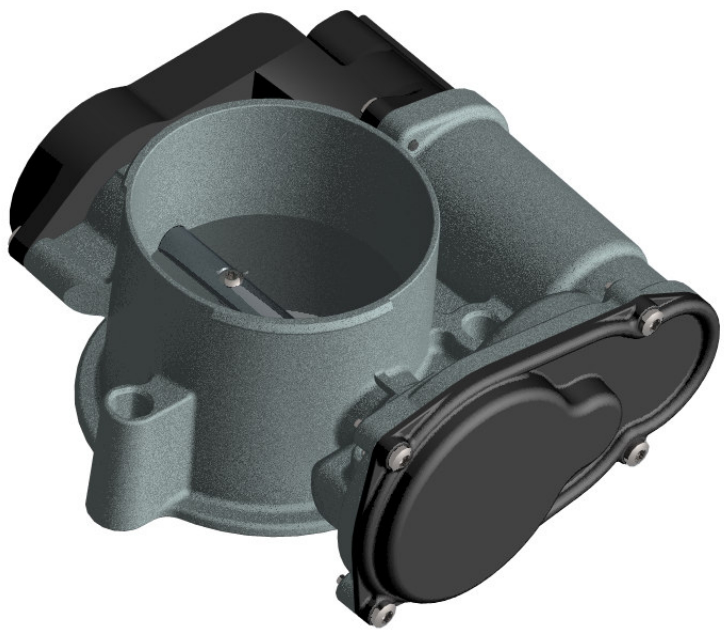

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ETC-ACV Application Manual
Release/Revision Summary Sheet

CHANGE NO.	DATE	REASON FOR CHANGE	Changed By	PAGE(S)
Original	26SE00	N/A		N/A
1	23JA02	Update to latest technology	Iannone	All
2	13JN03	Update figures and graphs to reflect current ETC designs. Update company information. Update ETC Specific Software Recommendations. Update interface information. Update ETC Specific Precaution information. Update ETC specific Validation Information. Add latest lessons learned.	Iannone	All

Table of Contents

1.0 Introduction

1.1 Scope of Document

This Application Manual communicates application requirements for Delphi-E&C Electronic Throttle Control Air Control Valve (ETC-ACV) Assemblies.

1.2 Classification

The information and specifications in this manual are applicable to vehicles and systems that regulate intake air of Spark Ignition internal combustion engine applications with Electronic Throttle Control using a Delphi ETC Air Control Valve Assembly.

1.3 Document Management

This document and all content herein shall be maintained and controlled by Delphi-E&C. Any changes or revisions must come through agreement with Delphi E&C. Express written consent of Delphi-E&C must be obtained before any modification of this document.

1.3.1 Document Release and Updates

The information contained in this manual is accurate and current as of the date of publication. As changes occur that update the content of the manual a new manual revision shall be released. All updates shall be issued and distributed by Delphi-E&C electronically. The latest revision shall be uploaded to an Applications Engineering website for access throughout Delphi.

Releases/Revisions Summary Sheets shall contain the following information:

- Sequential number of the revision
- Date the revision is implemented
- Discussion:

  The reason the revision was made

- The last name of the change originator
- The section or page numbers affected

1.3.2 Document Revision Procedure

Change requests may originate from within Delphi-E&C, or be made by users. All suggested changes must eventually be directed to the Delphi-E&C Applications Group in Rochester, NY.

On receiving a revision request, the Delphi-E&C Applications Group will submit the request to the appropriate individuals for review. Approved requests will result in revision of the affected section(s).

1.4 Commercial Considerations

All commercial considerations, cost, and scheduling requirements shall be handled by a Delphi-E&C Program Manager. The Applications Manual is a technical resource, and not intended to address specific commercial issues.

1.5 Objectives of This Manual

This ETC-ACV Application Manual has been developed to support your work as you apply this technology to your powertrain control system.

The objectives of this document are to help you:

- Obtain maximum value and optimum performance from the ETC-ACV Assembly.
- Integrate the ETC-ACV Assembly within your Electronic Throttle Control (ETC) system (hardware and software).
- Protect the ETC-ACV Assembly from damage caused by improper mounting, handling, or installation.
- Prevent testing errors that might result in an inaccurate evaluation of the ETC Air Control Valve Assembly or system performance.
- Prevent application errors that may prevent the ETC Air Control Valve from operating properly.

To accomplish these objectives, this manual provides the following:

- A description of the components and features of the ETC Air Control Valve.
- ETC Air Control Valve operating parameters.
- Application guidelines.
- Handling and installation recommendations.
- Testing recommendations.

1.6 How This Manual is Arranged

This manual provides a logical and sequential model to follow when applying the ETC Air Control Valve to any application. An overview of each section in this manual is provided below.

Section 1.0 — Introduction

Section 1.0 provides an overview of the scope, objectives, and format of this manual and lists documents on which it is based. You may wish to refer to the listed documents for additional detail to aid in understanding the requirements set forth in this manual.

Section 2.0 —Fundamentals

Section 2.0 describes basic principles of ETC Air Control Valve Assemblies and their components.

Section 3.0 — Product Description

Section 3.0 provides an overview of the Delphi-E&C ETC Air Control Valve, defines physical and electrical specifications of the sub-components, discusses critical characteristics and presents the operating conditions within which the throttle bodies are designed to perform. The quality, reliability, and durability goals of Delphi-E&C for the ETC Air Control Valve also are described.

Section 4.0 — System Interface

Section 4.0 describes and illustrates the mechanical and electrical interfaces required to obtain optimum performance from the ETC Air Control Valve. The electrical interface with the engine controller is also discussed.

Section 5.0 — Software

Section 5.0 provides an overview of the software requirements of the ETC-ACV Assembly.

Section 6.0 — Product Handling

Section 6.0 presents Delphi-E&C recommendations for the handling, storage, installation, and servicing of the ETC-ACV Assembly. Proper handling of the product, from the time it arrives on the receiving dock until it is installed in the vehicle, reduces the risk of accidental damage and helps ensure that the ETC will function as intended.

Section 7.0 — Recommendations and Precautions

Section 7.0 provides a summary of Delphi-E&C recommendations and precautions for ETC-ACV Assembly use. Common misuses are identified and alternate solutions presented.

Section 8.0 — Testing Recommendations and Precautions

Section 8.0 discusses testing procedures and precautions that are based on the experience of Delphi-E&C and its customers. By adhering to the recommendations contained in this section, you will ensure that the throttle body is evaluated correctly under conditions that parallel normal use and operation. A concerted effort must be made to apply test strategies in ways that prevent bias from entering the evaluation process.

Section 9.0 — Validation Requirements

Section 9.0 outlines the process for validating the ETC-ACV Assembly (i.e., ensuring that it meets specified quality, reliability, and durability goals and conforms to governmental standards/regulations).

Section 10.0 — Appendix

10.1 — Glossary of Terms and Abbreviations

10.2 — Customer Component Checklist - ETC

Section 11.0 — Index

1.7 Conventions Used in This Manual

The pages in this manual are formatted with a wide left margin. The purpose of this format is to help you locate important topics as you read through the document. You will notice that the left margin contains the following information:

- Important words and information to which you should pay special attention.

Other important information is shown in italic type and is preceded with the boldface word **NOTE, CAUTION,** or **WARNING.**

- ***Note*** *— Presents important technical detail that is relevant to the topic being discussed.*
- ***Caution*** *— Presents information about a condition or an activity that must be performed to prevent damage to the ETC Air Control Valve, the engine, the powertrain control system, or the vehicle.*
- ***Warning*** *— Identifies a condition that might pose a risk to your personal safety and/or the safety of others.*

Note*: Unless otherwise noted, the numbered figures displayed in this manual are illustrations, not technical drawings. As such, these illustrations may not reflect actual dimensions. All final critical dimensions should be confirmed on part prints.*

1.8 Applicable Documents

1.8.1 Order of Precedence

When there appears to be a contradiction between this Application Manual and an outline drawing or other document, the conflict must be formally resolved through Delphi-E&C. Until the contradiction can be resolved, the part outline drawing will take precedence.

1.8.2 Government Documents

To be supplied by customer for specific country.

Examples of government documents are Federal Motor Vehicle Safety Standards (FMVSS) documents.

1.8.3 Other Delphi-E&C Reference Documents

1.8.3.1 ETC-ACV Assembly P/N

1.8.3.2 ETC Specific Component Requirements Documents

1.8.3.3 Delphi-E&C Engineering Specification, Number, Date

1.8.3.4 SFMEA

1.8.3.5 DFMEA

2.0 Electronic Throttle Control Fundamentals

2.1 Air Control Valve Function

The ETC Air Control Valve function is to regulate airflow to an engine in response to commands from an engine controller. The ETC Air Control Valve provides feedback relative to its current operating position to the engine controller.

An Electronic Throttle Control (ETC) system replaces the traditional mechanical Throttle Body Assembly, mechanical accelerator pedal and cables with an Accelerator Pedal Module, wiring, a Throttle Controller (commonly integrated in the engine controller), and an ETC Air Control Valve. The ETC Air Control Valve regulates airflow by positioning the throttle valve in response to commands from the engine controller (in conjunction with the Throttle Controller) that incorporate driver inputs and inputs resulting from Engine Management and security diagnostics.

The ETC Air Control Valve can be used to function as a cruise control servo, a traction control system throttle relaxer servo, a speed governor servo, an Idle Air Control Valve (IACV) or any other device that would traditionally externally regulate the fresh intake airflow to an engine. Using an ETC Air Control Valve instead of a mechanical throttle system eliminates the need for adding extra servo/actuators, wiring, and control electronics when adding these vehicle system features.

Most automotive engines operate in a transient environment. (i.e. From idle, to part throttle, to cruise, to wide open throttle (WOT) and back to idle again.) ETC Air Control Valve design may impact the transitions during these modes (depending on control strategy) and therefore, may be critical to drivability and performance.

An ETC system is more flexible through calibration to accommodate these transient conditions than a traditional mechanical throttle body system would be. The ETC Air Control Valve follows a command signal that can be calibrated to engine airflow requirements, rather than simply following a throttle cable that is controlled by a foot pedal. The ETC Air Control Valve design affects how well the calibrations will work.

In use, the ETC Air Control Valve has one major difference from the function of a mechanical throttle body. The ETC ACV will not often be commanded fully closed (to minimum mechanical position), where the throttle body will be fully closed for a significant portion of its normal use.

The ETC Air Control Valve may have additional functions included in its design. These additional functions are options that can be designed to add value to the product. The ETC can provide a source of vacuum. The ETC can provide a source of "fresh" filtered air (for PCV system).

2.2 Air Flow Function

The ETC-ACV is an air valve that regulates the airflow into the engine and thereby contributes to the control of engine speed and power.

The throttle valve and bore provide the smallest flow area in the intake system except at or close to Wide Open Throttle (WOT). Under typical conditions, most of the intake system pressure drop occurs across the throttle valve.

The air mass flow rate across the throttle valve is directly related to the effective cross-sectional areas which may be described as the "crescent moon-shaped" open areas on either side of the throttle valve. The following factors should be considered when analyzing the flow through the throttle valve:

1. The minimum stop is set at a position above the complete closed bore position in order to prevent binding in the throttle bore. This position is defined as minimum mechanical position.

2. The throttle shaft diameter is large enough to affect the throttle effective open area, especially at the near wide open throttle condition.

3. Some air leakage is expected due to manufacturing tolerances. The leakage is expected to be very small.

4. The pressure drop across the throttle valve under the actual engine application flow conditions may be less than under steady flow conditions. Consequently, the actual airflow may be less than the calculated airflow.

5. The discharge coefficient (Cd) of the throttle valve varies with throttle angle, pressure ratio, and Reynolds number. This coefficient can be obtained experimentally.

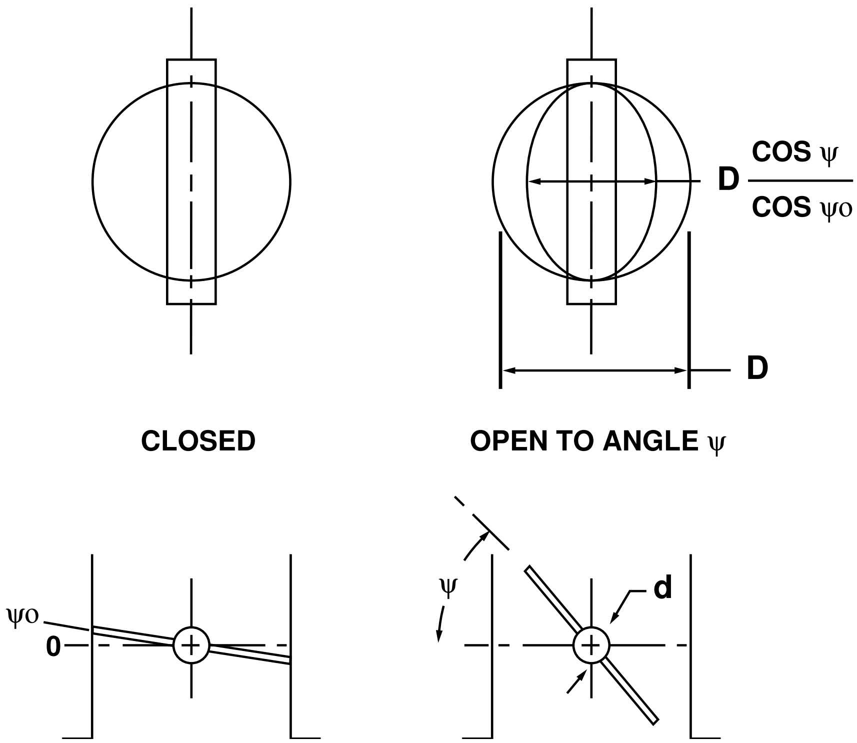


Figure 2-1. Air Control Valve Sizing.

Under sub-sonic flow conditions or when pressure ratios across the throttle valve are less than the critical value (Pt/Po ≤ 0.528), the mass flow rate is approximated by the following relationship:

$$m_{th} = \frac{C_D A_{th} P_O}{\sqrt{R T_O}} \left(\frac{P_T}{P_O}\right)^{1/\gamma} \left\{ \frac{2\gamma}{\gamma - 1} \left[1 - \left(\frac{P_T}{P_O}\right)^{(\gamma-1)/\gamma} \right] \right\}^{1/2}$$

where: P_o and T_o are the upstream pressure and temperature

P_T is the pressure downstream of the throttle valve

C_D is the discharge coefficient (determined experimentally)

R is the Reynolds number

γ is the specific heat ratio

A_{th} is the throttle valve open area and is obtained from the equation below: (Straight bore design only. For spherical bore design, consult Delphi-E&C.)

$$\frac{4A_{th}}{\pi D^2} = \left(1 - \frac{\cos\psi}{\cos\psi_O}\right) + \frac{2}{\pi}\left[\frac{a}{\cos\psi}\left(\cos^2\psi - a^2\cos^2\psi_O\right)^{1/2} + \frac{\cos\psi}{\cos\psi_O}\sin^{-1}\left(\frac{a\cos\psi_O}{\cos\psi}\right) - a\left(1 - a^2\right)^{1/2}\sin^{-1} a\right]$$

where: a = d/D, d is the throttle shaft diameter, D is the throttle bore diameter

Ψ_o is the throttle plate angle at the closed bore position

Ψ is any opening angle

Under sonic flow conditions or when pressure ratios across the throttle valve are greater than the critical value (Pt/Po is greater than 0.528), the mass flow rate is approximated by the following relationship:

$$m_{th} = \frac{C_D A_{th} P_O}{\sqrt{RT_O}} y^{1/2} \left(\frac{2}{y+1}\right)^{(y+1)/2(y-1)}$$

ETC-ACV design is critical to the intake system. Engine power is maximized when the induction system and throttle body are sized and shaped to provide optimal air intake for the intake manifold.

Maximum Airflow Equation

A rough estimation of a required Air Control Valve air flow can be obtained by the following equations:

maximum air flow in g/s = 0.8 gram/second x horsepower

Another estimation may be made using the following equation:

$$\frac{\text{Max RPM x Engine Displacement in cc x Volumetric Efficiency x 1.02083}}{100000}$$

ie. A 3.5L engine running at 6000 RPM with a 90% V.E. will flow approximately 193 g/s.

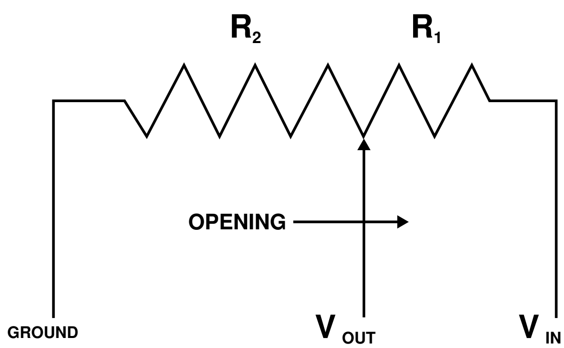
2.3 Throttle Position Sensor

The Throttle Position Sensor (TPS) is used to indicate the throttle valve angle. It responds to movement or rotation of the throttle shaft. The TPS provides the feedback for the closed loop position control of the ETC Air Control Valve.

For most ETC Air Control Valves, two Throttle Position Sensors (Dual Track TPS) are utilized. The two sensors use opposite slopes. One signal increases while the other signal decreases with throttle valve rotation. The use of two sensors enables diagnostic capability that can reduce the undesirable effect of some potential failure modes. If one of the two TPS signals becomes compromised, the ETC system can detect that the signal is compromised (by seeing a discrepancy in the other TPS signal) and can take appropriate action, rather than try to control to a bad signal.

2.3.1 Throttle Position Sensor Technology

In most cases, a TPS is a thick-film resistive potentiometer with a movable contact that instantaneously provides a signal proportional to the throttle shaft position (see Figure 2-2).



$$V_{OUT} = \frac{V_{IN} * R_2}{(R_1 + R_2)}$$

Figure 2-2. Basic Potentiometer Circuit.

Alternative technologies for position sensing are possible. Non-contacting position sensors are becoming popular replacements to the resistive potentiometer sensors. Non-contacting sensors by their nature do not have some of the durability issues that the resistive potentiometers have. They generally are somewhat more sensitive to electrical interference and temperature changes.

2.3.2 Electrical Output vs. Angle

A Throttle Position Sensor's output is typically a linear function from idle to WOT.

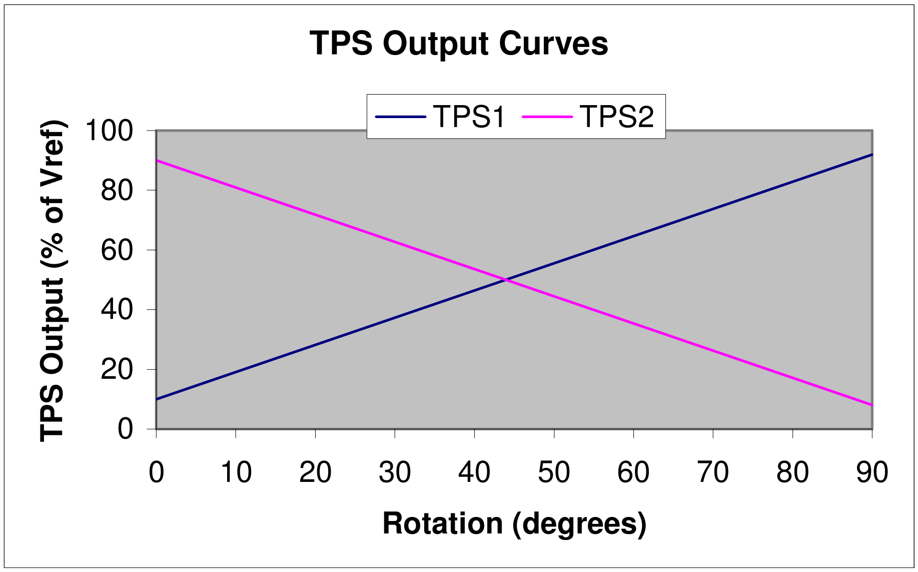


Figure 2-3. Typical Dual Track TPS Output vs. Throttle Rotation (Linear).

In a dual track potentiometer sensor, electrical input power is applied between the high and low end of the sensor. Rotation of the rotor from idle to wide open throttle typically provides one analog output signal from 10 to 90 percent of applied voltage, and a second output signal from 90 to 10 percent of applied voltage.

2.4 Vacuum Source

A Vacuum port may be used to operate engine accessories such as the brake system, HVAC, and/or to bias a fuel pressure regulator. A Vacuum port (tube) may be installed as an option to the ETC Air Control Valve. The Vacuum port will be located or ported to a point downstream of the throttle valve.

2.5 Filtered Air Source

A filtered (fresh) air source is typically used for the Positive Crankcase Ventilation (PCV) system. A port (tube) may be installed as an option to the ETC Air Control Valve. The fresh-air port is located or ported to a point upstream of the throttle valve.

3.0 Product Description

3.1 Scope

This section and the remaining sections of this Application Manual describe and provide application guidelines for ETC Air Control Valve models supplied by Delphi-E&C.

3.2 ETC Air Control Valve Assembly Description

The ETC Air Control Valve is an electromechanical device that is used to regulate airflow to an engine. It also provides position feedback. The components in the ETC Air Control Valve assembly include

- ETC housing (typically cast aluminum with some machining)
- Throttle valve (typically Aluminum or Brass)
- Throttle shaft
- Throttle shaft bearings
- Throttle return spring and lever that provide default or “pop-up” unpowered position (single wire spring utilized)
- 2-stage gear reduction (Gear at throttle shaft, and intermediate gear)
- Cover to protect gears and motor from external contamination
- Electric DC Brush Motor Actuator
- Dual Track Throttle Position Sensor
- Vacuum supply passages (optional)
- Coolant passages (optional)
- PCV Fresh air supply passages (optional)
- Connector(s) (Motor and TPS are usually integrated in one connector)

3.2.1 Product Examples

Shown are some pictures of Delphi ETC Air Control Valves with various bore sizes:

Figure 3-1. Wrap-around 90mm, inline and wrap-around 75mm ETC-ACV's

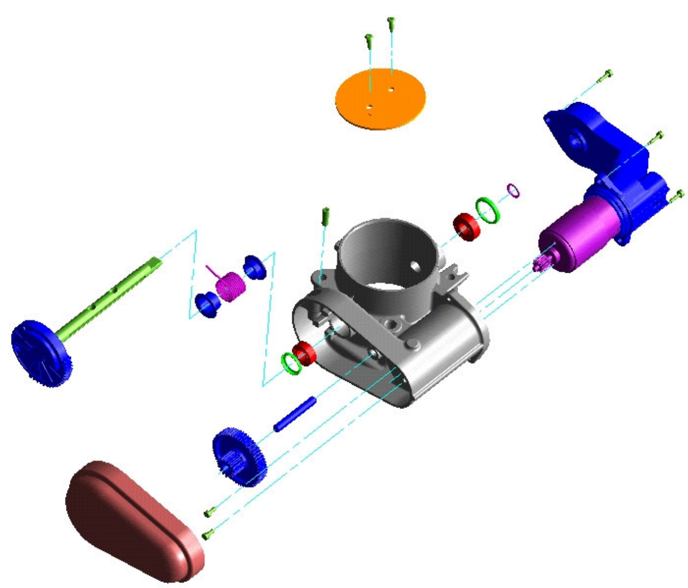


Figure 3-2 Breakout picture of a Delphi ETC

3.2.2 Functions, Performance Requirements and Features

The functions, performance requirements and features of typical ETC-Air Control Valve Assemblies are listed in Table 3-1.

ETC-ACV Functions:	• Regulate intake air flow • Sense throttle position • Provide vacuum signals (i.e. the brake booster, EGR valve, and canister purge system if required) • Provide filtered air source if required (i.e. PCV fresh air) • Provide mounting features if required
Design Performance Requirements:	• Maximum air flow capacity • Idle air flow resolution (and minimum controllable air flow) • Default Position Airflow • Throttle Response Time • Maximum leak rate (through throttle shaft bearings)
Design Features:	• Various bore sizes • Various valve and bore geometry and valve angles • Throttle position sensor (shaft drive) • Various Connector Configurations • Various Actuator Configurations • Optional coolant flow passageway • Optional Vacuum ports • Optional Fresh Air Port

Table 3-1. Functions, Performance Requirements and Features of Typical Throttle Bodies.

A thorough description covering the selection of every ETC-ACV feature is outside the scope of this manual due to the diverse nature of ETC-ACV applications. Therefore, the following is a brief summary of some of the more important ETC air control valve features:

3.2.2.1 Air Progression

Air progression can be designed with any combination of the following features:

- Software "transfer function" between desired throttle (i.e. pedal command) and commanded throttle position.
- Bore size – With a large bore size, there is less progression controlled by the throttle valve and bore interface. If the bore size is too big, the engine will not have full power progression from idle to WOT.

- Bore shape – There are two basic bore designs: straight bore and shaped (spherical) bore. Straight bore is easy to manufacture but provides a typical air progression. Spherical bore is more complicated and costs more to manufacture, but it provides a higher degree of air progression at lower throttle angles.

- Valve angle – The edge of the valve is manufactured to provide an angular position when the valve is at the closed bore condition. The higher the valve angle, the more sensitive the air rate is per degree valve rotation.

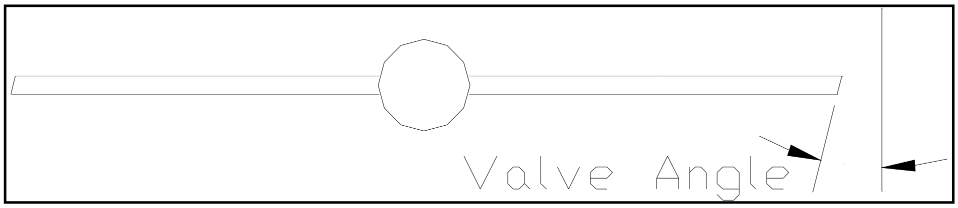


Figure 3-3 Description of Valve Angle

- Valve wedge – A valve wedge is an add-on feature behind the valve. The wedge controls airflow when the valve opens from the idle position. It essentially decreases the air rate gain at the low throttle angle range defined by the thickness and the shape of the wedge. *Note: Thickness of the wedge often restricts a certain amount of airflow at WOT.*

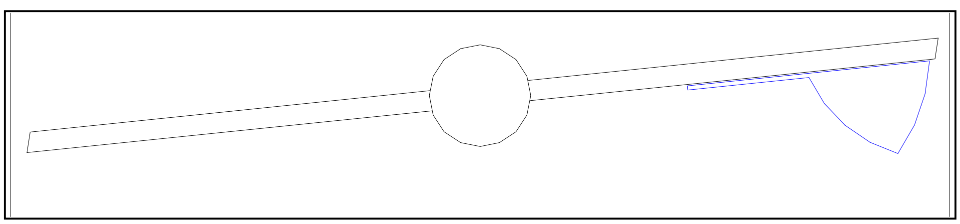


Figure 3-4 Description of a Valve Wedge

Many of the above Air Progression features can be customized and combined to achieve customer's requirements and preferences. Due to the complexity of the design involved, detail information can be obtained from Delphi-E&C Application Engineering.

3.2.2.2 Throttle Position Feedback

Throttle position feedback to the engine controller and/or Throttle Controller is provided using a Throttle Position Sensor. The TPS provides a voltage output that relates to actual throttle position. More than one TPS may be used on a single ETC Air Control Valve for added signal diagnostic capability.

3.2.2.3 Vacuum Sources

Vacuum sources may be provided through tubes that terminate on the downstream side of the throttle blade.

- Provide a vacuum source for fuel pressure regulator bias.
- Provide a vacuum source for engine accessories.
- Provide a vacuum source for chassis accessories (brakes).

3.2.2.4 Clean Air Source

A clean air source may be provided through tubes that terminate on the upstream side of the throttle blade.

- Accommodates crankcase blow-by
- Provides clean air for the canister

3.2.2.5 Heating Source (Coolant Passageway)

Provides a heating source to the throttle body for icing prevention.

- Coolant tube and hose routing
- Can be internal to the casting through the manifold interface seal

Note: *When coolant tubes are used, a one-piece tube inserted through an aluminum hole is the recommended method to avoid leaks.*

3.2.3 Appearance

ETC-Air Control Valve Assemblies described in this manual use cast aluminum as the main body material. The casting may be subjected to a “shot blast” process to improve its appearance.

Note: *Customized appearances are application specific. See Delphi-E&C for additional information.*

3.2.4 Exterior Outline

Exterior packaging must meet under hood packaging constraints per vehicle specifications. These requirements shall be defined in approved Engine/Induction Layouts from the customer.

3.2.5 Usage Definition

The ETC Air Control Valve Assembly regulates airflow into the engine and provides throttle position feedback. It can be configured for use on any type of internal combustion engine.

The validation of the ETC Air Control Valve Assembly varies with design and application.

3.2.6 Failure Diagnostics

ETC Air Control Valve Assembly diagnostics are achieved through the unit's electrical components: the Throttle Position Sensor (TPS) and the Electrical Actuator.

The Throttle Position Sensor is usually monitored by the throttle control module and/or engine control module for two failure modes: sensor voltage high and sensor voltage low. If two sensors are used, the two signals are additionally checked for correlation.

3.3 Physical Specifications/Flow Characteristics

3.3.1 Dimensions

The physical dimensions of the ETC-ACV Assembly are customized per application or standard package. The packaging of a typical ETC Air Control Valve Assembly is discussed in Section 6.0.

3.3.2 Characteristics

The following specifications and characteristics identified in Table 3-2 need to be considered when determining the appropriate application of an ETC Air Control Valve. Only the most basic electrical specifications are included here. Many of the more detailed electrical specifications are a result of the Air Control Valve Design.

Characteristic	Specifications	Definition
Regulate Air Flow	Maximum Air Flow Rate	Specify the maximum (wide open throttle) air flow rate with the vacuum level required by the engine. Section 2.0 provides a procedure for determining a rough estimate of required airflow at WOT.
	Minimum Air Flow Rate	Specify the vacuum level and maximum airflow rate when the throttle is at its minimum mechanical position
	Default Air Rate	Specify the vacuum level and airflow rate that the ETC-ACV provides when there is no actuator power.
	Air Flow Curve	A curve of the required airflow rate versus throttle rotation. (The airflow progression is important to consider for idle air control.)
	Noise	The allowable audible noise for the ETC Air Control Valve Assembly at all airflow rates.
	System Voltage	Specify the voltages at which the ETC-ACV actuator is expected to operate.
	System Current	Specify the maximum electrical current to allocate to Air Control Valve actuation. This will also determine wiring harness specifications.
Provide Clean Air Source	Air Flow Rate	Specify the airflow rate required for the clean air source. (Or specify port size or diameter).
Provide a Constant Vacuum Source	Air Flow Rate	List the airflow rate required for each of the manifold vacuum ports. (Or specify port size or diameter).

Table 3-2. (Part 1 of 2) Application Specifications and Characteristics (Applied Under Engine Operating Conditions).

Characteristic	Specifications	Definition
Sense Throttle Position	Sensors supply voltage	Specify the voltage and tolerance of the sensors supply circuitry from the ETC controller.
	Sensors Resistance (Contacting TPS design)	The two sensors can have different resistances. Specify the minimum resistances for the two sensors. (Or specify the maximum supply current for the sensors.)
	Output at Minimum Mechanical Position	Throttle position in percent of the supplied reference voltage on the Throttle Position Sensor output when the throttle is closed to the minimum mechanical position stop. Vibration and vacuum may contribute to the position output. Tolerance must be accounted for when specifying the acceptable output range at minimum mechanical position.
	Output at WOT (Span Angle) ***Note**: This is typically not the same position as the maximum mechanical position)*	Minimum throttle travel output from idle to WOT is sometimes referred to as "span angle". WOT is the engine controller's 100% throttle position. For current systems, the output at WOT is 78% of reference voltage higher than the output at the minimum mechanical position. This is obtained from nominally 87° of rotation with a 0.9% per degree TPS slope. Actual output would be around 88% of Vref (± the tolerance at minimum mechanical position).
	Correlation	Correlation is the maximum variation between the two outputs of a dual track TPS after they have been converted to the same scale. (One output is inverted).
	Repeatability	Repeatability is the maximum variation for the TPS Output at any given Throttle shaft angular position. This is strictly a TPS specification that is difficult (at best) to measure when installed on an Air Control Valve.

Table 3-2. (Part 2 of 2) Application Specifications and Characteristics (Applied Under Engine Operating Conditions).

3.3.3 Mass

The mass of the ETC-ACV Assembly varies with the specific application.

3.3.4 Identification and Markings

Each ETC-ACV is identified with permanent markings, which include the last five digits of the Delphi-E&C part number, vendor identification, and Julian date code.

Typical ETC Air Control Valve Assembly Identification

See Figure 3-2 below for ETC Air Control Valve Assembly Identification.

1. Eight digit part number
2. Serial number (optional)
3. Julian Date (Last digit is year)
4. Line code letter
5. Shift number

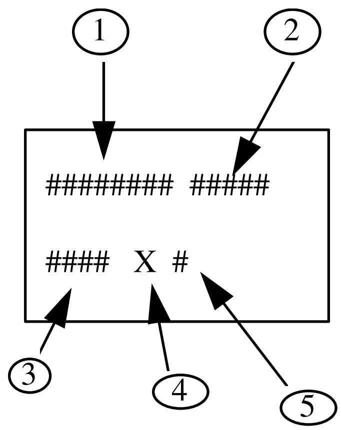


Figure 3-5. An Example of Identification and Markings.

3.3.5 ETC Air Control Valve Housing (Casting)

The housing mounts to the intake manifold providing a conduit for intake air. A throttle valve varies the airflow rate as required. The electric actuator and Throttle Position Sensor attach to the ETC Air Control Valve Housing. All tubes for vacuum, fresh air and coolant supply also attach to the housing.

3.3.6 Throttle Bore Options

ETC Air Control Valve housings may have cylindrical or shaped (spherical) bore designs. Spherical bore designs offer more resolution for low flow air control such as idle air control. Spherical bore designs are more expensive than cylindrical bore designs because of the additional machining required in their manufacture.

3.3.6.1 Cylindrical Bore ETC-Air Control Valve

A cylindrical ETC-Air Control Valve bore is the most economical and is the most common design. Figure 3-6 illustrates a cylindrical bore. With a cylindrical bore design, throttle valve edge angle becomes a critical consideration for the air rate gain during the first few degrees of rotation. The change of bore/valve effective area per an opening throttle angle of a 5 degree valve is smaller than the one of a 10 degree valve. Therefore, the air rate gain during the first few degrees of rotation is less sensitive for a 5 degree valve than a 10 degree valve.

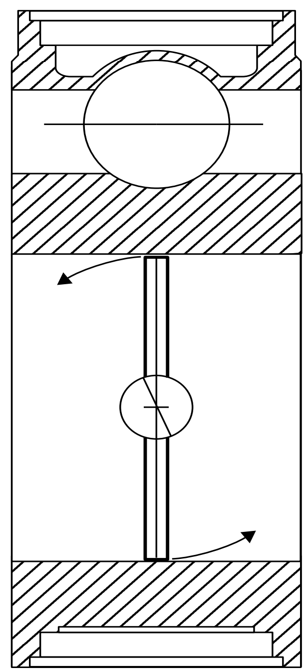


Figure 3-6. Cylindrical Bore ETC-ACV.

3.3.6.2 Spherical Bore ETC Air Control Valve

As Figure 3-7 illustrates, the throttle valve moves within a spherical cutout area in the throttle bore. This offers more progressive airflow transition compared with a cylindrical bore. The spherical angle, radius and location are critical in meeting air progression requirements. In essence, a spherical bore design customizes the air progression for each throttle angle up to the specified spherical angle with a finer resolution and a smaller air rate change. The example from Figure 3-7 illustrates two different spherical angles: 25 degrees for the left side and 20 degrees for the right side. Once the throttle valve rotates beyond the spherical angle, the airflow becomes similar to the airflow of the cylindrical bore design. *This type of bore can increase idle air control resolution when compared to a cylindrical bore. Higher resolution analog input technology advances have made this feature unnecessary for most applications.*

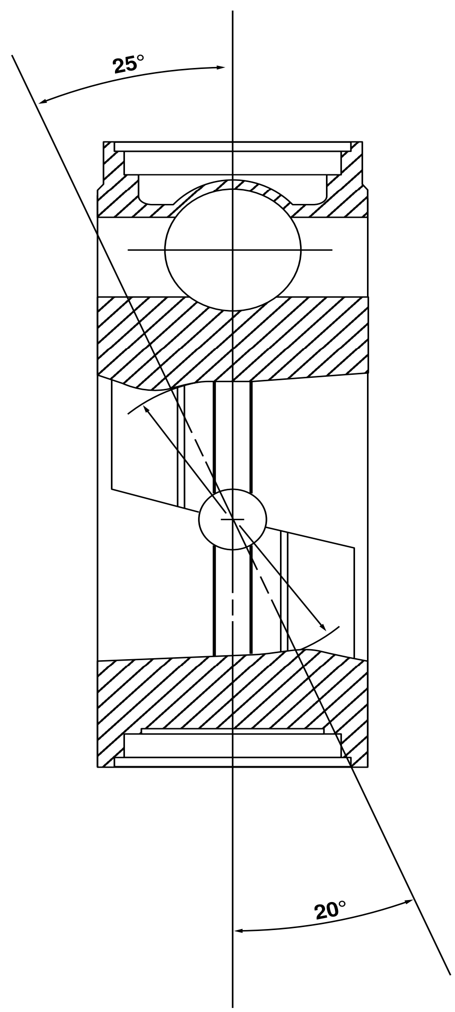


Figure 3-7. Spherical Bore ETC-Air Control Valve.

3.3.7 Throttle Valve Options

Another critical part of air progression selection is throttle valve design. There are three major design considerations:

1. Throttle valve angle
2. Throttle wedge
3. Throttle valve thickness

The first two options were already covered in Section 3.2.2.1.1. Throttle valve thickness is typically between 2.0 and 2.5 mm. More air progression is achieved at the initial rotating angle off idle when the valve is thicker. However, thicker valves have additional weight and a higher material cost.

Valve thickness increases with bore diameter due to material strength requirements. Large bore diameters mean large surface areas of throttle valves which translates in more force acting upon the valve due to air pressure. When the throttle valve is subjected to the vacuum produced by the engine, it needs to be strong enough to resist deflecting towards the intake manifold.

3.3.8 Throttle Position Sensor

The Throttle Position Sensor (TPS) is a potentiometer. It sends a voltage signal (or signals) to the engine controller and/or throttle controller. The signal is proportional to throttle valve position, which is an indication of airflow. The signal is a ratio of the supply (or reference) voltage to the TPS.

3.3.8.1 Throttle Position Sensor Components

A contacting Throttle Position Sensor consists of the rotor, contactor, housing, element, terminals, cover and other application specific components such as a seal or spring.

Rotor

The rotor is the moving component of the sensor. It interfaces with the shaft whose rotary position is being measured.

Contactor

The contactor is the sensor component (normally mounted to the rotor) that contacts the element and transmits the output voltage to the output circuit.

Housing

The housing provides an interface for the ETC-ACV, element, rotor and terminals. It holds all the internal components and provides mounting features to properly locate the TPS to the ETC-ACV.

Element

The electrical element is made of thick-film resistive ink. Its design determines the output characteristics of the sensor.

Terminals

There are 4 or 6 (depending on configuration) electrical terminals that provide electrical interface with the engine controller and/or throttle controller. (Dual Track TPS)

Cover

The plastic cover is designed to hold the rotor, electrical element and internal components in place. The cover also provides the compression for the rotor and dynamic seal.

3.3.8.2 Throttle Position Sensor Characteristics

Output at Minimum Mechanical Position

A typical example of TPS output at minimum mechanical position is 10% ± 3% of the reference voltage (Vref). This specification includes allowable degradation or change tolerance for non-adjustability. The second TPS output of a dual track TPS would have an output of 90% ± 3% of Vref at the minimum mechanical position.

Note: *Degradation must be included to keep within specification limits over the life of the component.*

Slope

The slopes of the Throttle Position Sensors are designed to be +0.9%, and –0.9% of Vref per degree of rotation. (The two sensors have opposite slopes.)

Output at WOT

A typical example of TPS output at WOT position is 89 percent +/- 3 percent of “reference voltage.” The definition of WOT is the throttle angle at which the TPS output is a certain percentage (typically 77.4%) of the TPS reference voltage added to the output voltage at minimum mechanical position. The tolerance specified here is the tolerance on the minimum mechanical position output voltage.

Note: *WOT is not the same as the maximum mechanical position for ETC.*

Span

For current systems, span is nominally 85 degrees. The output change from idle to WOT must be a minimum of 77 percent of reference voltage. This value is calculated by multiplying the minimum mechanical throttle rotation (degrees) by the TPS slope and subtracting system errors (accuracy).

Correlation

Correlation is the ability of the two Throttle Position Sensors to produce the same output at the same angular position. The output value of one of the sensors is normalized (usually by subtracting the TPS voltage output value from the supply voltage value: Vref.). The normalized value is compared to the other TPS output value. The two values should agree (be equal) within a tolerance band.

Repeatability

Repeatability measures the ability of the Throttle Position Sensor to produce the identical sensor output during repeated rotor maneuvers. For example, coming to a stop at the same rotor position from the same direction should produce the same sensor output.

At lower throttle positions (idle controlling region), the TPS output shall be repeatable within 0.5 percent of "reference voltage" (including hysteresis). Idle output repeatability requires all ETC-ACV components to maintain very tight positional control under conditions of varied loading. This requires a positional control allowance less than 0.13 mm (0.0052 in) at the element or 0.054 mm (0.002 in) at the shaft interface. The design must be maximized for geometric robustness to attain position control and load response.

3.3.9 Vacuum Source

Vacuum sources are tubes ported downstream of the throttle valve.

3.3.10 Fresh Air Source

Fresh air sources are tubes ported upstream of the throttle valve.

3.4 Operating Conditions

The ETC-Air Control Valve Assembly operates normally in the modes in Table 3-5.

Operating Mode	Operating Conditions
Air Temp.	-40°C to 40°C
Underhood Temp.	-40°C to 125°C
Intermittent Temp.	150°C (1 hour maximum)
Max. Vacuum Load Across Throttle Shaft	90 kPa

Table 3-5. Operating Conditions.

3.4.1 Environmental Exposure

The ETC-ACV Assembly meets performance and physical requirements for environmental conditions that it may be exposed to, as defined by Delphi-E&C Validation Plans. The ETC-ACV Assembly is compatible with those specifications for:

Lifetime Cycling	Temperature	Humidity	Vibration
Dust	Ozone	Corrosion	Temperature Shock
Salt Spray	Contamination	Noise	Fuel Compatibility

4.0 System Interface

4.1 General

The ETC-ACV Assembly interfaces with the other powertrain subsystems as described in this section and shown in Figure 4-1.

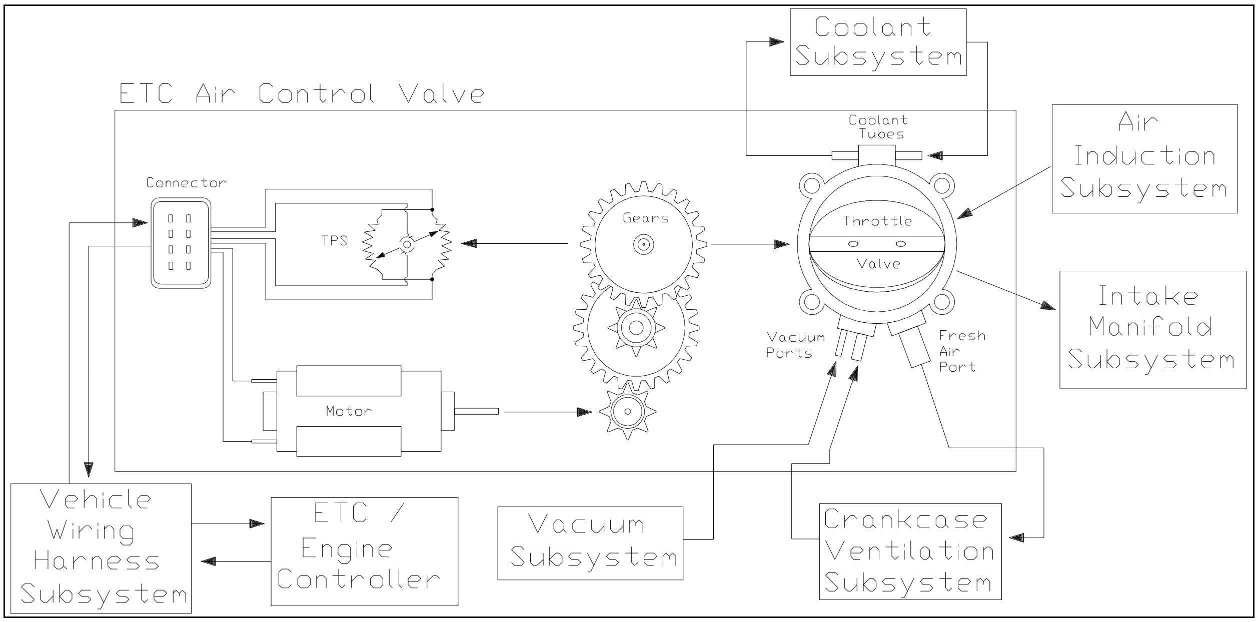


Figure 4-1. ETC-ACV Interfaces.

4.2 Interfaces

The following are typical interfaces to the ETC-Air Control Valve Assembly along with their potential sensitivities and areas of concern that should be addressed during the development of subsystem requirements. This list may need to be expanded to meet specific application needs.

4.2.1 Mechanical Interfaces

The ETC Air Control Valve serves an additional function when its mechanical interfaces are considered. The ETC-ACV acts as a structural member of the air intake system. The ETC-ACV performance can be adversely affected when it is subjected to excessive force from its mechanical interfaces. It is important to keep this in mind when addressing all of the mechanical interfaces to the ETC.

4.2.1.1 ETC-ACV to Air Induction Subsystem

A list of key considerations regarding the ETC-ACV-to-air induction subsystem interface is as follows:

- Type of connection (flange, clamp, etc…)
- Type of seal (face seal, radial seal, etc…)
- Proximity of Air Meter (The effects of ETC design on air meter performance are greater when the air meter is in close proximity of the ETC-ACV.)
- Sensitivity to velocity profiles (Sharp turns in duct before ETC inlet)
- Sensitivity to cooling effects
- Sensitivity to icing (introduction of moisture)
- Dust intrusion
- Coking (possible introduction of oil vapor from PCV system)
- Air flow generated acoustic noise
- Leakage at inlet to ETC-ACV (Especially for customer leak tests)

4.2.1.2 ETC-ACV to Intake Manifold Subsystem

The ETC-ACV interface with the intake manifold can be critical to ETC performance as well as engine performance.

The ETC-ACV is the structural member between the air induction subsystem, and the intake manifold subsystem. An ETC-ACV commonly mates to an intake manifold with bolts, and a face seal.

A list of key considerations regarding the ETC-ACV-to-intake manifold subsystem interface is as follows:

- Intake Manifold composition (usually aluminum or plastic composite)
- <u>Sealing & gasket.</u> Delphi-E&C uses the following gasket materials:
    - Graphite
    - Paper
    - Polymer (Spaghetti)
- Flatness of mating components on intake manifold:
    - If the ETC bolts to a plastic manifold with brass inserts, the brass inserts should be proud of the plastic, and flat within 0.5mm.
    - If the ETC bolts to an aluminum manifold, the mating surface should be flat within 0.13mm.

Note: *The mating surface of a machined aluminum ETC-ACV will have 0.3mm flatness over the entire mating surface, with 0.1mm flatness within any 25.4mm length.*

Note*: Gasket selection is critical when specifying ETC-ACV mounting surface flatness.*

- <u>Bolt pattern</u>. An ETC-ACV generally has a 4-bolt design with a fair amount of distance between the bolt holes. A 3-bolt interface however, may meet tighter flatness requirements.
- <u>Flow profiles.</u> Fluid velocity and turbulence may affect cylinder-to-cylinder distribution and may contribute to noise. The flow profile produced at the ETC to intake manifold interface will contribute to these effects.

- Sensitivity to cooling/heating. Heat conduction to the ETC-ACV comes from various sources including the manifold, engine coolant, and engine compartment.

  Manifold material and the mounting location of the ETC-ACV on the manifold are key heat conduction considerations. For highest conduction, the ETC-ACV is generally located on the top of the manifold with the bore pointing straight down.

  The inclination of the ETC-ACV when it is mounted on the side of the manifold is another important heat conduction consideration. A slight upward inclination is typically desirable because it allows water to be drained into the manifold and away from the throttle valve. This type of inclination can complicate manifold design with regards to the hood-line.

- Vacuum ports. Manifold, and ETC design groups must work together to achieve optimal vacuum port location.

- Coolant passage. Sealing becomes an important issue when *ETC-ACV* coolant is provided through the manifold. Delphi-E&C currently uses gaskets in production.

4.2.1.3 ETC-ACV to EGR

The ETC may have a direct or indirect interface to an EGR valve. A list of key considerations regarding the ETC-ACV to an EGR Valve interface is as follows:

Refer to Section 7.2.5

- Sensitivity to icing. Exhaust gas (EGR) should ideally be introduced as far away from the throttle valve as possible (the minimum distance is 2.5 inches).

- Vacuum ports required. The ETC-ACV can provide metered air through a port to a backpressure style EGR valve using a hose and tube design.

- Exhaust gas port size/location. Exhaust gas port size/location is application specific. Consult Delphi-E&C for further assistance.

- Sensitivity to exhaust gas. EGR contributes to the build-up of coking deposits on the throttle valve and bore. See Section 7.2.4 for further information.

4.2.1.4 ETC-ACV to Vacuum Accessories

A list of key considerations regarding the ETC-ACV to vacuum accessories system interface is as follows:

- Size of ports. Port size is application specific. Hole sizing is typically achieved via machining.
- Number or ports. The number of ports is also application specific. If more than two holes are within close proximity, a single vacuum port module can be used instead of two sets of tubes and clamps
- Location. Location is application specific but may be restricted by casting design.

4.2.1.5 ETC-ACV to Coolant System

There are two ways to introduce engine coolant to the ETC-ACV. One is through an existing coolant passage in the intake manifold, and the other is through tubes added to the ETC-ACV casting.

A list of key considerations regarding the ETC-ACV to coolant system interface is as follows:

Refer to Section 7.2.5 for icing considerations.

- When is a coolant passage required? An icing test plan should be devised and evaluated prior to determining whether the ETC-ACV requires a coolant passage. Expected customer usage, and engine configuration are considerations for this decision.
- Size. Size of the coolant passage is application specific. Too small may be ineffective. Too large may reduce engine output power by adding heat to intake charge air.
- Location. Location is application specific but may be restricted by casting design. In general, the heat from the engine coolant is introduced at the bottom of the ETC-ACV casting.
- Sealing of Coolant Tubes (when a tube and hose design is integrated in an aluminum casting). Loctite material is applied on the tube to ensure tube integrity and to facilitate tube insertion on the assembly line.
- Mating Hoses. The mating hoses should not introduce excess loads to the ETC-ACV
- Gasket Material (when coolant comes from intake manifold). The gasket must be compatible with coolant, and seal effectively.

4.2.1.6 ETC-ACV to Wiring Harness

Proper electrical connection systems are critical for reliable operation of the ETC Air Control Valve for the life of the vehicle.

- Type of connector contact. Electrical contacts used in the ETC mating connector should be plated with the same material that is used to plate the contacts in the ETC connector. (ie. Do not use tin plated contacts mated to gold plated pins.) Electrical contacts for low current signals (like the TPS signals) should be gold plated.

- Connector sealing. Connector designs need to provide seals that prevent external moisture and foreign material intrusion.

- Connector angle. Orient the Electric Actuator and TPS connectors to allow gravity to direct moisture away from the terminals.

- Wire Routing. Avoid excess side loads, or sharp bends (90° to 180°) in the wiring harness to the ETC Air Control Valve. These can lead to contamination of the connector (through leak paths) and/or degraded terminal retention.

- Use Drip Loops. The use of drip loops in the wiring harness before connections to the ETC-ACV are recommended to route excess moisture away from the connectors.

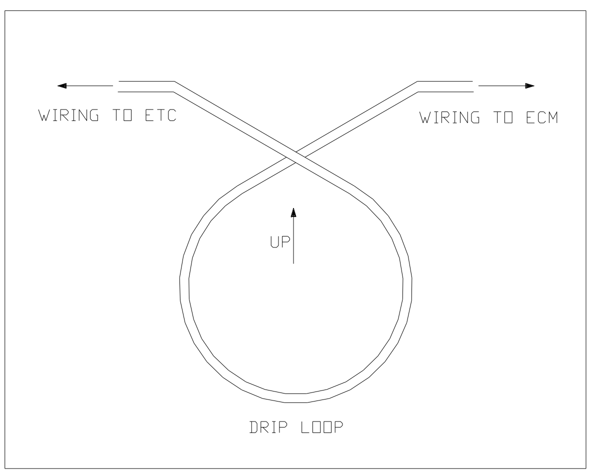


Figure 4-2. Example of a Drip Loop

- Wire Harness Tie Down. The wiring harness conductors should be secured by a tie down within 100mm (4 inches) of the ETC connector to prevent any "whip" action of the conductors causing wear at the connector contacts.

4.2.1.7 ETC-ACV to Positive Crankcase Ventilation (PCV) System

There are two possible interfaces from the ETC-ACV to the PCV system. One is to supply fresh air to the PCV system, the other is to provide a place to purge the PCV vapor to.A list of key considerations regarding the ETC-ACV to PCV interface is as follows:

- Port size or flow rate of metered air. Port size or flow rate of metered air is application specific. Too much flow may increase engine oil consumption rates.
- Location. Location is application specific but may be restricted by casting design.

Refer to Section 7.2.5

- Sensitivity to icing. A vehicle icing test plan should be devised and evaluated.

4.2.1.8 ETC-ACV to Miscellaneous

The ETC-ACV sometimes provides holes, pads, or brackets for mounting cables, hoses, and various other components not normally associated with the ETC-ACV.

Caution: *It is important to evaluate the possible adverse effects of attaching other components to the ETC. Adding external loads to the ETC housing (casting) often can result in deformation of the bore. (Make the bore less round.) It is important that any deformation is evaluated to assure that the round throttle valve is not (or does not get to be) "stuck" in the less than round deformed bore.*

4.2.2 Electrical Interfaces

The ETC Air Control Valve electrical interfaces are achieved through the throttle position sensor(s) and the electrical actuator (motor).

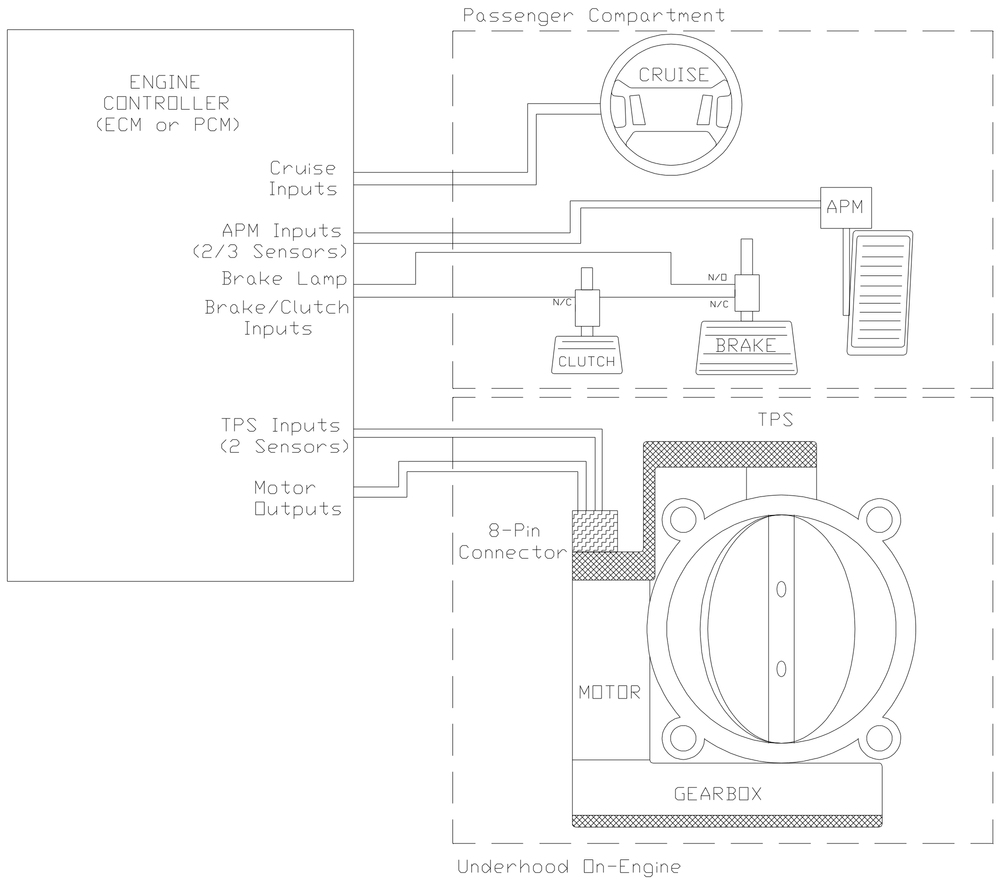


Figure 4-3. Diagram of ETC Subsystem Electrical Interfaces.

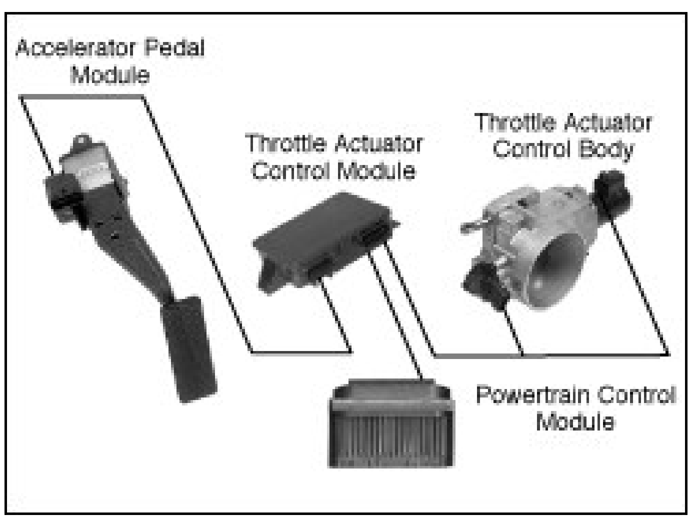


Figure 4-4. ETC-ACV Interface Visual Aid.

4.2.2.1 TPS Electrical Interface

Figure 4-5 shows a schematic of a dual track TPS as it would be installed on a throttle shaft of an ETC/ACV. It illustrates how the TPS output changes as the throttle shaft rotates.

Figure 4-6 shows a similar schematic of a dual track TPS, but with separate power supplies provided for the two individual sensors.

Note: *The pin letters shown are for reference only. The actual pinout of a particular ETC/ACV TPS connector is specific to the application.*

- The reference voltage applied across the two sensors should be 5.0 ± 0.5 VDC. (ie. applied across pins A and D in Figure 4-4)
- The sensors' electrical output voltages (TPS1 and TPS2) are a percentage of the reference voltage across their respective sensor.
- The sensors' output voltages move in opposite directions as the throttle shaft rotates.

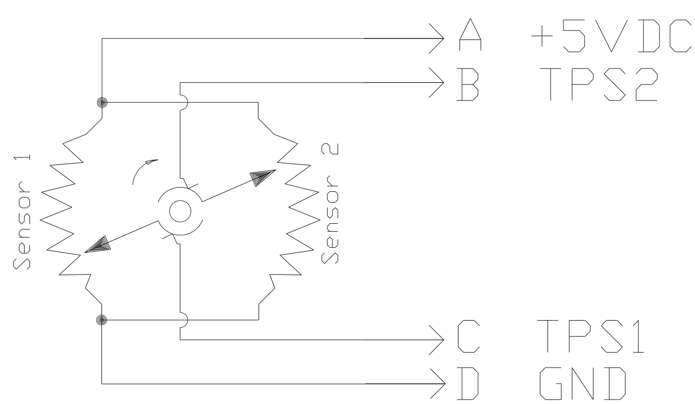


Figure 4-5. Dual Track TPS Circuit Diagram.

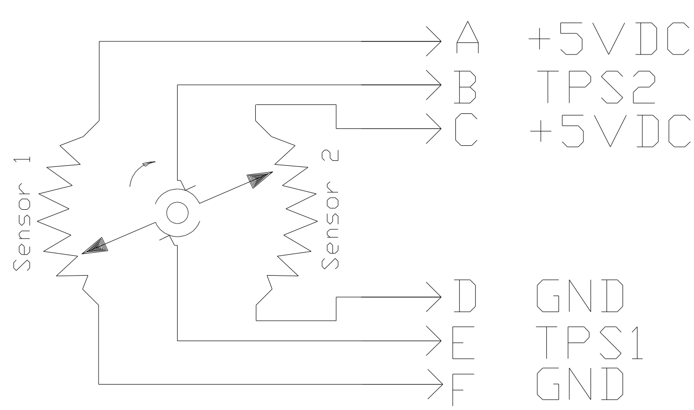


Figure 4-6. TPS Circuit Diagram with separate reference voltages for two sensors.

4.2.2.1.1 TPS 1

Pin:	A	B	C
Name:	TPS1ref	TPS1	TPS1rtn
Function:	Sensor 1 reference voltage input	Sensor 1 throttle position output	Sensor 1 reference voltage return (Ground)

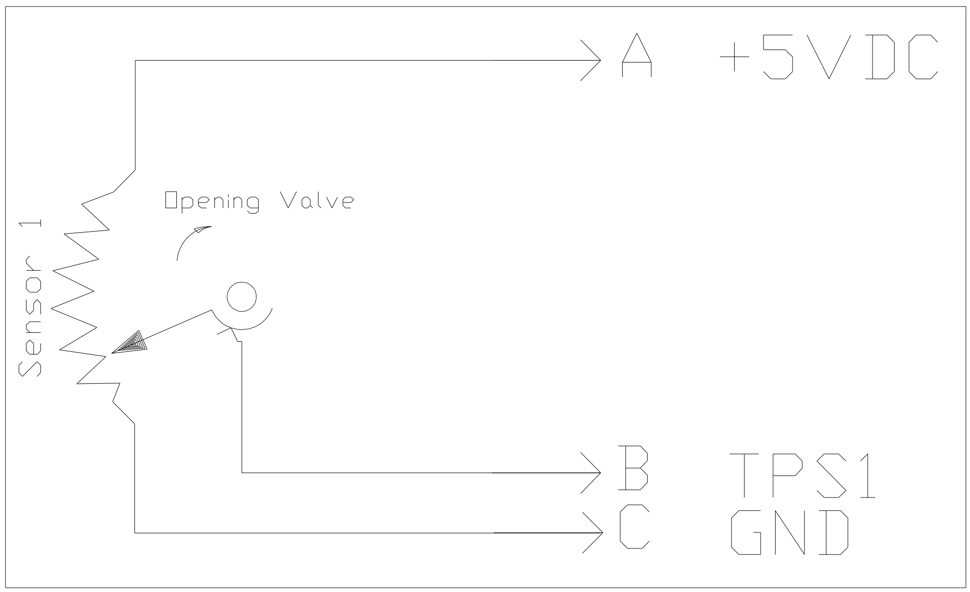


Figure 4-7. TPS 1 Mechanization Diagram

Parameter	Conditions	Minimum	Typical	Maximum	Units
Resistance, Pin A-C	All	4K	5K	6K	Ω
Contact Resistance, Pin B-Wiper	All	N/A	750	2.5K	Ω

Table 4-1 TPS 1 Parameters

4.2.2.1.2 TPS 2

Pin:	A	B	C
Name:	TPS2	TPS2ref	TPS2rtn
Function:	Sensor 2 throttle position output	Sensor 2 reference voltage input	Sensor 2 reference voltage return (Ground)

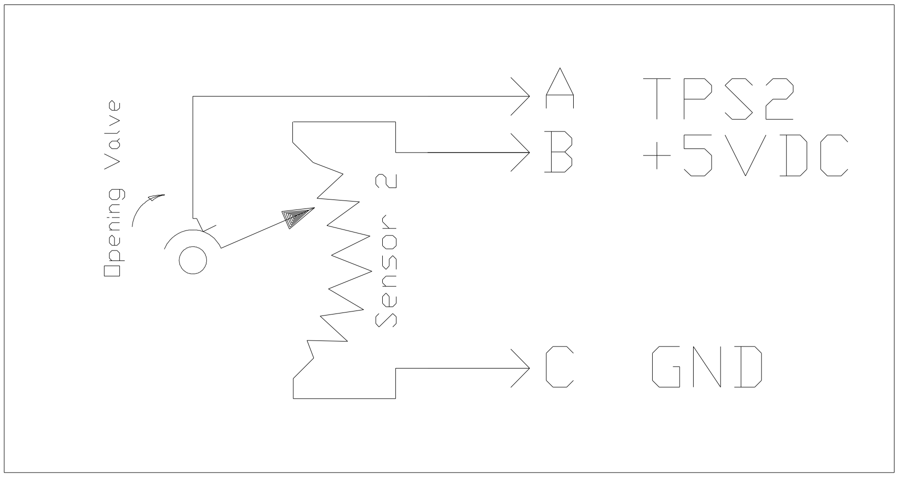


Figure 4-8. TPS 2 Mechanization Diagram

Parameter	Conditions	Minimum	Typical	Maximum	Units
Resistance, Pin B-C	All	2.7K	3.4K	4.1K	Ω
Contact Resistance, Pin A-Wiper	All	N/A	750	2.5K	Ω

Table 4-2 TPS 2 Parameters

4.2.2.2 Actuator Motor Electrical Interface

This manual will discuss the DC brush type motor actuator. Other electrical motor actuators are possible.

Pin:	A	B
Name:	Motor1	Motor2
Function:	Actuator motor operating current1	Actuator motor operating current2

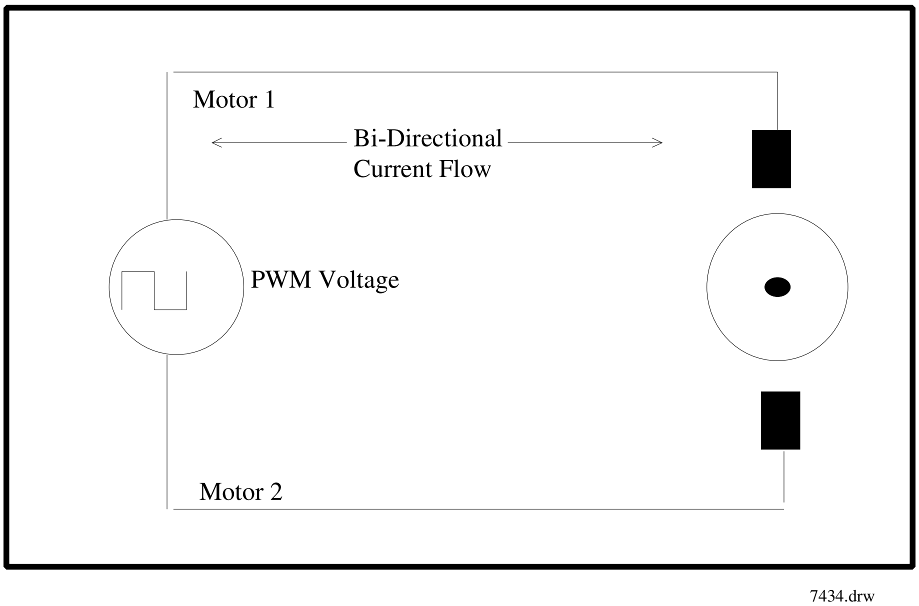


Figure 4-9. Actuator Brush Motor Mechanization Diagram

Parameter	Conditions	Minimum	Typical	Maximum	Units
Design Voltage		5.5	12.0	16.5	V
Current, Average	>10 sec	2.2			A
Current, Peak	< 10 sec			9.6	A
Inductance, Pin A-B	@ 100 Hz		0.83		mH
PWM Frequency		1.5	varies	24	KHz

Table 4-3 Typical Brush Motor Parameters. This is application dependant.

***Caution**: Do not apply voltage directly to the motor pins.*

***Caution:** Motor operation can be compromised during an over-voltage condition.*

4.2.2.2.1 Motor High Current

Current limiting can be achieved in the circuit hardware to limit peak current and motor control software can limit the effective current resulting from moderate current levels held for long periods. Excess effective current can damage the motor either at the brush to commutator interface or by degrading the wire insulation. The current levels should be established for the specific Air Control Valve design in the specific engine application.

4.2.2.2.2 Motor Reversing Current

Excessive reversing current can damage the motor either at the brush to commutator interface or by degrading the wire insulation. Excessive reversing current activity can be caused by too slow sample rate or inaccurately applying a spring compensation algorithm.

4.2.2.2.3 High Battery Voltage

High battery voltage can create increased momentum of the Air Control Valve internal drive mechanism resulting in inadvertent overshoot beyond the maximum or minimum controllable positions.

Recommendation:

Regulate battery voltage, limit current to the Air Control Valve motor, and/or compensate voltage with the motor control algorithm. *See section 5.*

4.2.3 Electromagnetic Compatibility

Electromagnetic Compatibility (EMC) is important to consider with any electrically actuated device on a vehicle. The electrical devices of the ETC-ACV should not be adversely affected by electromagnetic fields in its normal operating environment. The ETC-ACV should not create electromagnetic fields that interfere with operation of other electrical devices on the vehicle.

Two electrical devices on the ETC-ACV need consideration to comply with EMC requirements.

- The actuator (DC brush motor)
- The Throttle Position Sensor (TPS)

4.2.3.1 EMC for the Actuator

The DC brush motor actuator is an integral part of controlling the ETC-ACV, and as such is a Class C device for Electromagnetic Compatibility. A Class C function is essential to the operation and/or control of the vehicle.

In general, the DC brush motor actuator will utilize choke coils integral to the motor to suppress any radio interference the motor may generate while it is in operation.

4.2.3.2 EMC for the TPS

The TPS is an integral part of controlling the ETC, and as such is a Class C device for Electromagnetic Compatibility. A Class C function is essential to the operation and/or control of the vehicle.

A resistive potentiometer type contacting TPS does not generate any electromagnetic fields of its own.

4.2.3.3 EMC Environment

It is expected the ETC-ACV be subjected to the EMC environments listed below as part of the Engine Management System (EMS). The ETC-ACV actuator and TPS is an electrical load to the engine controller in the EMS.

- Susceptibility to Conducted Transient Voltage
- Electrostatic Discharge (ESD)
- Radiated Susceptibility (BCI)
- Radiated Emissions (RFI)
- Susceptibility to Radiated Fields
- Conducted Transient Emissions
- Susceptibility Conducted Sinusoidal Bursts
- Jump Start Voltages
- ESD Handling

4.2.4 Interfaces Internal to ETC-ACV Assembly

The component interfaces within the ETC-ACV Assembly (such as actuator gears and bearings) should be defined by the ETC-ACV Assembly Design Engineer to meet the system and customer specific performance and usage requirements.

The internal interfaces that generally require tight tolerances are:

- The throttle shaft to TPS interface
- The throttle valve to bore interface
- The throttle shaft to bore interface

The internal interfaces that may require 100% testing are:

- Port tubes to casting interfaces (coolant, vacuum, fresh air)
- The throttle return spring interfaces
- Any internal seals

5.0 Software

5.1 ETC Air Control Valve Software Considerations

There are several mechanizations of an ETC system where the ETC Air Control Valve is used. The ETC Air Control Valve requires a controller to perform its functions in an intake system. This translates into a requirement for software to control the ETC Air Control Valve position, and even more software to command the ETC Air Control Valve to work with the engine control system.

5.1.1 Motor Control (Position Control of Throttle Valve)

5.1.1.1 Unstable Actuation

Motor control gains are developed to maintain consistent time response and accuracy when positioning the throttle of the Air Control Valve. Unstable actuation that results from aggressive motor control could cause excess dither and premature wear of some of the Air Control Valve internal components.

5.1.1.2 Motor Drive Frequency

The motor drive frequency can influence electrical power dissipation, Electro-Magnetic Compatibility (EMC) and acoustical noise whenever the Air Control Valve actuator is powered. If the motor drive frequency is too low, the return spring may move the throttle slightly in between drive pulses resulting in excess dither and premature wear of some of the Air Control Valve internal components.

Recommendation: Apply motor drive frequencies greater than 1500 Hz.

5.1.1.3 System Controls

High frequency, low amplitude changes in commanded position (such as engine speed governing and speed control) can result in excess dither and premature wear of some of the Air Control Valve internal components.

Recommendation: Apply reasonable RPM and speed control thresholds that minimize Air Control Valve dither.

5.1.1.4 Motor Control Overshoot

Large step responses that allow the valve to overshoot beyond the maximum or minimum controllable positions may result in damage to gear teeth as the internal hard stops impact.

Recommendation: Calibrate the motor control to limit overshoot to less than 1% beyond maximum controllable throttle position (where max controllable is defined as 100% throttle).

5.1.1.5 Learn Minimum Position

The "learn minimum" position function is usually performed at key-on (before the engine is started) to establish the 0% throttle position sensor value. Doing this routine quickly is important to guarantee a fast start time. However, if the minimum position is learned incorrectly, then the maximum controllable position (as defined in the engine controller) may actually approach or exceed the maximum hard stop position. This may result in damage to gear teeth as the throttle is commanded to open beyond the internal hard stop.

Caution: *Take care not to drive the throttle closed so fast that gear teeth break while learning the minimum position.*

Recommendation: ETC Actuator Control gains may need to be different for the "learn minimum position" maneuver, than for normal operation. Use diagnostic software to check that the learned minimum position value is reasonable. The learned minimum position should be a lower TPS value than the de-energized ETC TPS value.

5.1.2 Throttle Position Sensing and Diagnostics

5.1.2.1 Handling of Throttle Position Sensor Open Circuit Condition

It is important to address a situation when a Throttle Position Sensor is not connected to the throttle actuator controller. The throttle actuator controller is usually driving the throttle to open or close to reduce the error between the commanded throttle position and the actual throttle position, as it is read by the controller. In the case of an open circuit in a TPS signal at the controller, the throttle position signal will not be representative of the actual throttle position. If the signal indicates a position lower than the commanded position, the controller will try to open the throttle against the wishes of the driver.

Recommendation: Use electrical interface circuitry described in Figure 5-1: with a pull-up resistor on the TPS signal that increases with throttle angle, and a pull-down resistor on the TPS signal that decreases with increased throttle angle. The result in the case of an open circuit will be that the controller will sense a throttle position signal that is higher than any possible commanded position, and it will try to close the throttle to reduce the error between the commanded and actual signals.

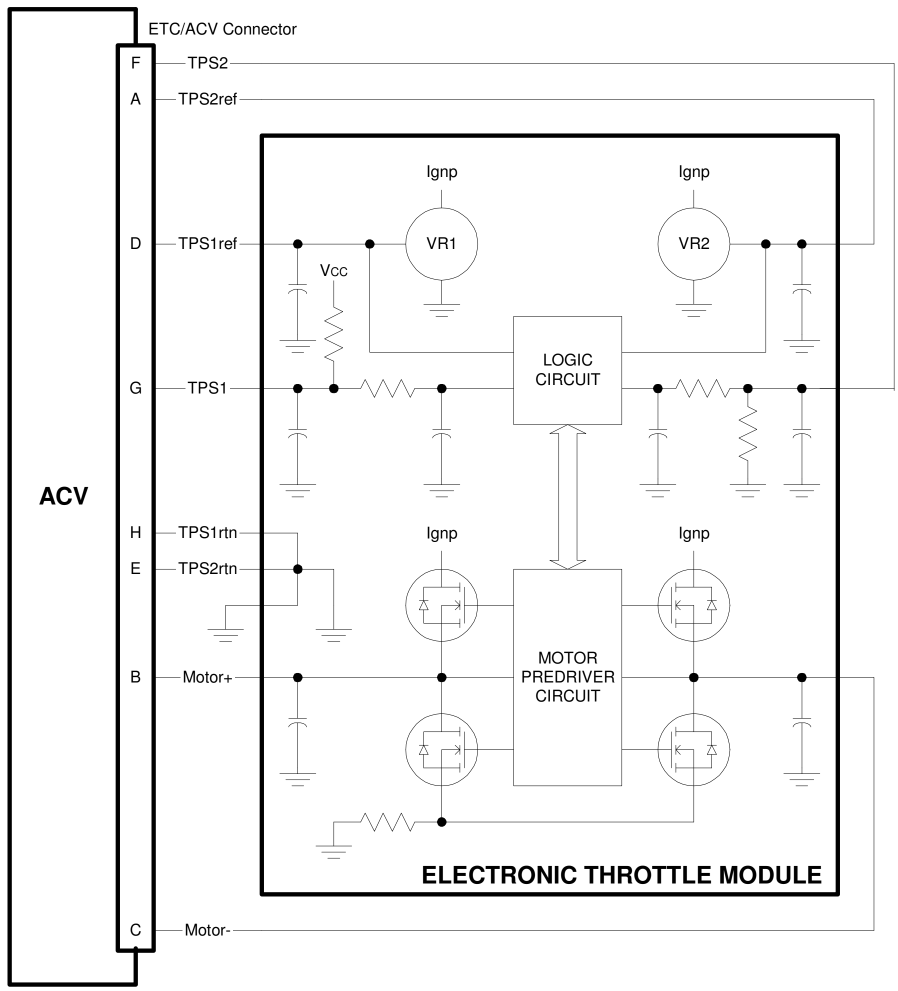


Figure 5-1 ETC Subsystem Schematic

Recommendation: Turn on an indicator lamp to inform the driver that an ETC system problem (the open circuit on the TPS) has occurred. This requires careful design of the ETC to make sure the signal voltage during an open circuit condition is always higher (or lower depending on TPS slope) than the TPS signal voltage defined at Wide Open Throttle (WOT).

5.1.3 ETC-Air Control Valve Contribution to Engine Control

The ETC Air Control Valve is used to regulate airflow to an engine. When used in conjunction with fuel control and spark control, the combustion in an internal combustion engine is controlled.

5.1.3.1 Controllability

The air rate progression of the ETC-ACV, along with the position sensor resolution, determines the resolution of control afforded to the ETC – ACV. Higher resolution generally translates into better controllability.

The ETC controller software should be written in a way to take advantage of the resolution provided by the ETC-ACV to maximize the controllability. (i.e. An ETC-ACV with 12 bit feedback resolution is not utilized fully by a controller that only uses an 8-bit commanded position resolution.)

The ETC Air Control Valve design has mechanical characteristics (bore shape, valve size and angle, etc…) that will affect engine controllability by changing the air rate progression.

Characteristics of the ETC actuator will also have an effect on engine controllability.

5.1.3.2 Advantage of ETC over Mechanical Throttle

A major advantage to using ETC instead of using a mechanical throttle system is the ability to use software to control the airflow to the engine. (With a mechanical throttle body system, the airflow rate is commanded directly by the accelerator pedal.) This enables better control of the combustion process during all operating conditions and maneuvers, enabling an equivalent engine to achieve higher efficiency, and lower exhaust emissions.

Engine control algorithms can be written to optimize air control during transient maneuvers rather than simply react to a change in airflow command.

ETC plays a large role in enabling "Displacement On Demand" (DOD) systems where multiple engine cylinders are effectively turned off to increase fuel economy when a vehicle is in "cruise" mode. Using the ETC to control the change in air needed by the engine running on fewer cylinders, makes seamless operation of DOD systems possible.

5.1.4 ETC System Configurations

Figure 5-2, shows the most common mechanization for new ETC systems including the ETC Air Control Valve. Other configurations have been used in the past, and are possible, such as using a separate engine and throttle controllers.

The integration of cruise control is demonstrated in the diagram to show how adding this feature requires fewer components when using an ETC Air Control Valve, than with a traditional Throttle Body Assembly.

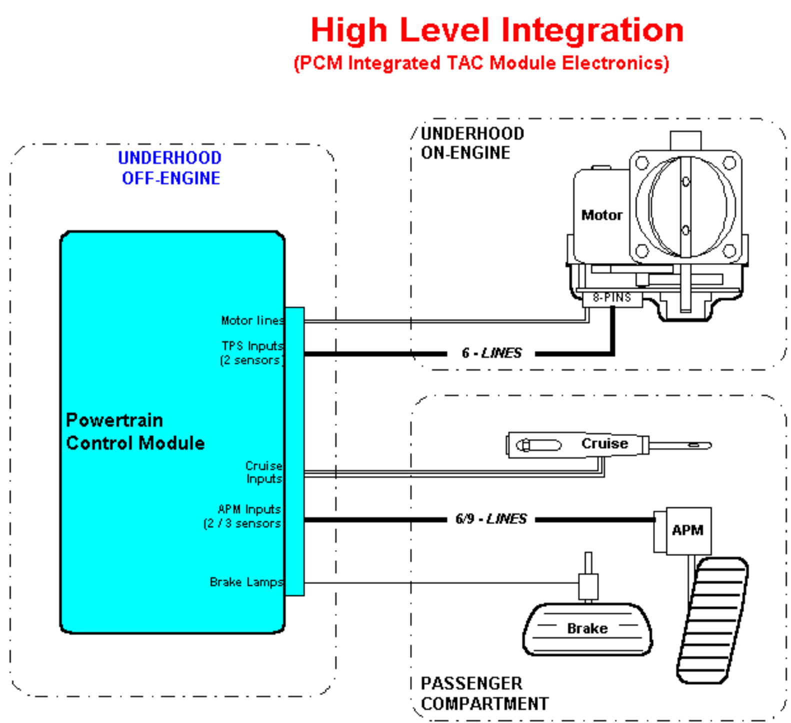


Figure 5-2 High Level ETC System Integration

5.1.5 Throttle Control/Air Rate Progression

The airflow rate change per unit change in throttle position is determined by the ETC-ACV design. (The resolution of the airflow progression is determined by the controller hardware/software configuration.) The change in airflow rate per unit change in driver command is determined by the Engine / ETC system actuator control software.

Figure 5-3 shows a typical airflow curve from an ETC-ACV. A curve of airflow vs. driver command for ETC is programmable, and may look different.

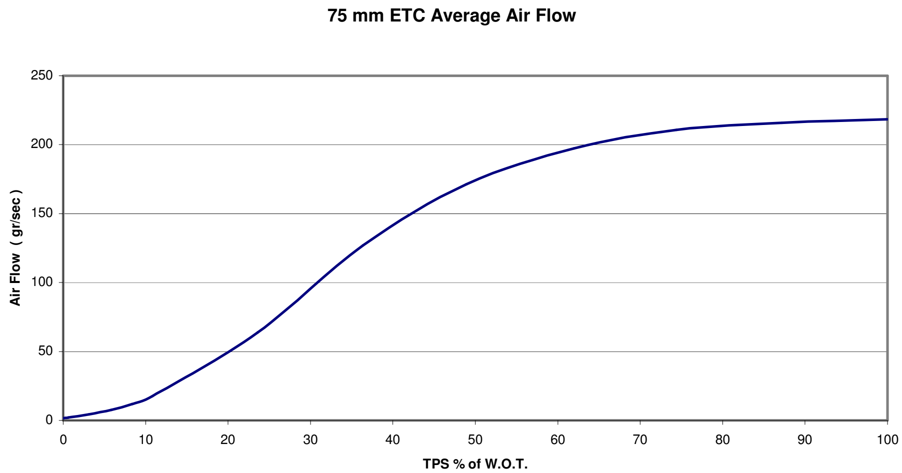


Figure 5-3. Example of Air Flow vs. Rotation.

The engine control software (using an ETC-ACV) can be used to program different engine (torque output) response vs. driver command (accelerator pedal position).

5.2 Load Compensation

Engine load may vary due to power steering, engine friction induced by temperature differentials, air conditioning, or electrical demands. The worst condition requiring additional air typically occurs in high altitude and cold ambient temperature conditions.

The ETC-ACV can be commanded to provide additional air to compensate for the additional loads occurring during idle and other steady state operating conditions, with minimal changes to the engine speed (RPM). The additional air should, of course be accompanied by additional fuel command.

5.3 Idle Control Considerations

5.3.1 Interaction of Spark and Fuel

During steady-state idling, the ETC-ACV should not be moving. Idle problems at steady-state are usually caused by poor combustion related to spark, fuel, EGR, or the base engine design. Spark advance and air/fuel ratio control can be used to improve idle control performance.

5.3.1.1 Spark

An engine will respond much faster to a change in spark advance than it will to a change in ETC-ACV position.

- Typical spark delay is 90 crank degrees.
- Typical air delay is 360 crank degrees. Intake manifold volume significantly delays and filters engine response.
- A modifier to spark advance based on RPM error can be effective in reducing RPM variations during idle.
- Spark control allows the system to control RPM closer to the desired value than would be possible with the ETC-ACV alone.

5.3.1.2 Fuel

Since variations in the A/F ratio can produce severe idle problems, accurate calibration of both open and closed loop fuel delivery is important.

5.3.2 Other Idle Control Contributors

5.3.2.1 Cold Engine Compensation

Extra air is required to compensate for the increased friction in cold engines. Desired idle speed is also raised in cold engines to improve idle quality after starting and during warm-up.

5.3.2.2 Load Compensation

Load compensation allows the idle control system to compensate for changes in engine loads before they can affect idle quality. Idle control may not respond fast enough to compensate for high transient loads. Additional inputs may be needed to provide adequate response, or a compromise in system design may be required.

5.3.2.3 A/C Load Compensation

The air-conditioning system represents the greatest engine load at idle. There is also a momentary peak load when the A/C compressor clutch engages. A/C loading is a function of:

- Ambient temperature
- Blower speed
- Humidity
- A/C setting (Max/Norm)

In most applications, the engine controller controls engagement of the A/C compressor clutch. It delays compressor clutch engagement until extra air and fuel are added to cover the transient load. The engine controller also disengages the compressor during a stall condition.

5.3.2.4 Cooling Fan Calibration

Electric cooling fans have a high turn-on electrical load which drops quickly to a small load once the fan reaches operating speed.

In many applications, the cooling fan is controlled by the engine controller. This allows extra air and fuel to be added before energizing the fan(s).

5.3.2.5 Power Steering Calibration

Power steering pump loads can increase drastically during a steering cramp (steering wheel turned to full stop). In addition, the total load of both the power steering pump and the A/C compressor can exceed the engine's torque capacity.

- A power steering pressure switch is a pressure operated make/break switch in the power steering hydraulic supply line. It is used to signal the engine controller of high system pressure.
- The engine controller may de-energize the A/C clutch under high power steering loads.
- The engine controller may also add air and fuel to compensate for compressor load during a high power-steering load.

5.4 TPS Software

The Throttle Position Sensor (TPS) is a critical component to any ETC system. It provides the signal that the software controls to. It is very important to control to a good throttle position signal. Controller software should be written in a way that a corrupt TPS signal is not used for ETC control.

5.5 TPS Diagnostics

See Section 5.1.2

Most control modules check TP sensor operation for high voltage on-signal line, low voltage on-signal line, and skewed rationality. Dual Tracking TPS's are additionally checked against each other. TPS diagnostics are control-module specific.

6.0 Product Handling

The purpose of this section is to familiarize you with Delphi-E&C recommended handling procedures for the *ETC-ACV* Assembly. These recommendations cover storage practices and all handling that may occur from the time the ETC-ACV enters until it leaves the customer's plant. Use this information as a guide for product handling within your operations. Table 6.1 lists recommendations for handling the ETC-ACV Assembly.

Table 6.1 — ETC-ACV ASSEMBLY HANDLING

ACTION	REASON
DO: Use care during assembly of harness to ETC-ACV.	Avoid terminal damage.
DO: Avoid any liquid contamination in the ETC-ACV area.	Ensure proper operation.
DO: Handle skids with correct equipment.	Components may be damaged or emission settings disrupted.
DO: Use "first in, first out" inventory.	Maintain accurate cut-off dates for tooling/design changes.
DO: Unload and install units one at a time from packing trays.	Damage may be done to critical components.
DO: Return any dropped, damaged, or suspect material with a tag that describes the problem.	Ensure fast and correct diagnosis of root cause.
DO: Remove and discard protective caps just before assembling mating components.	Protects system from contamination which can prevent proper operation.
DO NOT: Transfer to assembly area skids that have been damaged or have packaging whose integrity is suspect.	Components may be damaged or emission settings disrupted.
DO NOT: Stack inventory skids above the recommended weight limit.	Pallets or trays may flex or break.
DO NOT: Stack units on top of each other.	Damage may be done to critical components.
DO NOT: Use any dropped unit.	Internal damage may have occurred or emissions settings may have been upset.
DO NOT: Store units without protective caps in place.	Contamination may impair correct operation.
DO NOT: Ship or store near saltwater without protection.	Corrosion buildup may impact proper operation.
DO NOT: Apply any voltage other than system voltage for testing.	Damage could occur.
DO NOT: Remove packing in a way that allows contact between parts.	Minimum air leakage could be affected and/or other damage could occur.
DO NOT: Rake, stage, or handle parts in a manner that allows contact between parts.	Damage will occur.

6.1 Packing Procedures

When the ETC-ACV is not to be installed and delivered on a Delphi supplied IAFM, the following packing procedures should be followed.

The ETC-ACV Assembly must be handled with reasonable care to prevent damage. Proper handling starts at the Delphi-E&C manufacturing operation where the packaging methods used help reduce the risk of damage due to impact, moisture, or contamination.

Note*: Although packaging may vary according to customer requirements, the following description summarizes key elements of the process.*

Typical ETC-ACV Assemblies are bulk-packaged in plastic trays. Examples of packaging specifications are as follows:

- Tray size: length 23”, width 21.5”, height 6”
- Quantity per tray: 20
- Quantity of trays per pallet: 64
- Tray layout on pallet: 6 trays each row, 4 trays each side
- Weight of full tray: 11.5 pounds
- Pallet size: 48” x 45” x 48” four way entry
- Weight of full pallet: 772 pounds

A one-piece cover covers each tray layer. A fully loaded pallet is covered with a plastic top board and stretch wrapped with plastic (see Figure 6-1). A label is applied to each skid (see Figure 6-2).

PROPOSED PACK FOR STORING MPFI THROTTLE BODY ASSEMBLIES

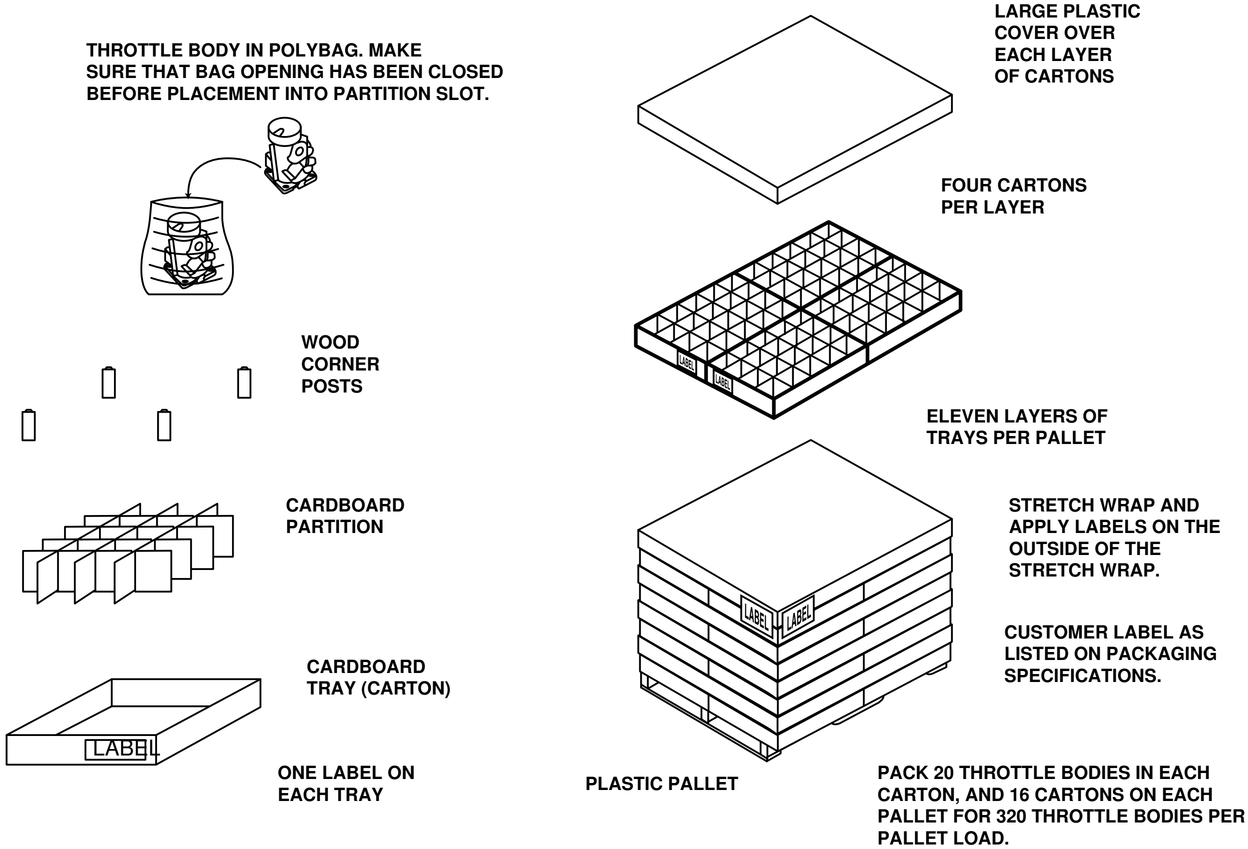


Figure 6-1. Packing Tray.

6.2 Receiving and Storage

The condition of each pallet should be checked on receipt. Check the label attached to the pallet to verify the model number. Report any damage to Delphi-E&C.

Store the ETC-ACV in a cool, dry, dust-free environment.

Caution: *To prevent corrosion, the ETC-ACV Assembly should never be exposed to liquid contamination.*

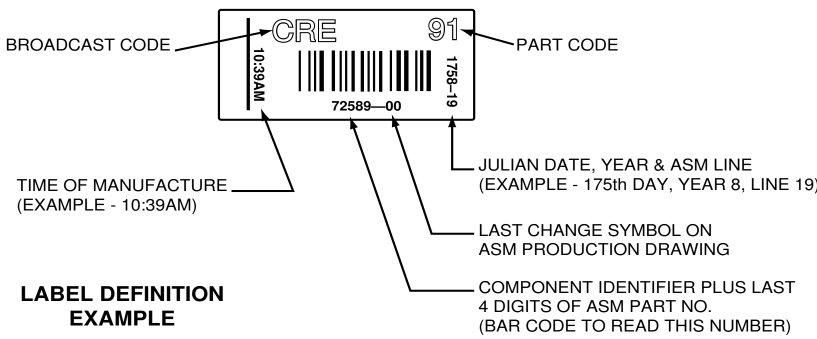


Figure 6-2. Pallet/Carton Label and Bar Code.

6.3 Movement within the Plant

Exercise care to prevent damage and contamination when ETC-ACV's are transported from storage to production lines or staging areas.

6.4 Installation on the Engine

Follow these guidelines to prevent damage to the ETC-ACV Assembly and its electrical interface during the build process.

Shipping cap

- To prevent contamination at the electrical connectors, do not remove the shipping (terminal) caps until vehicle assembly. Do not twist the shipping cap to remove it, pull it straight out.

Harness connector

- Install the harness connector carefully to prevent damage to terminals. Avoid unnecessarily disconnecting/reconnecting the harness connector.

Connector tabs

- Exercise care that the connector tab is not damaged during installation. Replace the ETC-ACV if the tab becomes damaged.

Voltage for testing, Refer to Section 9.0

- Never apply full system voltage to the actuator for testing purposes. (See Section 9.0 for additional test precautions).

6.5 Maintenance, Service and Repair

6.5.1 Diagnosing Malfunction Codes

If an ETC/ACV Malfunction Code appears during any phase of testing, evaluate all factors, which might prove to be the root cause. A Diagnostic Trouble Code may not indicate an ETC-ACV component or system failure. On the contrary, the diagnostics may be responding properly, indicating a failure or irregularity elsewhere in the engine or control system.

Note: *Procedures for diagnosing Diagnostic Trouble Codes are specific to each application.*

6.5.2 Replacement Techniques

ETC-ACV replacement varies with application — consult your Delphi-E&C application engineer for specific replacement techniques. The following removal and replacement procedure is for a typical ETC-ACV Assembly.

Warning*: The ETC-ACV Assembly and all associated hardware may be extremely hot.*

Remove or disconnect:

1. Negative battery cable
2. Air inlet duct
3. Electric Actuator and Throttle Position sensor electrical connector(s)
4. Engine coolant pipe nut to gain access to ETC-ACV attaching stud
5. ETC-ACV retaining bolt/stud
6. ETC-ACV Assembly
7. Flange gasket (discard)

Clean:

- Gasket surface on intake manifold

Note: *Use care in cleaning old gasket material from machined aluminum surfaces because sharp tools may damage sealing surfaces. Also, throttle bore and valve deposits may be cleaned on the vehicle using carburetor cleaner and a parts cleaning brush. Follow instructions on the container.* ***Do not*** *use a cleaner that contains methyl ethyl ketone. Methyl ethyl ketone is an extremely strong solvent and is not necessary for this type of deposit.*

Caution: *Do not submerge Electric Actuator or TPS in any cleaning fluid..*

Install or Connect:

1. New flange gasket
2. ETC-ACV Assembly
3. ETC-ACV retaining bolt/stud – Tighten to 25 N•m (18 lb. ft.)
8. Electric Actuator and Throttle Position sensor electrical connector(s)
5. Air inlet duct
6. Negative battery cable

Install or Connect (TPS):

Components	Installation Screw Torque
Gen III TPS	1.70 - 2.30 Nm
TPS / Motor Connector	1.7 – 2.3 Nm

Note: *Dynamic installation torque measured at screw head with a maximum driving RPM of 1000.*

Inspect:

- With the engine “OFF,” check to see that the accelerator pedal is free

6.5.3 Adjustments

There are no service adjustments for the ETC-ACV.

6.5.4 Interchangeability

The ETC-ACV Assembly should be replaced only with an equivalent assembly.

6.5.5 Support of Component After Sale

Depending on control module application, a diagnostic scan tool may be required to service the ETC-ACV Assembly.

7.0 Recommendations and Precautions

The recommendations and precautions presented in this chapter are for reference only. These are intended to be best practice guidelines, and not specifications. Following the recommendations will make the ETC system more robust.

7.1 Temperature

7.1.1 Normal Operating Temperature

Most ETC-ACV applications are designed to operate between - 40^{o}C and 125^{o}C measured as surrounding air and external component temperatures. Higher temperatures for short durations are acceptable for most applications (hot soak condition).

Recommendation:

Only operate the ETC-ACV within the normal operating temperature range.

To determine an application's ETC-ACV temperature across the full range of operating conditions, install a ETC-ACV equipped with thermocouples that can monitor temperature buildup and extremes. Recommended locations for thermocouples on an ETC-ACV appear in Figure 7-1.

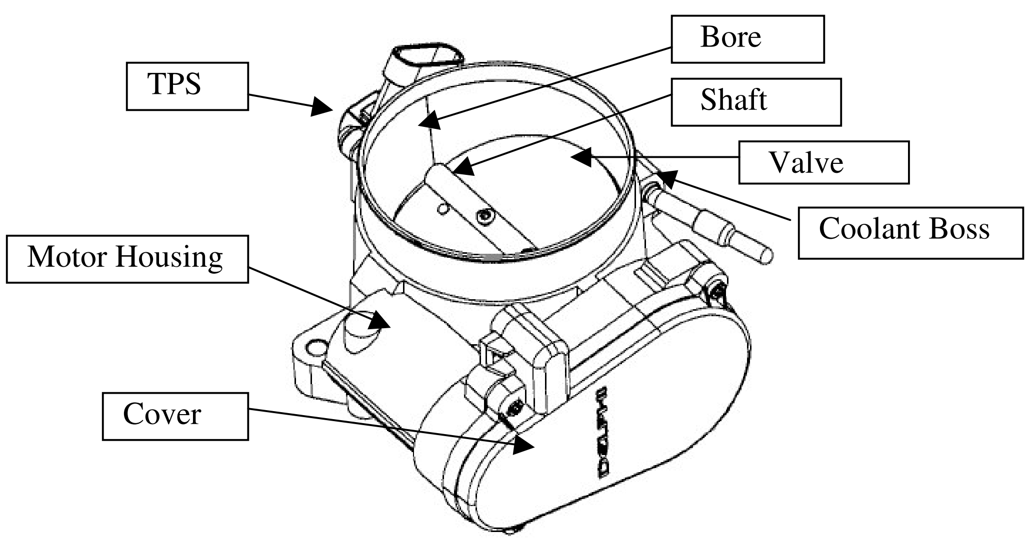


Figure 7-1 Thermocouple Locations on an ETC-ACV

7.1.2 Extreme Operating Temperatures

The resistance of the coils used in the ETC actuator changes with temperature. When the resistance changes, the electrical current carrying capability changes accordingly. The ETC actuator uses electrical current to generate an opening and closing force. When the temperature changes, the capability of the actuator to generate an opening or closing force changes.

7.1.2.1 Extreme Cold

When the ETC-ACV is operated in an extreme cold environment, the actuator resistance is rather low. The current carrying capability is high, and the torque output capability is high.

At the same time, the friction in the bearings is higher, and the gears (which are usually plastic) are more brittle. More torque from the actuator is required to rotate the ETC valve, and the added torque is applied to the more brittle gears. Using caution with the closed loop actuator control at extremely cold temperature makes for a more robust ETC system.

Recommendation:

Do not allow the engine controller to command the ETC to the minimum or maximum mechanical positions when the ambient temperature is below the low end of the normal operating environment specification. Hitting the hard stops with the additional torque available at the actuator may result in internal ETC damage.

Recommendation:

Disable any “learning” of minimum or maximum mechanical position throttle position sensor values when the ambient temperature is outside the normal operating environment specifications.

Recommendation:

Some ETC systems may use specific high torque maneuvers to break ice away in the ETC bore. Take care that these maneuvers do not result in the ETC hitting the minimum or maximum mechanical positions with high torque. *(i.e. If the current throttle position is low, use an ice breaking maneuver in the opening direction rather than in the closing direction.)*

7.1.2.2 Extreme Hot

When the ETC-ACV is operated in an extreme hot environment, the actuator resistance is rather high. The current carrying capability is low, and the torque output capability is low. Extreme high temperature environments are usually short events for the ETC. The ETC is generally cooled by the fresh intake air that passes though it.

Recommendation:

Disable throttle position accuracy and throttle response time diagnostics during the short duration extreme high temperature events. The ETC-ACV actuator may not have the torque capability to reach all throttle positions until the ETC is cooled down to within its normal operating temperature.

Recommendation:

Disable any “learning” of minimum or maximum mechanical position throttle position sensor values when the ambient temperature is outside the normal operating environment specifications. The throttle may not reach the target positions.

7.2 Vibration

7.2.1 Vibration - ETC Mounting Location

An ETC-Air Control Valve, depending on where it is located on the engine, may be exposed to excessive vibration.

Recommendation:

The ETC-ACV should be mounted as close to the centerline of the crankshaft as possible to minimize the effects of vibration energy. Also, consider the rotational axis of the engine when packaging the ETC-ACV.

7.2.2 Vibration - Usage

An ETC-Air Control Valve, depending on how it is used, may be exposed to excessive vibration.

Recommendation:

Inform the ETC supplier of any extreme usage/vibration requirements for the ETC, so the design can be made robust enough for the application.

7.3 Contamination

7.3.1 Contamination from Improper ETC-ACV Intake Air Filtering

Internal contamination of the throttle shaft, valve, bore, and bearing may occur if the inlet air to the ETC-ACV is not properly filtered. This condition will cause premature wear.

Recommendation:

Filter inlet air with an air filter.

7.3.2 Contamination from Coking

Coking of the throttle valve and bore may occur if EGR and PCV gases are introduced close to the ETC-ACV.

Recommendation:

Do not introduce PCV and EGR gases directly at the ETC-ACV base (the minimum distance allowed between the ETC-ACV base and PCV and EGR gases is 2.5 inches). Furthermore, do not introduce PCV and EGR gases at the same location. The optimal design is to introduce PCV gases downstream of EGR gases.

Note: *Oxygenated fuels typically increase deposit formation. Some fuel additives that used to keep injectors clean now cause valve deposits to form.*

Temperature cycling is essential in order to form hard deposits. Steady state tests usually do not cause deposits to form. The temperature range associated with deposit formation on intake valves is from 195^{o}C to 230^{o}C. The temperature range associated with deposit formation on the EGR valve is from 320^{o}C to 370^{o}C.

To minimize the chance of forming deposits, it is recommended that the introduction points of EGR and PCV be as far apart as possible. In this instance, PCV is considered the carrier of oil, and EGR supplies the heat in the deposit formation process.

7.3.3 Contamination - External

Recommendation:

Locate the ETC-ACV so it is protected from exposure to road splash and road dirt.

7.4 Icing

There are two types of icing: soak icing and run icing. Refer to Table 7-1 for optimum icing-prohibiting conditions.

DESIGN FEATURE	OPTIMUM
Inclination	Angle down toward primary moisture source
PCV vapor introduction	As far downstream from throttle valve as possible
Clean air/bypass	ETC-ACV upstream
Location of EGR introduction	Supplemental heat used
EGR calibration	No EGR scheduled when cold
PCV vapor scheduling	Ability to optimize flow rate and location.
Shaft to journal clearance	2 - 4 mm sealing land length
Throttle shaft seals	Inboard and outboard
Orientation	Horizontal
Rotation of valve	Bottom away from primary moisture source

Table 7-1. ETC-Air Control Valve Non-Icing Guideline Matrix.

7.4.1 Icing Mechanisms

7.4.1.1 Accumulation During Road Load Driving Modes

Moisture in the air drawn into the engine can condense and freeze on induction system components. Certain pressure and temperature conditions may result in the immediate formation of ice through sublimation.

The flow of cold air through the ETC-ACV keeps the ETC-ACV at a lower temperature than other underhood components. At light to moderate throttle, the pressure drop across the throttle valve can also have an effect, especially at temperatures near freezing. The pressure drop across the throttle valve allows moisture to freeze at a reduced temperature and form ice on the back of the throttle valve. The high velocity of the air at the top and bottom of the throttle valve (assuming a horizontal shaft) will generally prevent buildup of ice on those edges, but ice can form on the back (downstream) side of the throttle valve. If sufficient moisture is introduced directly into the bore during operation, an ice build-up may occur on the bore and/or throttle valve, which could effect normal throttle function.

7.4.1.2 Ice Formation During Short Trip Driving or Soak

Short drive/soak cycles involve the effects of moisture condensing on areas of the induction system, which are at a temperature below the dew-point temperature, and the melting, and re-freezing of ice formed during driving modes. Short drive/soak cycles can cause the temperatures in the induction system to fluctuate from below freezing and dew-point temperatures to above these temperatures, with the majority of condensation and ice build-up occurring after the engine is turned off. Some temperatures may rise above the operating temperature immediately after shut down, but will eventually cool back down to the ambient temperature. During the initial stages of the soak, any ice that was formed on the back of the throttle valve, in the bore, bearing, or shaft area, or on any other surface of the induction system may melt. This moisture may accumulate over time on a number of drive/soak cycles. As the system cools, water vapor present in the air, natural or through PCV and EGR gases, will condense on the cooling components at the dew point. The water accumulated from melting ice and condensing vapors will drain into the local low point of the induction system. This accumulated water could affect normal throttle function upon re-freezing, depending on the amount of water in the system and the location of the collection sites.

7.4.1.3 Sources of Moisture

The water vapor contained in the ambient air inducted into the engine represents a small part of the moisture that can lead to ice formation in the induction system. This is due partly to the fact that at low temperatures relative humidity is usually also low. The major sources of moisture in the system are the PCV (positive crankcase ventilation) system and EGR (exhaust gas recirculation).

7.4.2 Failure Modes

7.4.2.1 Throttle Opening Force Too High

The force required to open the throttle can be adversely affected by ice formed between the throttle valve and the bore, freezing the throttle valve in water collected at the bottom of the bore, or ice in the throttle shaft.

7.4.2.2 Throttle Does Not Return to Idle after a Throttle Maneuver

This failure mode can occur due to ice formed while the throttle is not closed, or from pieces of ice in the system upstream of the ETC-ACV becoming dislodged and being caught between the throttle valve and the bore.

7.4.2.3 Loss of Feature Function

Vacuum Signals

The formation of ice in ports or passages can degrade the performance of the feature.

7.4.3 Icing Locations

7.4.3.1 Throttle Shaft/Bearing Clearance

A relatively small amount of moisture can cause an icing problem if it freezes between the throttle shaft and journal or inside the bearing elements in the ETC-ACV. This condition is more likely to occur in designs that incorporate a journal type bearing as opposed to a ball or roller bearing. The moisture can get into the small clearances as vapors and condense on the bearings and shaft as they cool. The pressure differential between the atmosphere and the intake manifold can draw in moisture from condensation, splash, or other external sources through any unsealed leak paths.

7.4.3.2 Throttle Valve/Bore

Throttle valve-to-bore icing can occur during driving modes and may prevent normal throttle function. Freezing between the valve and the bore may also occur following a melt and re-freeze of ice in the system, generally following a soak condition. This condition will inhibit valve opening. Loose chunks of ice, from the ETC-ACV or anywhere upstream of the ETC-ACV, can lodge between the valve and the bore, preventing the return of the valve to the idle position.

7.4.4 Contributing System Factors

7.4.4.1 Non-functional PCV System

The PCV system is a large source for moisture in the induction system. PCV system failure modes can result in even more moisture introduced to the induction system.

7.4.4.2 High Blow-by Engine

A high blow-by engine has more moisture in the crankcase, which results in more moisture introduced into the induction system by the PCV system.

7.4.5 ETC-ACV Design Considerations

7.4.5.1 Bearing Configurations

Sealed Ball Bearing

The simplest bearing design, a journal bearing, is also the most susceptible to icing problems due to the large clearance between the shaft and the bearing. The relatively large clearance provides a flow path for moisture introduced from road splash. A split sleeve type bearing is better than a journal bearing because of its reduced clearance, but is not as effective as a ball or roller bearing. In addition to improved throttle valve position control, sealed-ball bearings significantly reduce the flow path in the shaft/bearing interface area.

7.4.5.2 Shaft Sealing Land Length

The seal between the throttle bore and the atmosphere along the shaft/ETC-ACV Housing interface is achieved in most applications by maintaining a small clearance between a sealing land machined in the throttle body and the shaft. The length of this sealing land should be just long enough to provide adequate sealing. Excessively long sealing lands can provide enough surface area to obstruct throttle movement if ice forms.

7.4.5.3 Throttle Shaft Seals

Seals on the inboard and the outboard side of the bearings provide the most protection from moisture entering.

7.4.5.4 Orientation

The orientation of the throttle shaft should be such that the bearings are not in a position at the bottom of the bore, where moisture may collect and freeze. A horizontal shaft orientation is preferred, and a vertical orientation represents the worst-case configuration. Potential for the wicking of moisture along the shaft/bearing interface increases with the change in the angle from horizontal.

7.4.5.5 Rotation of the Throttle Valve

All failure modes of the air induction, PCV, and EGR systems must be considered when determining which way to rotate the throttle valve. In general, the bottom of the throttle valve should rotate away from the primary moisture source. This general rule should only be applied after considering the severity of the failure modes that may occur on a given application. A throttle valve stuck in a closed position may represent a preferred failure mode over a condition that allows the valve to open with large flows of ice upstream of the throttle valve.

7.4.5.6 Inclination

It is generally advantageous to have a slight inclination (5 to 10 degrees along the axis of the throttle bore) to allow any frost or ice build-up on the valve to drain away from the valve/bore interface when it melts. Failure mode severity and frequency must be evaluated when considering throttle body inclination, as described in the section on valve rotation. The effect on intake manifold design requirements, including possible air/fuel distribution effects, must also be evaluated.

7.4.5.7 PCV Vapor Introduction

The location of the introduction of PCV vapors can have a significant impact on the robustness of the system against icing because PCV vapor is a major contributor of moisture in the system. In general, the PCV vapor should be introduced as far downstream from the throttle body as possible, while still allowing for adequate mixing of the PCV vapors and incoming air. The location should also be selected to allow moisture to drain away from the ETC-ACV. If this drainage path is not possible, due to manifold design or failure mode precedence considerations, a sump in the intake manifold should be incorporated to keep the moisture from collecting in the ETC-ACV. The sump should have sufficient capacity to contain worst case “water in oil” levels observed during the low duty cycle water accumulation tests.

7.4.5.8 Clean Air/Bypass

The PCV bypass or clean air system can also introduce significant quantities of moisture into the system upstream of the ETC-ACV. Operation conditions that result in moisture from this source include heavy load points where engine vacuum levels are not sufficient to handle the blow-by levels, or PCV system failure modes, such as a non-functioning PCV valve or a blocked or loose hose. The design considerations are the same as for the PCV vapor introduction — introduction should be far away from the ETC-ACV with no downhill path to the ETC-ACV.

7.4.5.9 Location of EGR Introduction

The products of combustion being introduced into the induction system contain water vapor, so the location of the EGR introduction should be chosen with icing considerations in mind. EGR gases should be introduced away from the ETC-ACV if the heat of the exhaust gases is not being used to heat the ETC-ACV to prevent road load icing. Failure mode evaluation and sump designs previously discussed should be considered for the EGR introduction also.

7.4.5.10 Vacuum Signal Ports Location

The various ports in the bore of the ETC-ACV should be located such that moisture will not collect in the port in any of the ice formation, melt, and re-freeze scenarios possible. The worst case for a port is the bottom of the bore, which should be avoided. Some applications may require a “bottom out” valve rotation with a timed (ported) vacuum signal, which would not allow for a top of bore introduction. In these cases, a quarter bore introduction (port located one quarter of the way from the bottom of the bore to the shaft axis) could be used, assuming proper distribution. Locations above the centerline provide protection against feature loss due to water and/or ice in the ports, with optimum distribution performance delivered with the port at the top of the bore.

7.4.5.11 External Moisture Protection

Many factors related to the under-hood layout of a given application contribute to the degree of protection against splash that may be inherent to the application. It should be noted that in many applications the engine compartment momentarily fills with water in water trough testing, so splash protection alone will not protect the system entirely. Leak paths in the ETC-ACV must be considered. Outside seals on the shaft/bearing interface and splash shields may be required, and electrical connectors should be designed with good sealing capability.

7.4.6 System Control Considerations

7.4.6.1 EGR Calibration with Respect to Cold Engine

Delaying EGR introduction until after the engine has reached a specific temperature is effective to prevent icing from this moisture source during short trip cycling.

7.4.6.2 PCV Vapor Scheduling

PCV vapor scheduling offers some potential for improved PCV vapor handling in cold weather conditions and/or in re-directing vapors under certain operating conditions.

7.4.6.3 Development and Validation Testing

The following vehicle tests are designed to evaluate ETC system icing robustness with a focus on various key development variables. Consult Delphi-E&C for the recommended tests for your specific application.

- Road load cruise icing
- Soak icing schedules (based on 2 mile DRIVE/Soak cycles)
- Spark plug fouling
- Cold weather durability
- Cold weather development

The following vehicle tests are designed to detect system icing problems with a focus on various key development variables. Consult Delphi-E&C for the recommended tests for your specific application.

- Special “System Limits” Tests (add water to the crankcase)
- Failure mode with non-functional PCV system
- High humidity, moderate temperature
- Special external moisture (underhood splash, engine wash and cold soak)

7.5 Electrical Mating Connector

Increased contact resistance over time due to fretting corrosion or contact wear due to vibration.

Recommendation

Use the same contact material on the mating connector as is used on the ETC connector. *(ie. Use gold plated contacts when mating to gold plated contacts, and use tin plated contacts when mating to tin plated contacts.)*

Recommendation

Use lubricant in the mating connector contacts to reduce fretting corrosion and wear. (Nye Nyosil- M25, Nye Nyogel 760G, and Nye Fluorocarbon Gel 813-1 are some examples of possible lubricants.)

Recommendation

Tie down the wiring harness within 3 inches of the connector to minimize the movement of the connector terminals due to vibration.

7.6 Handling an ETC Air Control Valve

The ETC Air control valve is a precision-machined engine control component that is designed to be self-actuated. The ETC valve and bore have very little clearance at low throttle angles. Care must be used when handling the ETC to prevent any bore or valve distortion.

Recommendation

Do not actuate the ETC (rotate the throttle valve) manually. Pressing on the throttle valve to close the ETC can distort the valve, and damage the bore.

Caution: Valve and/or bore distortion can lead to a zero or negative clearance situation. (The throttle valve has difficulty rotating in this condition.)

8.0 Testing Recommendations and Precautions

Every vehicle/engine manufacturer has developed a set of standard and application specific test procedures for component validation. Since most test procedures are unique and proprietary to the manufacturer, there will not be an attempt to list them all here. Instead, provided are some general examples that are specific to the ETC-ACV subsystem.

8.1 Dynamometer Testing

It is important that the ETC System be tested under conditions that approximate normal operating conditions. When dyno testing an engine, be sure to allow throttle cycling routing so that the TPS is not subjected to a fixed position under high engine vibration and long testing hours. A typical cycling routing is one wide open throttle cycle per nine throttle cycles. Do not exceed a 30 g setting on the accelerometer when evaluating the vibrational effect on ETC-Air Control Valve.

Note: *subjecting the ETC-ACV to a severe dyno, testing schedule may be appropriate or necessary for a specific application. In this case, please be sure to communicate this intent, and include such testing in the product requirements, so the appropriate design features may be included on the ETC design for such an application.*

8.2 Dynamic Vehicle Testing

Dynamic Vehicle Testing (DVT…the end of line test of a vehicle at the vehicle assembly plant) should be performed to the same specifications as those to which the vehicle is calibrated where it is applicable. Any reduction in tolerance bands should be reviewed with the Delphi-E&C Application Engineer.

In the instance that the vehicle calibration does not specify limits for a specific Dynamic Vehicle Test, then the test limits should correspond to the ETC-ACV component specifications.

The ETC-ACV components most commonly tested at DVT are the TPS and Electrical Actuator.

8.2.1 Dynamic Vehicle Test (DVT) Limits Recommendations

8.2.1.1 TPS Limits

Any voltage limits for testing the TPS at DVT should be derived from the component drawing. Do not use voltage limits that are derived from experience with prototype or pilot vehicles. Parts that meet their specifications may fail at DVT unless the full range of voltage limits from the component drawing is used.

8.2.2 DVT Test Precautions

Dynamic Vehicle Testing can be a powerful tool to diagnose specific errors or problems in engine or vehicle assembly. The methods used to test for common specific problems or errors however, can lead to misdiagnosis of a problem with the ETC Air Control Valve.

The ETC Air Control Valve is usually not the only path for air to enter the engine intake manifold. Other air sources such as PCV, canister purge, and vacuum assisted brakes are air sources to the engine. These systems have to work correctly for the ETC Air Control Valve to work as expected.

Air leaks can cause mis-diagnosis of a ETC Air Control Valve problem. Check the installation of all components that seal to the intake manifold or cylinder head on the intake side when too much air is getting to the engine.

8.2.2.1 TPS Test Precautions

The tests performed at DVT should not test for conditions that the ETC Air Control Valve was not designed or specified to handle.

For example: There should not be a test to check for the repeatability of the TPS voltage with and without vacuum unless a specification for such a test is included in the component drawing.

8.3 Standard Vehicle Testing

Vehicle testing is generally under the responsibility of the ETC-ACV customer. Some of the vehicle tests Delphi has experience with supporting are discussed in this section.

8.3.1 Icing Tests

Icing tests are vehicle tests intended to evaluate the ETC system performance in the presence of an environment where icing is more likely to occur. (Icing is the formation of ice in the bore or on the throttle valve of the ETC Air Control Valve.)

Icing tests are performed in very cold temperatures. The cold temperature is naturally occurring (cold trip), or in an Environmental Vehicle Lab (EVL). Temperatures should not rise above –20°C throughout the testing.

The ETC Air Control Valve should perform trouble free for at least 10 consecutive soak icing tests. For Run icing testing, the ETC Air Control Valve should perform trouble free while driving a vehicle for 60 minutes immediately after 10 consecutive soak icing tests.

8.3.2 Altitude Driveability and Emissions Test

Altitude testing verifies vehicle operation in high altitude areas where the air is less dense. The ETC Air Control Valve should not adversely affect engine performance in high altitude areas. (This is more for calibration verification.)

8.3.3 Hot Environment Tests

8.3.4 Cold Start Tests

8.3.5 Acoustic Noise Evaluations

8.3.6 Under Hood Splash / Water Intrusion / Corrosion Tests

8.3.7 Trailing Dust Tests

8.4 Durability Testing

Refer to Section 9.0

Durability tests are performed in an application environment and conditions need to be specified by the manufacturer. A typical example of a ETC-ACV durability bench test schedule is outlined in Section 9.0.

9.0 Validation Requirements

9.1 General

This section outlines the validation requirements for the ETC-ACV Assembly.

Validation is the process whereby the components and/or system are evaluated through methods of testing, analysis, inspection, and/or demonstration, to ensure that the component/system meets the specified quality/reliability/durability goals and conforms to governmental standards/requirements. The evaluation aims to verify the design, manufacturing and usage of the component/system.

The validation process could entail various types of evaluation based on three medium levels - component, system, and vehicle. The DFMEA and SFMEA should be used to pinpoint component/system strengths, weaknesses, and possible failure modes, relative to actual vehicle operation. Laboratory tests can be used in evaluating component and/or system conformance to performance goals and government standards. Delphi-E&C schedules, along with field/road tests, are procedures used to provide validation data for the component/system/vehicle relative to the "overall" package.

Delphi-E&C subjects all new and modified designs to development and/or design verification testing to confirm design integrity. Once the product is released to the customer for final validation, testing should be performed on the vehicle using production-intent calibration.

9.2 Standard Durability Test

Standard durability tests to which Delphi-E&C subjects its ETC-ACV are extensive and thorough.

Measurements include:

- Allowable Degradation — The unit must meet all functional and design requirements before and during all testing. Failure (end-of-test) occurs when there is a greater than specified deviation from product functional specifications.
- Life Target — Specified by customer.

***Note**: Testing should simulate actual vehicle conditions and be synergistic by design. Test fixtures should reflect the full range of mating part tolerances as defined in application design requirements. Electrical connectors should remain mated (sealed) throughout the test.*

A typical testing should include elements of the following:

***Note:** This requirement is application specific.*

- Temperature Shock — -40°C to 100°C with 1.5 hour dwell hot and 2.0 hour dwell cold. 48 hours total exposure.

***Note**: This requirement is application specific.*

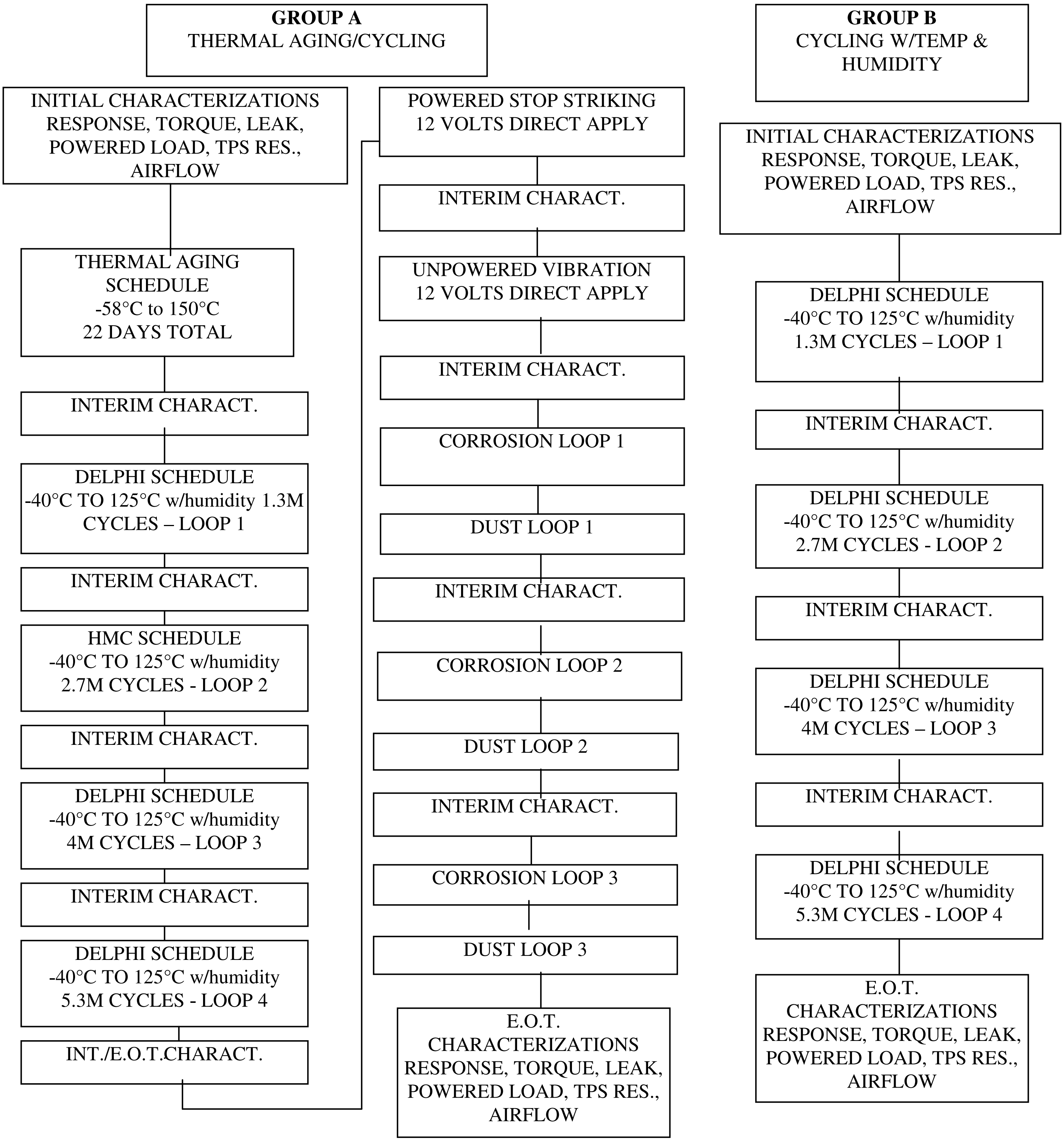
- Durability Duty Cycle Testing with Temperature Humidity — -40°C to 125°C, 0% to 85% R.H. schedule while exercising the units to a position command schedule for 1.5 lives (from Target Life Specification). Interim Characterizations are done to monitor performance at regular intervals.
- Durability Oscillation Testing with Temperature Humidity — -40°C to 125°C, 0% to 85% R.H. schedule while exercising the units to an oscillation type position command schedule for 1.5 lives (from Target Life Specification). Interim Characterizations are done to monitor performance at regular intervals.
- Corrosion — Each loop consists of 5% neutral salt spray for 48 hours, followed by 120 hours at 60°C and 100% RH. Units are sprayed once per day while in temperature/humidity exposure with a 1% salt solution. Units cycle at 1 cpm while in salt spray only. Two loops are typically run.
- Vibration — Severity is based on specific engine application and is accelerated to 20 hours per mode. Throttles cycle at 15 cpm and temperature cycles from -40° to 125°C.
- Dust — Delphi-E&C "coarse" dust density of 3.5 - 10.5 g/m^3 at 80° C, circulating at 48 km/hr. 9 hours total exposure with throttles cycling at 15 cpm and 60 kPa vacuum applied at idle.
- Ozone — Only if ETC-ACV contains untested polymer or composite components. 72 hours at 38°C at 100 pphm ozone concentration.

9.3 Validation Tests

The standard validation tests to which Delphi-E&C subjects its ETC Air Control Valves are listed below. A comprehensive validation plan may entail performing the complete array of tests or a combination of them, based on the characteristics of the product. Consult Delphi-E&C for the appropriate requirements for your specific application.

***Note**: Except where noted, the part is to be mounted and connected per application design requirements. The requirements/tests represent minimum life expectancy and are normally divided into three loops.*

- Thermal Aging — -58^{o}C to 150^{o}C environment schedule for 22 days or as required to support customer required test schedule.
- Durability Duty Cycle Testing with Temperature Humidity — -40^{o}C to 125^{o}C, 0% to 85% R.H. schedule while exercising the units to a position command schedule for 1.5 lives (from Target Life Specification). Interim Characterizations are done to monitor performance at regular intervals.
- Powered Stop Striking — Apply 12 Volts directly to motor pins for a number of events. (This should not occur during normal service.)
- Corrosion and Salt Fog Test— Salt Spray environment equivalent to ½ life, followed by Salt Fog environment for ½ life equivalent.
- Dust — Exposure to airborne sand (ACR coarse dust), at 3.5 to 10.5 GM per cubic meter density, air velocity at 48 km/hour and temperature between 77^{o}C and 83^{o}C for 9 hours
- Vibration — Requirement is application specific. For example, vibration in each of three modes for twenty hours per mode. RMS random or sine on random vibration between 20 and 2,000 Hz. Units are cycled full travel during test. Units are also exposed to a scheduled Temperature and Humidity environment during testing.
- Oscillation Testing — -40^{o}C to 125^{o}C, 0% to 85% R.H. schedule while exercising the units to an oscillation type position command schedule for 1.5 lives (from Target Life Specification). Interim Characterizations are done to monitor performance at regular intervals. This test is done to a separate group of parts than those from above.
- Discrete Tests — Temperature Storage, Pressure Storage, External Hot Quench, Contaminants Tests, Spray Wash Tests, Corrosion Tests, Drop Test, and Flammability Tests.


GROUP A
THERMAL AGING/CYCLING
INITIAL CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
THERMAL AGING SCHEDULE -58°C to 150°C 22 DAYS TOTAL
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 1.3M CYCLES – LOOP 1
INTERIM CHARACT.
HMC SCHEDULE -40°C TO 125°C w/humidity 2.7M CYCLES - LOOP 2
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 4M CYCLES – LOOP 3
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 5.3M CYCLES - LOOP 4
INT./E.O.T.CHARACT.
POWERED STOP STRIKING 12 VOLTS DIRECT APPLY
INTERIM CHARACT.
UNPOWERED VIBRATION 12 VOLTS DIRECT APPLY
INTERIM CHARACT.
CORROSION LOOP 1
DUST LOOP 1
INTERIM CHARACT.
CORROSION LOOP 2
DUST LOOP 2
INTERIM CHARACT.
CORROSION LOOP 3
DUST LOOP 3
E.O.T. CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
GROUP B
CYCLING W/TEMP & HUMIDITY
INITIAL CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
DELPHI SCHEDULE -40°C TO 125°C w/humidity 1.3M CYCLES – LOOP 1
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 2.7M CYCLES - LOOP 2
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 4M CYCLES – LOOP 3
INTERIM CHARACT.
DELPHI SCHEDULE -40°C TO 125°C w/humidity 5.3M CYCLES - LOOP 4
E.O.T. CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW

GROUP C
POWERED VIBRATION

- INITIAL CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
- VIBRATION W/TEMPERATURE & HUMIDITY -40°C TO 125°C FULL TRAVEL - DUTY CYCLE LATERAL MODE
- INTERIM CHARACTERIZATIONS
- VIBRATION W/TEMPERATURE & HUMIDITY -40°C TO 125°C FULL TRAVEL - DUTY CYCLE VERTICAL MODE
- INTERIM CHARACTERIZATIONS
- VIBRATION W/TEMPERATURE & HUMIDITY -40°C TO 125°C FULL TRAVEL - DUTY CYCLE LONGITUDINAL MODE
- E.O.T. CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW

GROUP D
CORROSION/DUST

- INITIAL CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
- POWERED STOP STRIKING 12 VOLTS DIRECT
- INTERIM CHARACTERIZATIONS
- CORROSION LOOP 1
- DUST LOOP 1
- INTERIM CHARACTERIZATIONS
- CORROSION LOOP 2
- DUST LOOP 2
- INTERIM CHARACTERIZATIONS
- CORROSION LOOP 3
- DUST LOOP 3
- E.O.T. CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW

GROUP E
OSCILLATION CYCLING

- INITIAL CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW
- THERMAL AGING SCHEDULE -58°C to 150°C 22 DAYS TOTAL
- OSCILLATION CYCLING W/TEMP AND HUMIDITY -40°C TO 125°C
- CYCLING LOOP 1 3 million CYCLES
- INTERIM CHARACTERIZATIONS
- CYCLING LOOP 2 6 million CYCLES
- INTERIM CHARACTERIZATIONS
- CYCLING LOOP 3 9 million CYCLES
- INTERIM CHARACTERIZATIONS
- CYCLING LOOP 4 12 million CYCLES
- E.O.T. CHARACTERIZATIONS RESPONSE, TORQUE, LEAK, POWERED LOAD, TPS RES., AIRFLOW

Group F

Temperature Storage

Pressure Storage Test

External Hot Quench

External Contaminant Test
Various fluids and chemicals

Road Contamination Test

Spray Wash Test

Unpowered Load Test

Cosmetic Corrosion Test

Sea Coast Corrosion Test

Impact Test
One Meter Drop on Concrete

Under Hood Flammability Test

9.4 Verification

Verification is sometimes also referred to as Product Validation. Testing for Verification is the same for verification purposes, as is done for validation purposes. Verification tests are done on parts built using production tooling and components. Consult Delphi-E&C for the appropriate requirements for your specific application.

Note: *Some validation tests are not necessarily repeated for verification. Those tests that have to do with material compatibility are not repeated on production parts. (The results will be the same.)*

10.0 0 Appendix

10.1 Glossary of Terms and Abbreviations

A/C - Air Conditioner

A/F - Air/Fuel

AWG - American Wire Gauge

C/L - "Closed Loop"

DFCO - Decel Fuel Cut Off

DFMEA - Design Failure Mode Effects Analysis

DLA - Digital Link Actuator

DLC - Data Link Connector

DVT - Dynamic Vehicle Testing

ECT - Engine Coolant Temperature

EGR - Exhaust Gas Recirculation

EMI - Electromagnetic Interference

IAC - Idle Air Control

IAT - Intake Air Temperature

MAF - Mass Air Flow

MAP - Manifold Absolute Pressure

MIL - Malfunction Indicator Lamp

NAO - North American Operations

PCP - Process Control Plan

PWM - Pulse-width Modulation

QA - Quality Assurance

RFI - Radio Frequency Interference

SCR - Specific Component Requirements

SFMEA - System Failure Mode Effects Analysis

STG - Service Technology Group

TCC - Torque Converter Clutch

T/C - Thermocouple

TPS - Throttle Position Sensor

VSS - Vehicle Speed Sensor

WOT - Wide Open Throttle

10.2 Customer Component Checklist

		Revision Dates	Item No.
Customer Name:			
Customer Manager:		12/13/2001	Added detail
Engine/ Model Yr.:			
Platform:			
Initial Date:			
CCD Number:			

	Subsystem Drivers for Component Selection	Application Manual Ref.	Requirements Doc Section	Value
	REQUIREMENTS			
1	Appearance			
2	Content (And any special component requirements... ie. non-contacting sensors)			
3	Operational Environment			
4	Temperature range			
5	Air Pressure range			
6	Contaminants			
7	Loads			
8	Vibration			
9	Humidity range			
10	Electromagnetic Compatibility Requirements			
11	Nominal operating voltage range			
12	Non-Operational Environment (On Vehicle)			
13	Temperature			
14	Energy Source			
15	Manufacturing Environment			
16	Temperature			
17	Pressure			
18	Contaminants			
19	Loads			
20	Vibration			
21	Interfaces			
22	General			
23	EACV to Subsystem			
24	Mounting (to manifold)			
25	Attachment to intake duct (or air meter)			

26	Fresh Air (PCV supply air)			
27	Coolant Heat (to prevent adverse effects from icing)			
28	Leak Rate (maximum)			
29	EACV to Controller (contacts / connectors)			
30	Reference Voltage Input(s)			
31	Reference Voltage Return(s)			
32	Analog Inputs			
33	PWM Output (Frequency, Current capacity, H-bridge?)			
34	Usage			
35	Service Life (and warranty requirement)			
36	Performance			
37	WOT air flow rate and pressure drop across EACV (or specify bore size)			
38	Minimum mechanical position airflow (at 60 kPa pressure drop)			
39	Default Air Flow (flow at default position with 60 kPa pressure drop)			
40	Air Flow Resolution for Idle air control			
41	Air flow resolution above idle control airflow			
42	Powered Response Time			
43	Unpowered Response Time (FMVSS-124)			
44	Physical Characteristics			
45	Exterior Outline			
46	Mass			
47	Reliability / Durability			
48	Reliability			
49	Maintenance, Service, and Repair			
50	Maintenance			
51	Service			
52	Repair			

Note:

10.3 Conversion Chart (Air Only)

Note: *Only valid at 70°F with 29.92 inch Hg. Pressure*

Multiply → by the values in the table to obtain ↓	**cc/min**	**ft^3/min**	**lbs/min**	**gr/sec**
cc/min	1	2.832×10^4	3.7807×10^5	5.000×10^4
ft^3/min	3.531×10^{-5}	1	13.35	1.766
lbs/min	2.645×10^{-6}	0.07492	1	0.1323
gr/sec	2.000×10^{-5}	0.5664	7.560	1

Example: 100 cc/min = $100 \times 3.531 \times 10^{-5}$ ft^3/min = 3.531×10^{-3} ft^3/min

11.0 Index