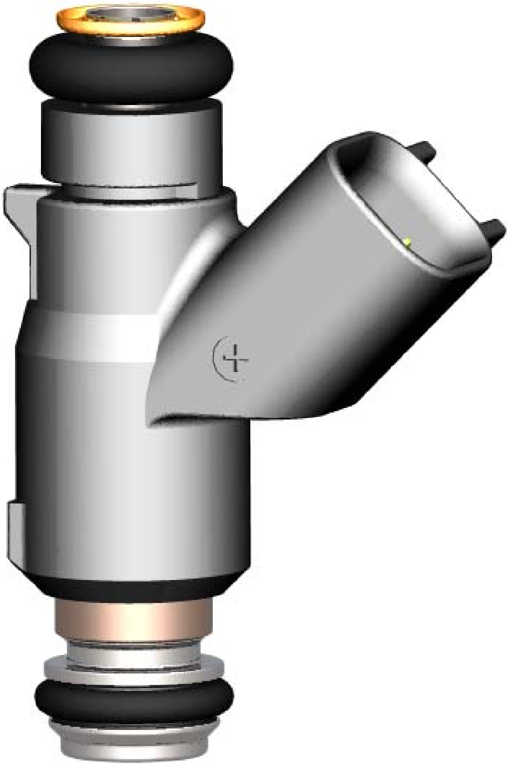
Multec 3.5 Top Feed Fuel Injector

Application Manual



DELPHI

Fuel Systems Applications Engineering
Delphi Energy & Chassis Systems
5500 W. Henrietta Rd.
P.O. Box 20366
Rochester, New York 14602 USA

Multec 3.5 Top Feed Fuel Injector Application Manual
Release/Revision Summary Sheet

CHANGE NO.	DATE	REASON FOR CHANGE	PAGE(S)
Issued	April 2004	N/A	N/A
1	July 2005	Replaced “J-spray…” with “J-2715 (Draft)” in section 1.9.4.2	1-7
1	Nov. 05	Added shutdown throttle closure note to section 8.4.4	8-4
1		Changed ‘and applicable’ to ‘any applicable’ in section 1.9.1	1-5
1	Nov 05	Added reference to Worldwide Emissions Standards booklet to section 2.2.3 and 1.9.3	1-6, 2-8
1	Nov 05	Updated MTBE phase out plans in section 2.2.6.2	2-10
1	Nov 05	Updated gasoline sulfur requirements in section 2.2.6.3.4	2-12
1	Nov 05	Re-worded section 2.2.7.3 for clarity	2-18
1	Nov 05	Corrected return and inlet locations in Figure 2-5	2-23
1	Nov 05	Added extended tip description to section 3.2.2 and view to Figure 3-2	3-3, 3-4
1	Nov 05	Changed “core” to “valve” in section 3.2	3-1
1	Nov 05	Added rotational orientation note to section 3.3.5	3-6
1	Nov 05	Reworded section 3.5.1 for clarity	3-11
1	Nov 05	Added Zener diode voltage range and injector flow test for vehicle calibration note to section 3.6.3	3-13
1	Nov 05	Revised calculation example from max flow to min flow in section 3.7	3-19
1	Nov 05	Added J-2715 to section 3.8	3-21
1	Nov 05	Revised 96% spray volume for dual spray to 90% in section 3.8.2	3-22
1	Nov 05	Updated Figure 3-12 to current data format	3-26
1	Nov 05	Removed word “serviceable” from filter requirements in section 3.12	3-36
1	Nov 05	Changed “Component Technical Specification” to “Engineering Product Specification” in section 3.16	3-39
1	Nov 05	Added “absolute” to manifold air pressure in Table 3-2	3-40
1	Nov 05	Revised Figure 6-1 to include o-ring installation tool	6-3
1	Nov 05	Added section 6.4 and Figure 6-2 – injector installation into fuel rail and renumbered remaining sections	6-4
1	Nov 05	Added reference to Figure 6-1 in section 4.3	4-8
1	Nov 05	Added “total” to A/F variation” in section 3.10.2	3-33
1	Nov 05	Added section 5.2.3.3 “Variable Fuel Pressure Compensation”. Renumbered remaining sections.	5-10
1	Nov 05	Added reference to terminal lubricant (section 7.5) in Table 6-1	6-2
1	Nov 05	Added reference to terminal lubricant (section 7.5) in section 4.4.4	4-14
1	Nov 05	Added reference to Figure 6-1 in section 6.5	6-6
1	Nov 05	Added metal fuel line recommendation to section 7.3.5	7-5

1	Nov 05	Renumbered pages in section 4 starting at 1	4-1
1	Nov 05	Changed dwell time from 1 hr to 0.5 hr and duration from 240 hours to 120 hours in section 9.3.2.1	9-3

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1.0 Introduction

1.1 Scope of Document

This Application Manual communicates Multec 3.5 Top Feed Port Fuel Injector application guidelines for spark ignition engines.

1.2 Classification

The information and specifications in this manual covers Multec 3.5 gasoline fuel injectors.

1.3 Document Management

This document shall be maintained by Delphi. Express written consent of Delphi must be obtained before any use or modification of this document is permitted.

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. http://hal.roc.acr.gmeds.com/applications/

1.4 Commercial Considerations

All commercial considerations/cost and scheduling requirements shall be handled by the Delphi Sales and Marketing Group.

1.5 Objectives of this Manual

Delphi provides advanced fuel systems technology for both automotive and non-automotive applications. The Multec 3.5 Fuel Injector is an example of Delphi leadership and its commitment to continuous improvement and world-class quality.

This Multec 3.5 Fuel Injector Application Manual has been developed to support the efforts to integrate the Multec 3.5 Fuel Injector into a specific fuel system or engine management system.

The objectives of this document are to help:

- Obtain maximum value and optimum performance from the Multec 3.5 Fuel Injector
- Integrate the Multec 3.5 Fuel Injector within the engine control system (hardware and software)
- Protect the Multec 3.5 Fuel Injector from damage caused by improper usage, mounting, handling, or installation
- Prevent testing errors that might result in an inaccurate evaluation of Multec 3.5 Fuel Injector performance
- Prevent calibration errors that may interfere with the proper operation of the Multec 3.5 Fuel Injector

To accomplish these objectives, this manual provides the following:

- A description of the components and features of the Multec 3.5 Fuel Injector
- A description of the process used to determine the requirements needed to achieve the following objectives:
  - Accurate fuel flow requirements
  - Proper injector spray
  - Proper injector spray targeting
- A description of the options for packaging and mounting, as well as the optional features available to meet underhood packaging, serviceability and diagnostic requirements
- Calibration and testing guidelines
- A checklist of interface details required for Delphi to ensure that the proper fuel injector selection is made to meet customer requirements. The fuel injector should be specified based upon the constraints/ demands of the engine control module (engine controller and software) and the chassis fuel supply subsystem (fuel rail, fuel pressure regulator, fuel pump, fuel filter and supply lines).

1.6 How this Manual is Arranged

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. The documents listed in section 1.9 can be referred to for additional detail to aid in understanding the requirements set forth in this manual.

Section 2.0 — Injector Fundamentals

Section 2.0 describes the characteristics and requirements of the Multec 3.5 Fuel Injector and its related components. Also discussed is an overview of combustion fundamentals with a detailed description of how the fuel system works together with the air/fuel delivery system and exhaust gas treatment to meet vehicle emissions requirements.

Section 3.0 — Product Description

Section 3.0 provides an overview of fuel injector construction, materials, performance and cost drivers. Physical and electrical specifications for standard assemblies are defined and flow and performance specifications for commonly available fuel injectors are provided. Also discussed is the process Delphi uses to provide custom products.

Section 4.0 — System Interface – Hardware & Electrical

Section 4.0 describes and illustrates the mechanical and electrical interfaces required to obtain optimum performance from the fuel injector. The electrical interface, chassis fuel supply and fuel filtration interface are also described.

Section 5.0 — System Interface – Software Controls

Section 5.0 provides both an overview and specific detail on the software requirements to operate the fuel injector. Various control algorithms commonly used to achieve optimum performance under varying engine conditions are described, and additional algorithms, which are based on emissions and driveability requirements, are recommended. Calibration and diagnostics are also discussed. Understanding this section is critical to achieving optimum performance from the Multec 3.5 Fuel Injector.

Section 6.0 — Product Handling

Section 6.0 presents Delphi recommendations for the handling, storage, installation, and servicing of the fuel injector. 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 fuel injector will function as intended.

Section 7.0 — Recommendations and Precautions

Section 7.0 provides a summary of Delphi recommendations and precautions for proper fuel injector use. Common misuses are identified and alternate solutions presented.

Section 8.0 — Testing Procedures

Section 8.0 discusses testing procedures that are based on the experience of Delphi and its customers. Adhering to the recommendations contained in this section will ensure that the fuel injector is evaluated correctly under conditions that parallel normal use and operation.

Section 9.0 — Validation Requirements

Section 9.0 outlines the process for validating the fuel injector, i.e., ensuring that it meets specified quality, reliability, and durability goals and conforms to governmental standards/regulations.

Section 10 - Appendix

- **10.1— Introduction**
- **10.2— Injector/ System Component Checklist**
- **10.3— Multec 3.5 Injector Application Guideline Checklist**
- **10.4— Component Assembly Best Practices**
- **10.5— Glossary of Terms and Abbreviations**

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 locate important topics throughout the document. The left margin contains additional information:

- key words and information to which special attention must be paid.

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

- ***Note****—Indicates important technical detail that is relevant to the topic being discussed.*
- ***Caution*** *—Indicates information about a condition or an activity that must be performed to prevent damage to the Multec 3.5 Fuel Injector, fuel system, electronic control system, engine or the vehicle.*
- ***Warning*** *—Indicates a condition that might pose a risk to personal safety.*

***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 Hyperlinks

All references to section numbers, figures and tables are hyperlinks that will jump to the section of the document containing the reference when the mouse is left clicked over the reference number. (Applies only to WORD version of the applications manual.)

1.9 Applicable Documents

1.9.1 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 the Delphi application engineer. Until the contradiction can be resolved, the part outline drawing will always take precedence. Nothing in this document shall be considered to supersede any applicable law or regulation unless a specific exemption has been obtained.

1.9.2 Government Documents

To be supplied by customer for specific country.

1.9.3 Other Delphi Reference Documents

1.9.3.1 Multec 3.5 Fuel Injector specific Part Number and associated outline drawing

1.9.3.2 Multec 3.5 Fuel Injector Component Technical Specification (or equivalent document) if available

1.9.3.3 Delphi Fuel Rail Applications Manual

1.9.3.4 Delphi Catalytic Converter Applications Manual

1.9.3.5 Delphi Fuel Pump Applications Manual

1.9.3.6 Delphi EGR Applications Manual

1.9.3.7 SFMEA

1.9.3.8 OBD-II Diagnostic Procedures

1.9.3.9 Delphi Worldwide Emissions Standards summary booklet

1.9.4 Industry Documents

1.9.4.1 SAE Standard Procedure J1832

1.9.4.2 SAE J-2715 (Draft) Gasoline Fuel Injector Spray Measurements and Characterizations

1.9.4.3 ASTM D86, "Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure"

1.9.4.4 ASTM D2533, "Standard Test Method for Vapor-Liquid Ratio of Spark-Ignition Engine Fuels"

1.9.4.5 ASTM D4814, "Standard Specification for Automotive Spark-Ignition Engine Fuel"

1.9.4.6 ASTM D5191, "Standard Test Method for Vapor Pressure of Petroleum Products (Mini Method)"

1.9.4.7 World Wide Fuel Charter

1.9.4.8 Internal Combustion Engine Fundamentals. John B. Heywood, McGraw-Hill Publishing, 1988.

1.9.5 Useful Web Sites

1.9.5.1 EPA Vehicle Emissions Information:

http://www.epa.gov/ebtpages/airmobilevehicleemissions.html

1.9.5.2 **CARB Web Site:** **http://www.arb.ca.gov/**

1.9.5.3 **Delphi Corp Web Site:** **http://www.delphi.com/**

2.0 Fundamentals

2.1 General

The Multec 3.5 Fuel Injector is a component of the Air/Fuel Subsystem. The function of the fuel injector is to provide the required fuel quantity and spray geometry to the each engine cylinder to meet vehicle performance and emissions requirements over a wide range of operating conditions. The Multec 3.5 Fuel Injector is designed for electronic port fuel injection systems, which maintain an individual fuel injector for each engine cylinder and operate the individual injectors via an electrical signal. The control logic for each injector is typically governed through an electrical control module that is provided by the customer. The customer develops the logic with input from Delphi.

The fuel injector supply system typically consists of the fuel injectors, a fuel rail or conduit, a fuel pressure regulator and connections to fuel supply and return lines. This portion of the fuel system is installed directly to the intake system of the engine. On some applications, especially returnless fuel systems, a mechanical device for damping fuel pressure pulsations may be incorporated to reduce fuel line "hammer". Returnless fuel systems do not have a return line connection and typically incorporate the pressure regulator either closer to or within the fuel supply tank. (See Fuel Rail Applications Manual for more details.)

The vehicle fuel system includes the above mentioned injector supply system as well as fuel supply and return (optional) lines, fuel filter, fuel pump and fuel tank. The evaporative emissions system, while not directly linked to the fuel injector supply system, must be considered, as vapor purge from this system into the engine intake system will directly impact how the fuel injector is controlled under certain conditions.

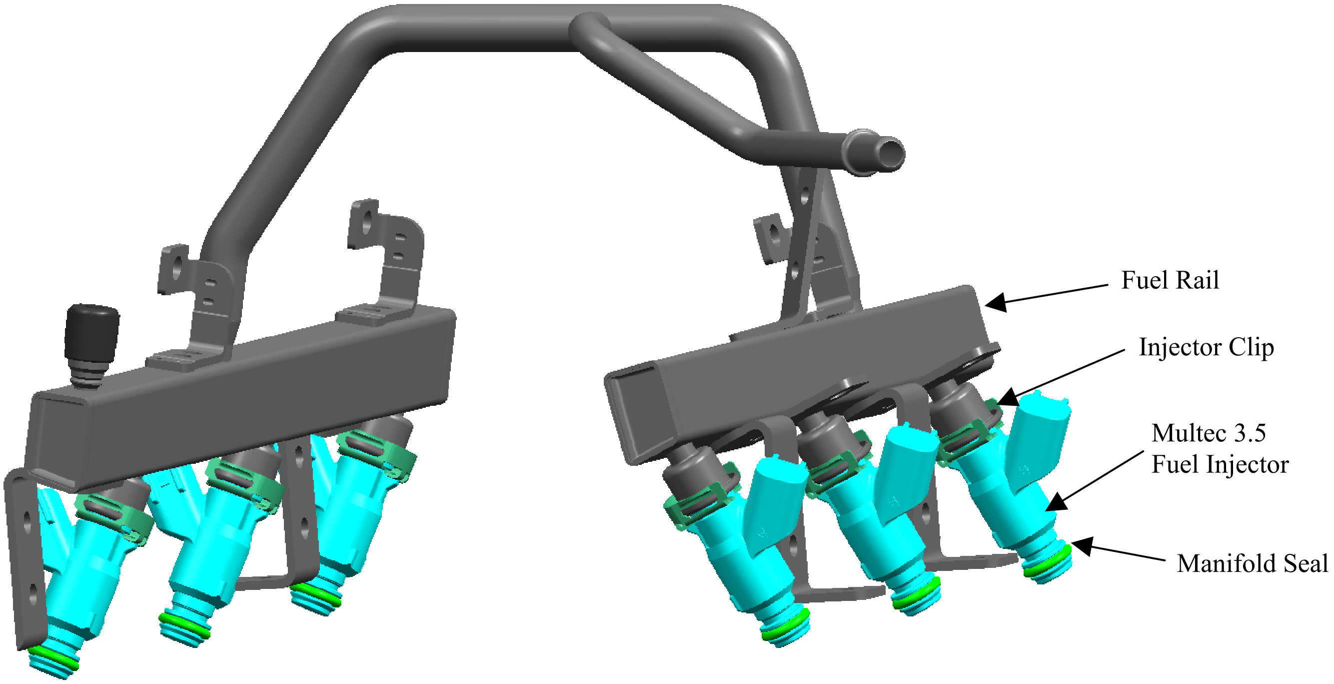


Figure 2-1- Engine Fuel System (shown is a demand fuel rail for a V6 application)

2.2 Engine Combustion Fundamentals

Internal combustion is a complex process involving interactions of many engine subsystems over widely changing conditions. A complete explanation of these interactions and requirements and the theory of combustion are outside the scope of this manual. The following sub-sections summarize the major considerations involved with the fuel injector's impact on combustion. If a more detailed explanation is required on any of these topics, please contact Delphi Energy and Chassis Systems.

The following text is suggested for those who would like a more comprehensive understanding of internal combustion engine operation and theory:

Internal Combustion Engine Fundamentals. John B. Heywood, McGraw-Hill Publishing, 1988.

2.2.1 Air/Fuel Ratio Effects on Combustion

The goal of the Multec 3.5 Fuel Injector is to supply the correct fuel mass to achieve the correct air/fuel ratio (A/F). Complete combustion will depend, in general, on the following:

- The air and fuel must be in the proper portions (referred to as the stoichiometric mixture or ratio); this proportion will depend upon the chemistry of the fuel.

Ref. Sec 2.2.1.1	***Note**: Stoichiometric A/F refers to the quantitatively derived ratio of air to fuel that will allow the chemical process of combustion to be delivered to ideal equilibrium. In this manual, A/F is stated in terms of their molecular weights – that is, molecular weight of air over molecular weight of fuel.*

- The mixture must be in vapor state, as liquid fuel is not combustible.

Ref Sec. 2.2.7.2 & 8.4.1	***Note**: In order to eliminate any confusion, it is important to note that for the fuel injection process fuel must be in a liquid state in order to be properly metered by the fuel injector. Vapor formation before the injection process is highly undesirable and can cause a host of driveability problems (See Sec. 2.2.7.2 and 8.4.1). However, it is important for the actual combustion process that fuel is in the vapor state. This is typically achieved through the fuel spray and particle size characteristics of the liquid fuel after it is injected. Other factors, such as injection time, fuel spray targeting, residence time and the air induction characteristics all play a role in this process.*
Note	*Throughout this manual, it should be assumed that when A/F ratios are stated as being stoichiometric, it is in reference to standard non-oxygenated fuels unless specifically stated otherwise. It should be noted that oxygenates (MTBE, ethanol) have a higher (lower numerically) stoichiometric air/fuel ratio than standard gasoline. This effectively means that more fuel is needed for the same intake airflow to obtain complete combustion.*

2.2.1.1 Stoichiometric Mixtures, Definitions

As noted in the last section, stoichiometric A/F refers to the quantitatively derived ratio of air to fuel that will allow the chemical process of combustion to be delivered to ideal equilibrium. Typical values for this are 14.7:1 for standard, non-oxygenated gasoline. Stoichiometry values for alternate fuel blends are shown in Table 2-1.

Since the A/F will vary depending on the makeup of hydrocarbons in the gasoline, a more appropriate method for referencing A/F is to use a normalized value. In this way, we can refer to stoichiometric A/F as equal to 1, regardless of the makeup of the gasoline. Two such terms are commonly used:

- Lambda (λ), where λ= (A/F actual) / (A/F stoichiometric). This is also referred to as the excess air ratio.
    - $\lambda > 1.00$ for lean mixtures
    - $\lambda < 1.00$ for rich mixtures
- Equivalence Ratio (ϕ), where ϕ= (F/A actual) / (F/A stoichiometric)
    - $\phi < 1.00$ for lean mixtures
    - $\phi > 1.00$ for rich mixtures

Fuel Type	**Stoichiometric Air /Fuel Ratio**
Typical Unleaded Gasoline	14.5 (Range 14.2 – 14.8)
10% Ethanol Blend	13.9
24% Ethanol Blend	13.3
85% Ethanol Blend*	9.95
15% MTBE Blend	14.1
100% Ethanol*	9.0

*Non-standard fuels requiring special fuel rail and injector components.

Table 2-1 - Stoichiometry of Alternate Fuel Blends

2.2.1.2 Stoichiometric "Ideal" Combustion Mixtures

Complete or "ideal" combustion produces by-products of carbon dioxide (CO_2), nitrogen (N_2) and water (H_2O). However, ideal combustion does not occur in an actual engine. The chemical equilibrium required is often difficult to achieve. Transient operating conditions, combustion chamber design, fuel quality (contaminants and other non-combustibles) and the limited time available to complete the process (especially at high engine rpm.) all contribute to less than ideal combustion.

A catalytic converter is usually used in the exhaust system to transform the harmful by-products of combustion to less harmful gases:

HC, CO, NOx ⟶ Three-way catalyst ⟶ H_2O, CO_2, N_2

Figure 2-2 illustrates the relationship between the air/fuel ratio and catalytic converter efficiency. Optimum converter efficiency is achieved at 14.5 +/- 0.3 A/F.

2.2.1.3 Rich Mixtures

- A mixture with "excess fuel"; also described by a Lambda < 1.00 or an equivalence ratio >1.00

Rich mixtures have a larger proportion of fuel relative to the stoichiometric ratio, which typically results in increased fuel consumption and hydrocarbon emissions. As the amount of fuel in the ratio increases, it displaces intake air, and thus oxygen, in the mixture. This lack of oxygen results in some portion of the fuel to be incompletely combusted, thus increasing hydrocarbon emissions. If excessively rich, the lack of oxygen can also result in a large increase in carbon monoxide emissions (CO).

Controlled rich mixtures are regularly used at vehicle start-up when the engine is cold. This is done to help ensure vehicle start and performance quality, as it is more difficult for fuel to vaporize under these conditions. Rich mixtures may also be used under conditions where maximum engine power is required, or to help protect the catalytic converter under high load conditions.

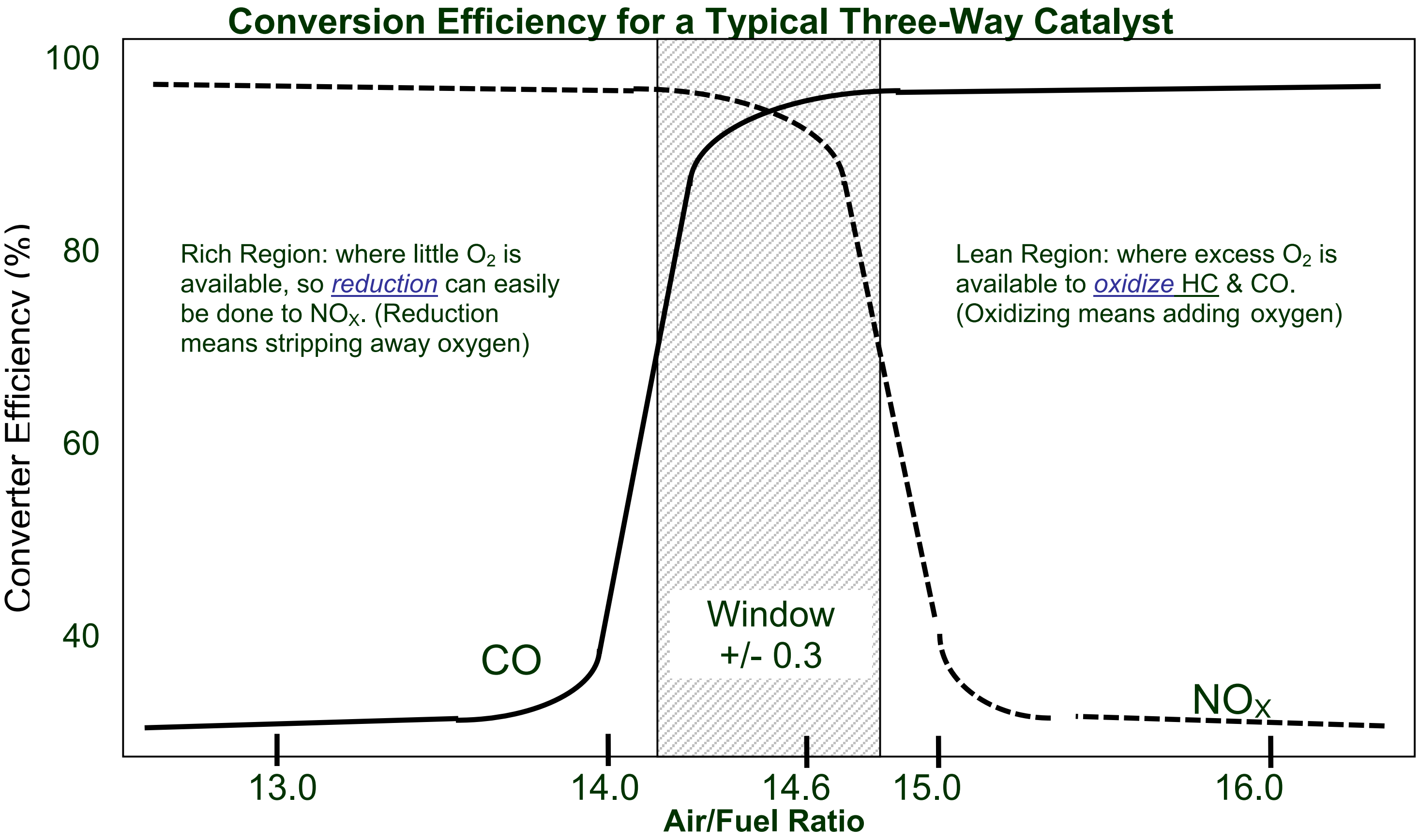


Figure 2-2 - Air Fuel Ratio Effect on Catalytic Converter Efficiency

2.2.1.4 Lean Mixtures

- A mixture with "excess air"; also described by a Lambda >1.00 or an equivalence ratio <1.00

Lean mixtures have excess oxygen and higher combustion temperatures resulting in increased oxides of nitrogen (NO_x) emissions. Nitric oxide (NO) is the primary oxide created. It forms at a significant rate when combustion chamber temperatures are above 1200 ^{o}F (650^{o}C.) The rate of NO_x formation increases with excess oxygen concentration, temperature and time at temperature. NO_x is typically highest just lean of stoichiometry. Lean mixtures above a 16 – 17 to 1 air/fuel ratio decrease NO_x production due to the lowering of combustion temperatures.

While NO_x production is an undesirable product of running slightly lean, there are several benefits that can be realized by running lean of stoichiometry. A controlled lean combustion process can reduce the output of hydrocarbon (HC) and carbon monoxide (CO) emissions, as well as reducing fuel consumption. Diluting the intake charge with a non-combustible dilutant can reduce NOx. One of the most common of these is exhaust gas, recirculated into the mixture via an EGR system. (Ref. Delphi EGR Applications Manual for more information on this process).

2.2.1.5 Non-Combustible Mixtures

Air/fuel ratios outside the combustible mixture limits (too rich or too lean) cause engine misfire, reduced power, a significant increase in emissions (primarily HC from unburned fuel) and poor overall engine performance. Combustible mixture limits are dependent on many factors, some of which are combustion chamber design, ignition system energy, fuel composition, amount of EGR, etc.

2.2.2 Fuel Atomization

Fuel atomization is the transformation of bulk fuel into spray. Fuel enters the intake port as an atomized stream. The fuel droplets evaporate when they mix with the air and also when they contact a hot surface. When the intake valve opens, the air/fuel mixture passes into the cylinder where it mixes with residual exhaust gases. Combustion is initiated near the end of the compression stroke when the spark plug fires.

The optimum fuel spray characteristics for a particular application are dependent upon the following:

- Intake manifold design
- Mixture motion control device
- Combustion chamber characteristics
- Spark plug configuration
- Injector spray targeting
- Injection timing
- The temperature of the target area

These criteria must be validated.

Combustion requires vaporized fuel. One of the functions of the fuel injector is to atomize the fuel. Smaller fuel particles are both easier to mix uniformly with air and require less heat to vaporize. Fuel particle size is dependent on system fuel pressure, spray pattern, and injector spray orifice design.

Note

Limits to these characteristics must be totally understood. Combustion efficiency and rate are dependent on specific application and fundamental engine design.

2.2.3 Fuel Spray Characteristics and Injection Timing

For maximum vaporization, fuel is typically targeted at the intake valve, as it is typically the hottest surface in the combustion chamber induction path. Fuel is typically injected before the intake valve opens and is allowed some residence time to allow the fuel to vaporize. Fuel vaporization also occurs as the air/fuel mixture passes the valve on its way toward the combustion chamber. As the time between valve events decreases (as engine rpm increases), the time for vaporization is also reduced.

PZEV (partial zero emission vehicle) exhaust emission regulations have placed additional emphasis on fuel delivery (atomization and timing.) The majority of the tailpipe emissions measured during a Federal Emissions Test Procedure (FTP) are generated during the time period between engine start and catalytic converter warm-up (reference section 2.2.7.3.) Alternate fuel delivery schemes may be employed during this time period to minimize emissions. Consult with your Delphi Applications Engineer for more information.

Note

Reference Worldwide Emissions Standards booklet available from Delphi for emissions regulations and test profiles.

Spray not targeted at the intake valve can be stored as liquid on the intake port walls. The conditions when this collected fuel enters the combustion chamber may be difficult to predict, affecting engine emissions and driveability.

See Section 5 for calibrating optimum injection timing

Typically, open intake valve fuel injection timing is not recommended for conventional fuel injection systems with Multec 3.5 injectors because the fuel bypasses the heating effects of the intake valve. If injection takes place as the intake valve first opens, the reversion pulse at the end of the exhaust stroke can divert the spray, greatly affecting both the targeting of the spray and the particle size. If injection occurs just as the intake valve closes, the fuel spray may be affected by a back flow of air caused by the pressure wave generated by the valve's closure.

Direct injection schemes that utilize open valve injection require specific hardware. Please consult a Delphi representative for more information on Delphi direct injection (DI) fuel systems.

Note

This manual covers only the basics of spray particle size, targeting and injector timing. Consult a Delphi Applications Engineer for more information.

2.2.4 Benefits of Electronic Fuel Injection Over Other Types of Fuel Systems

Electronic fuel injection has enabled engines to meet tighter exhaust emissions standards through improved fuel control. Engine calibration software can be programmed to deliver the precise amount of fuel required by the engine under all operating conditions. Typical A/F ratio distribution requirements are +/- 1.0 cylinder to cylinder

In addition, evaporative emissions standards require closed fuel systems using seal rings and minimal tip leakage. The Multec 3.5 injector is a *dry coil* design. There are no internal seal rings, eliminating possible sources of evaporative emissions.

Purging the evaporative canister during engine operation requires better control of lower fuel rates, placing greater demands on the low pulse width capability of the injector (see section 2.4.3).

2.2.5 Impact of Transient Conditions on Combustion

The term "transient conditions" is used to describe a change in engine load and/or operating conditions. The primary focus is in response to driver-commanded vehicle acceleration or deceleration maneuvers, but other changes in state, such as transmission gear changes, torque converter lock condition (automatic transmissions) and air conditioning compressor engagement can impact fueling requirements. The impact of transient conditions on combustion and emissions are typically magnified during cold engine operating conditions.

During these transient conditions, the amount of fuel required and the amount of fuel delivered may be different as there is likely to be some "lag" between the actual change in state and the response of the fuel injection system to these changes. In addition, fuel that builds up on manifold walls or in crevices during steady state engine conditions may be suddenly forced into the engine due to rapid changes in engine pressure and airflow. This can be detrimental to driveability and emissions. These differences in fuel delivery can be accounted for by software corrections such as wall wetting compensations, deceleration enleanment and acceleration enrichment.

See Section 3.9.1

When the vehicle is in a coasting (overrun) condition with the throttle closed, the fuel supply to the cylinder can be stopped by shutting off the injectors. This aids in further reducing the power output of the engine and conserves fuel. Transitions into and out of this mode often require very small amounts of fuel delivered in rapid fashion to minimize the impact on vehicle performance and stability.

Caution

Extreme transient conditions can require low pulse-widths. Commanded pulse-widths must not fall below the application's minimum specifications. Inconsistencies in injector flow, pulse-to-pulse and part-to-part result when operated below minimum recommended ranges.

2.2.6 Impact of Fuel Composition

2.2.6.1 Overview

Gasoline is a complex variable mixture of hydrocarbons, and can include oxygenates such as ethanol, MTBE, etc. The net overall effect on combustion depends on both the average properties of the fuel, e.g., average hydrogen-to-carbon ratio (H/C) and the molar percent or molecular weight of each of the hydrocarbon species present. The lower molecular weight hydrocarbon constituents, which are easier to burn, tend to increase fuel volatility, making it easier to vaporize the fuel. The higher molecular weight constituents, which are harder to burn, tend to reduce fuel volatility. The presence of these higher molecular weight constituents may increase the potential for engine deposits. Reference Figure 2-3 for fuel distillation curve vs temperature properties, and the effects of changing distillation properties on vehicle and fuel system performance.

Fuel composition is adjusted by the fuel supply companies throughout the year to best match the volatility of the fuel to the climate in which the fuel is used. Reference World Wide Fuel Charter or ASTM D4814, "Standard Specification for Automotive Spark-Ignition Engine Fuel". Fuels outside these specifications can compromise fuel injector performance.

2.2.6.2 Gasoline Composition – Oxygenates – Reformulated Gasoline (RFG)

As part of the U.S. Clean Air Act of 1990, oxygenated fuels are required in ozone non-attainment areas to help reduce CO emissions. Oxygenates help reduce the reactivity of the exhaust gas, and thus help reduce smog formation. The California Air Resource Board (CARB) has phased out the use of MTBE as an oxygenate. CARB Phase III fuel was introduced during 2003 and uses ethanol as the oxygenate. In addition, many states in the US have or are planning to phase out MTBE.

MTBE and Ethanol are common oxygenates used to provide the additional oxygen in the combustion process to reduce CO emissions. Oxygenates have higher stoichiometric air fuel ratios (rich relative to standard gasolines) for optimum combustion, due to a reduction in the energy content of the fuel (see **Table 2-1**.) This must be considered in the flow sizing of the injector and fuel supply system, as a given application will have slightly higher fuel consumption depending on the percentage of oxygenate in the fuel.

Ref. Sec. 2.2.7.2 & 8.4.1

In addition, small additions of these oxygenated fuels can greatly increase the volatility of the fuel. Since this may require the fuel system calibration to be adjusted to accommodate these types of fuels, vehicle development testing at both hot and cold temperature extremes with these fuels is recommended.

In general, increasing oxygenate concentrations tend to increase deterioration of plastics and swell in elastomers. Because oxygenates increase the solubility of water in the fuel, use of these types of fuels can accelerate wear and corrosion in fuel system components.

For high ethanol concentration fuels, deviations from regulated or typical levels of pHe and corrosives could compromise fuel injector performance.

Note:

Delphi tests most fuel system components to be robust to typically available U.S. oxygenated fuel blends (maximum 2.7 mass% oxygen, which is roughly 15% MTBE or 10% denatured ethanol). Higher percentages of alcohols will shorten the operating life of the injector. Please consult a Delphi representative to obtain a current list of all fuels the Multec 3.5 Fuel Injector has been validated in.

Specific injector models are available from Delphi with enhancements to operate with higher oxygenated blends.

2.2.6.3 Gasoline Composition

The following provides an overview of how other constituents in gasoline can impact both performance and emissions.

2.2.6.3.1 Paraffins (approx. 54 %mass)

As paraffin concentration increases:

- Soot formation reduced
- Resistance to surface ignition increased
- Reduced heating value (thus lower energy content and increased fuel consumption)
- Effects octane rating

2.2.6.3.2 Aromatics (approx. 35 %mass)

As aromatic concentration increases:

- Increases octane rating
- Increases energy content (increases fuel economy)
- Makes fuel more difficult to burn
- Reduces fuel volatility
- Increases self ignition temperature
- Increases soot formation
- Increases deterioration of fuel system plastics and elastomer (swell)
- Increases solubility of water
- Reactivity of exhaust gas (smog formation)

2.2.6.3.3 Olefins (approx 10%)

Olefins are unsaturated hydrocarbons that can lead to deposit formation on intake valves and injector tips. Olefins are created in the refining process. Gasolines with high levels of olefins require additional detergent chemical additives to prevent deposit formation on the injector director plate.

2.2.6.3.4 Others

Silicon and lead content in gasoline can be detrimental to oxygen sensors; lead content can lead to products of combustion that can potentially cause injector plugging and have been shown to be detrimental to both catalysts and exhaust gas recirculation devices.

Sulfur in gasoline has been shown to reduce catalytic converter efficiency. CARB regulations reduced sulfur to 30 ppm average 80 ppm max for Tier 2 emissions. The EPA will complete the phase in of these regulations in 2006.

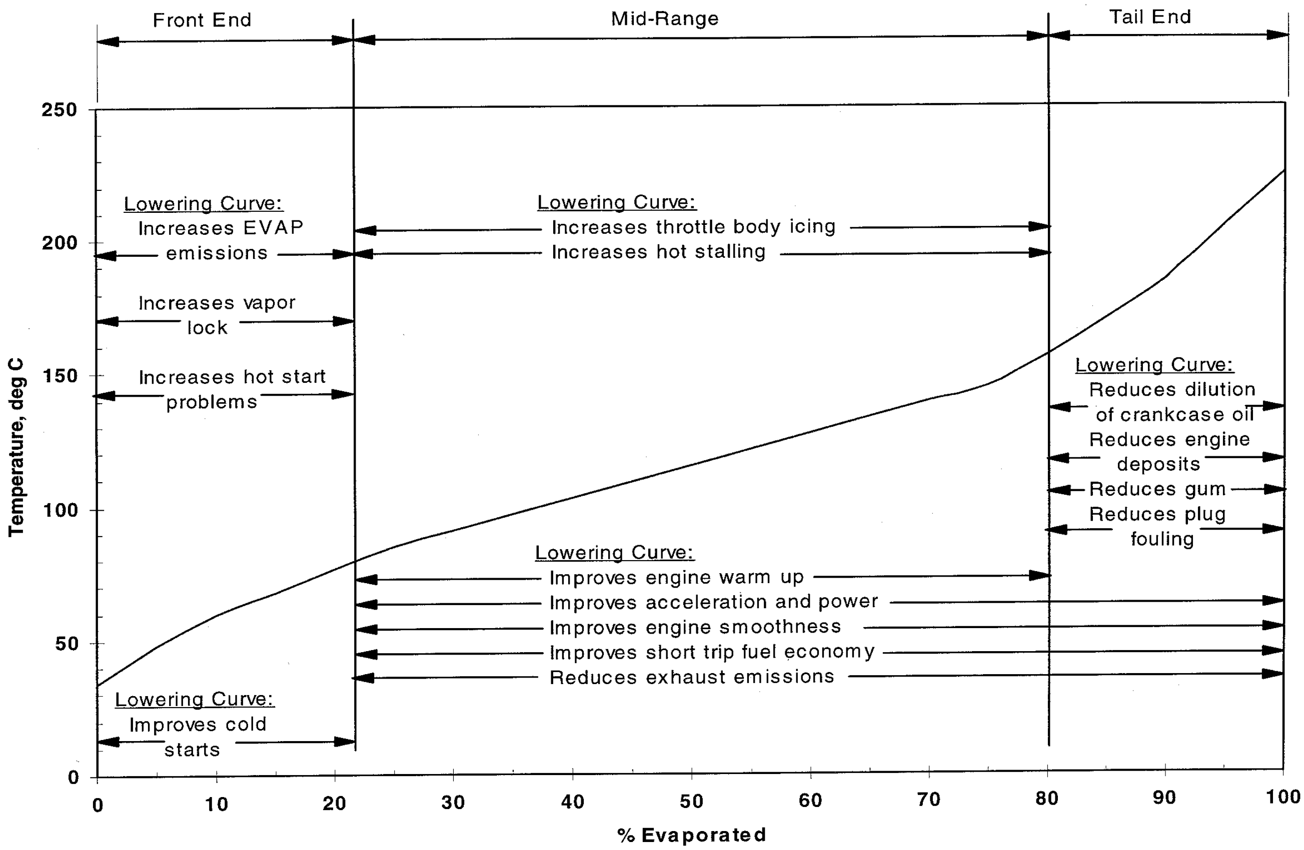


Figure 2-3 - Fuel Distillation Curve vs Temperature

2.2.6.4 Driveability Index

A more complete understanding of the impact of fuel volatility on fuel system performance can be obtained by measuring the fuel's distillation curve and computing the driveability index (DI). Figure 2-3 shows a fuel distillation curve and which aspects of engine performance are impacted for a typical gasoline.

DI = $1.5T_{10} + 3T_{50} + T_{90}$ where T_{10}, T_{50}, T_{90} are the 10%, 50% and 90 % evaporated temperatures measured by ASTM D86. Temperatures are specified in °F.

AAMA and ASTM proposed limits for DI are 1200 to 1290 max. DI values exceeding these limits have been documented to produce customer dissatisfaction due to reduced driveability.

2.2.7 Engine-Vehicle Environment

2.2.7.1 Impact of High Engine Temperatures on Combustion

As the engine and engine compartment temperatures increase, several factors must be considered to obtain optimum combustion. Hot air entering the induction system is lower in density and results in a reduced mass air flow rate. To maintain the optimum air/fuel ratio, the engine controller must reduce the amount of metered fuel. Speed density systems, which do not have the ability to directly measure intake airflow, utilize an inlet air temperature sensor to estimate the reduction in mass airflow at elevated temperatures. Mass airflow systems are capable of reading reduced airflow rates directly from the calibrated air flow meter

Refer to Section 5

***Note**: Low pulse-widths, such as at idle or during overrun conditions, could fall below the injector minimum working flow range under elevated temperature conditions. This could cause pulse-to-pulse variations that directly affect idle quality. The impact on idle quality depends on the injector firing scheme. Typically the minimum commanded pulse width is limited in the engine control software.*

It is important to consider these operating conditions when determining the proper flow size for the injector.

2.2.7.2 High Ambient Temperature Startability

Reference section 8.4.1 for Hot Fuel Handling Tests.

While high ambient temperature conditions must be evaluated for most engine components, several conditions in combination can cause specific problems for the fuel system.

In general, fuel system components reach their peak temperatures after the vehicle has been shut down. This period is usually referred to as the soak period. It is during this soak period that problems may occur if the vehicle is re-started.

During normal operation, the fuel injector does not typically see extreme temperatures because the fuel flowing through the tip helps dissipate heat energy. When the vehicle is shut down, fuel is no longer flowing through the injector. Injector tip temperatures rise and can eventually reach an equilibrium temperature with their surrounding environment in the intake manifold or cylinder head.

The problems typically encountered are due to the premature vaporization of fuel, either upstream of the metering orifice in the injector or as liquid fuel passes through the metering orifice and "flashes" to vapor. Although the fuel system is under pressure, the temperature can rise to the point that this pressure is no longer able to suppress formation of vapor.

The likelihood that a particular fuel will vaporize is characterized by its

Note

volatility. The volatility of gasoline is measured by the RVP (Reid Vapor Pressure). Typically, RVP is stated as the pressure required to suppress the formation of vapor at 100 °F (38 °C.) ***Fuel in the vapor state contains less heating energy by volume than fuel in the liquid state causing a lean air fuel ratio.***

Figure 2-4 shows the relationship between fuel vapor formation and fuel type, RVP, and pressure. For equivalent RVP levels, E10 fuels form vapor at lower temperatures than E0 (straight gasoline). Higher system pressures suppress vapor formation.

The fuel vapor causes two problems:

- Vapor "bubbles" above the metering orifice restrict the flow of liquid fuel through the metering orifice.
- Vapor "bubbles" do not deliver the same energy content as liquid fuel.

These two problems cause a lean shift, as the volume passed through the metering orifice contains some percentage of vapor rather than 100% liquid fuel. This lean shift can vary in severity, and in some cases may not be noticeable by the driver of the vehicle. However, potential driveability impacts are:

- No engine start
- Long engine crank time
- Engine stalls after start; stall will typically occur repeatedly after several starts
- Engine idles roughly (misfires) after start. Rough idle may or may not subside after some period of time

Because of this, it is critical that the fuel system be validated under severe conditions to determine if acceptable hot re-start performance can be achieved.

Hot re-start problems typically occur when the following conditions exist in combination:

- High ambient temperatures
- Vehicle is operated under high load (e.g. trailer towing) before it is shut down
- Vehicle re-start is attempted approximately 15 – 45 minutes after the engine is shut down.

- High volatility fuel is being used. This includes high RVP gasoline, especially moderate to high RVP ethanol/ methanol blends of gasoline.

One method of reducing susceptibility to hot re-start problems is to raise the fuel system operating pressure above this vaporization pressure. Other areas that should be investigated to make the fuel system more robust to premature vaporization are as follows:

- Fuel System Operating Pressure (as mentioned above). While higher pressure is better for hot re-start performance, it can have negative impacts on tip leakage, fuel pump noise and fuel pump durability. The trade-off between these issues should be well understood.

- Impact of vacuum bias at start-up. Biasing the regulator at start-up will tend to reduce the upstream pressure on the fuel. This can negatively impact hot re-start performance. While vacuum biasing should not be eliminated because of this, the impact of it needs to be understood when establishing the regulation pressure.

- Ability of fuel system to "check" pressure between the pump and injectors. The fuel system needs to be able to maintain some level of fuel pressure for extended periods of time. If it cannot, the pressure may drop low enough that vapor will form in the fuel system during a hot soak.

- Injector tip temperature. Consideration should be given to the location of the fuel injector. Cylinder head mounting will typically generate higher injector tip temperatures than intake manifold mounting.

- Fuel rail design. Recirculating fuel systems typically perform better than returnless systems under the same conditions. This is due to the ability of the recirculating system to replace the hot fuel in the rail with a fresh supply of cooler fuel from the fuel tank.

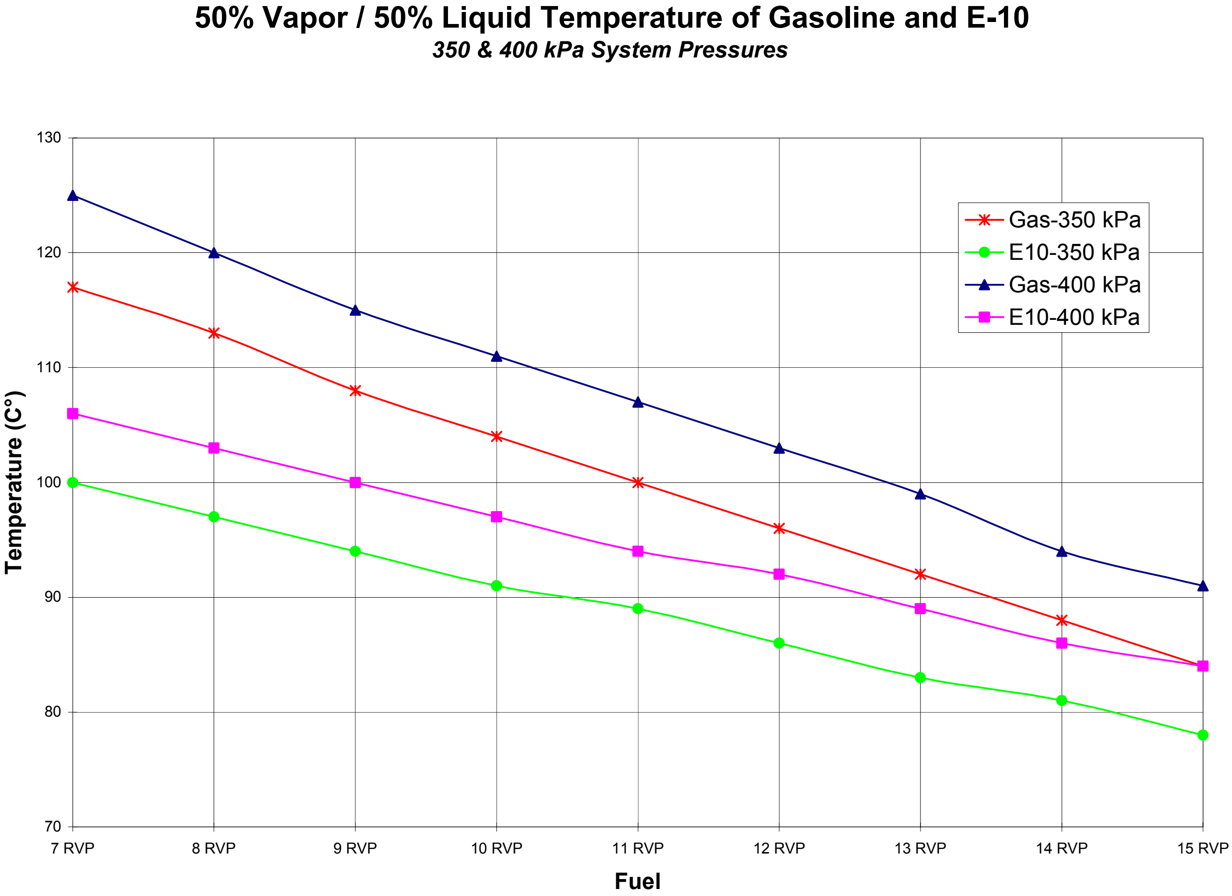


Figure 2-4 - 50% Vapor / Liquid Ratio vs RVP, Fuel and Pressure

Note:

Fuel rails are typically specified as either full recirculation, limited recirculation and returnless. The ability of the fuel rail to purge vapor is dependant upon whether the fuel can be recirculated back to the fuel tank from the location of the individual injector in the fuel rail. Due to increasingly stringent evaporative emissions requirements, there is a need to reduce fuel tank temperatures, which in turn is driving many engine applications to a returnless fuel system. It therefore is becoming increasingly important to consider the effect of hot fuel handling on overall system performance.

Refer to Section 5

Returnless fuel systems have been shown to require at least 7.3 psi (50 kPa) higher operating pressures to maintain the same hot fuel performance as a recirculating system due to higher fuel temperatures, and the lack of ability to purge vapors from the rail (See Fuel Rail Assembly Applications Manual).

2.2.7.3 Cold Engine/ Cold Ambient Effects on Combustion

During cold engine starts, additional fuel is required to make a combustible mixture due to the fact that the fuel will not vaporize as readily on the cold engine surfaces. Fuel atomization and spray distribution are extremely critical during this phase since there is little heat for fuel vaporization. The engine controller compensates by commanding a richer air-fuel mixture until intake valve and cylinder temperatures are adequate for fuel vaporization, typically estimated by using a coolant temperature sensor. Once adequate operating temperatures are reached, the engine controller typically reverts back to a stoichiometric A/F.

Due to the lack of heat to completely vaporize fuel, the richer A/F, and the exhaust catalyst not being up to full operating temperature for maximum efficiency, exhaust emissions (especially HC and CO) during the period just after start-up has a significant contribution to overall emissions output. Focus on reduction of start-up exhaust emissions generation has increased with the implementation of SULEV / PZEV (Super Ultra Low Emissions Vehicle / Partial Zero Emissions Vehicle) exhaust requirements.

Injector spray quality and spray targeting options can affect the cold start HC emissions. Engine development and calibration should include injector spray optimization where cold start HC emissions are a concern.

Note: *When sizing injectors, verify the injector's ability to supply extra cold engine fuel to accommodate lower numerical A/F ratios. This often requires vehicle cold weather testing with the engine under high load.*

2.2.7.4 Injector Tip Icing

Normal combustion processes generate large quantities of water vapor. Other sources, such as exhaust gas recirculation (EGR), also contribute to the quantity of water vapor within the intake system. When the engine is shut off and allowed to cool, water vapor will condense on the coolest surfaces within the intake manifold, such as the intake air passages and the tips of the fuel injectors. If ambient temperatures are low enough and the engine soak time is long enough, this condensate will freeze, potentially restricting or completely blocking the flow of fuel.

This phenomenon must be considered during the design of both the manifold passage shape and the placement of the injector in the manifold or head. Cold weather test procedures need to address this possibility. Since EGR can be a major source of water vapor, disabling EGR at low ambient temperatures is an option if icing is a problem. However, care should be taken when disabling EGR for extended periods, as this lack of operation can cause EGR system problems. Consult the Delphi EGR applications manual for advice on how to avoid problems when disabling the EGR system.

2.2.7.5 Cold Temperature/Low Battery Voltage Startability

Refer to Section 5

The combination of cold temperature and low system voltage places an added burden on the fuel system. Combustion at cold temperature requires additional fuel due to effects mentioned in the previous sections. Low system voltage not only affects the output of the fuel pump, but can also affect the ability of the injector to open (a minimum operating voltage (MOV) is specified for each Multec 3.5 injector model). Customer startability requirements under these conditions must be fully understood prior to the correct selection of the fuel rail assembly and fuel pump. Typically, customers require the fuel injectors to open at the low voltage limit for engine controller and ignition system operation. They also require the fuel pump and pressure regulator to provide adequate flow and pressure control for reliable starting. Engine controller software and calibration for fuel control is critical at these low voltage and temperature conditions. Delphi recommends the use of voltage offset compensation in the engine calibration to allow for precise metering of fuel even at low system voltage.

2.2.7.6 Altitude Effects on Combustion

See Section 5

The density of air is lower at higher altitudes, reducing the amount of fuel required to obtain complete combustion. On speed density systems, the engine controller compensates for this by using feedback from various sensors on the engine to reduce the commanded opening times for the injector. On mass airflow systems, the engine controller relies on feedback from the intake air flow meter to reduce the commanded opening times for the injector.

Lower atmospheric pressure also reduces fuel rail and injector absolute operating pressure, increasing the chance for vapor to form upstream of the injector outlet. The combination of lower atmospheric pressure and higher operating temperature can cause vapor handling problems. These problems must be addressed during system design.

2.2.8 Maximum Power Fueling Requirements

Under certain conditions, such as under hard acceleration (high throttle angle) or wide-open throttle (WOT) conditions, the air/fuel ratio is enriched to provide for maximum engine power. This condition is usually referred to as power enrichment (PE), and is typically scheduled at an A/F of 12.5:1 (although lower PE A/F is possible).

Likewise, it is sometimes necessary to protect the catalyst from high temperature degradation by enrichment of the intake fuel charge. This condition is typically referred to as catalyst protection or catalyst over-temperature protection (COT). Such a condition might be seen under high load conditions, such a towing a trailer or climbing a steep grade. Typical A/F ratios might be similar to those seen with PE.

Such enrichment modes are determined by the engine controller and must be considered when sizing a fuel injector for an application.

2.2.9 Injector Flow Tolerances

Consistent fuel delivery is critical

Cylinder-to-cylinder air/fuel variation is a function of both air and fuel flow fluctuations. To meet air/fuel ratio specifications, injector-to-injector flow differences in the rail must be minimized as any variation adversely affects the air/fuel ratios for all the cylinders. The engine controller, working in concert with the oxygen sensor (if present), usually cannot control the air/fuel ratio in each cylinder. Instead, it averages the air/fuel ratios for each cylinder together. So if one injector runs rich, the engine controller compensates by commanding all injectors lean. (Some V engine systems control each bank of cylinders independently through separate oxygen sensor feedback.)

Good system design requires consideration of optimum fuel spray targeting and preparation for consistent fuel delivery, and having a rail design that eliminates injector-to-injector pressure variations.

Injector flow tolerance increases for fuel supply rates that are outside of the “working flow range” (see section 3.10.2). This increase in tolerance results from operating the injector at pulse widths close to its opening and closing response times. The voltage supply available, injector operating temperatures, manifold absolute pressure and the pressure drop across the injector will also affect its flow performance. Typically compensation tables are used in the vehicle calibration software to correct for changes in voltage and manifold absolute pressure. Corrections for injector temperature are currently being developed.

2.3 Fuel Flow Considerations

Correct sizing of both the fuel injector (including rail assembly) and the fuel pump is essential for proper operation on the vehicle (refer to Section 3). For the fuel injector to operate properly, the fuel pump must meet the following requirements.

2.3.1 Minimum Fuel Pump Flow Output

The minimum fuel pump output must provide enough fuel to maintain regulated fuel pressure during all engine running modes. Regulated fuel pressure is defined as the pressure reached when the fuel pressure regulator has enough fuel passing through it to adequately control the fuel pressure in the rail. The fuel pressure regulator is normally mounted at the rail for recirculating fuel systems, and at the fuel pump for demand (or returnless) fuel systems.

Typically, the minimum fuel pump flow output is determined by taking the maximum required flow for the injector multiplied by the number of cylinders. Additional flow is added to ensure that there is always some minimum amount of flow for proper operation of the pressure regulator. The minimum flow through the regulator is a characteristic of each regulator design. Refer to the MPFI Fuel Rail Assembly Manual for more details.

This relationship should be maintained for all engine running mode system voltages. The required fuel pump supply pressure at minimum pump flow is determined by the set-pressure of the regulator at minimum flow and the supply line pressure-drop between the pump and regulator.

2.3.2 Nominal Fuel Pump Output

Nominal fuel pump output and nominal system voltage and conditions should be determined with consideration for the following:

- Minimum flow requirements for the system must be met. See above section for details on minimum flow requirements.
- Output must not be so large (especially for recirculating fuel systems) that large amounts of heated fuel are returned to the fuel tank, resulting in increased vapor generation. This will cause the fuel vapor pressure in the tank to increase and will also increase the demands on the evaporative canister storage and purge system.
- Output must not be so large as to exceed, at worst case maximum flow conditions, the maximum fuel pressure regulator flow rate for safe operation.
- Since the injector is a pressure-differential-sensitive device, avoid pump-induced pressure variations.

Note: *The information provided on fuel pump specification is provided only as an overview. For further information on fuel pump application criteria,* *consult the Delphi Fuel Pump Application manual.*

2.3.3 Fuel Pump Check Valve Requirements

To protect the rail assembly and fuel supply subsystem from exposure to extreme pressure during pump operation, a pressure relief valve (check valve) is incorporated in the fuel pump. For failure modes where the fuel return line is blocked causing a dead headed pump condition, the check valve will open to minimize the maximum pump generated pressure. This check valve relief pressure must be selected to meet the following conditions:

- Check valve relief pressure is always less than the maximum sealability and burst pressure for the fuel rail assembly and fuel supply subsystem.
- Check valve relief pressure is greater than the maximum required fuel pump pressure to achieve regulated system pressure in worst case conditions.

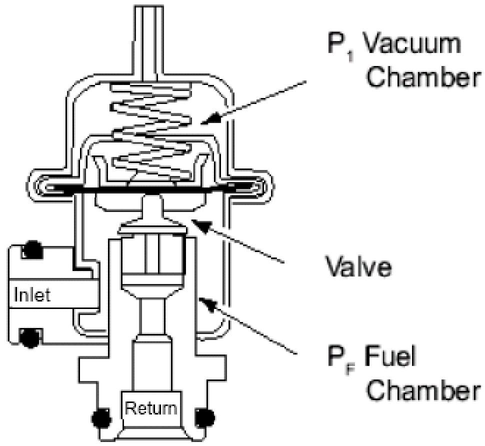
Note: The maximum relief pressure recommended for the Multec 3.5 injector is 1000 kPa.

2.3.4 Pressure Regulator Gain/Considerations (Vacuum Biased)

A typical vacuum biased fuel pressure regulator contains a vacuum chamber that is connected to manifold vacuum that is separated from the fuel by a diaphragm and valve assembly. The diaphragm has fuel on one side and engine manifold pressure (vacuum) on the other (vacuum biased recirculating fuel systems). A calibrated spring is located in the vacuum chamber side. Fuel pressure is regulated as pressurized fuel, acting on the bottom side of the diaphragm, works against the spring action and manifold absolute pressure (MAP) on the top side. When this happens, the diaphragm relief valve moves, changing the size of the flow orifice. This controls the amount of fuel returning to the fuel tank. Fuel rail pressure is controlled by the return spring calibration, as well as by engine manifold pressure acting on the top side of the diaphragm.

Fuel pressure varies as a function of fuel pump recirculation flow due to the gain of the regulator. Regulator gain is the slope of the “pressure versus recirculation” curve. It occurs because of flow passage pressure drops and the increase in valve lift required for increases in recirculation rates. Refer to Figure 2-5 for help in understanding and calculating pressure regulator gain. Other considerations include:

- Fuel pump check valve setting hysteresis failure modes
- Fuel pump impact on time-to-regulated pressure



Regulator Force Balance
Delta $P_B \cdot A_D = F_S$
$(P_F - P_1)\ A_D = F_S$
$P_F - P_1 = \frac{F_S}{A_D}$
Therefore Regulator Maintains
$P_F - P_1$ (Delta P) across diaphragm

F_S = Spring Force
A_D = Diaphragm Area
P_F = Fuel Pressure
P_1 = Ambient Manifold Vacuum

Figure 2-5 - Fuel Pressure Regulator and Gain Calculation

2.4 Impact of Emissions Requirements

2.4.1 The Impact of Emission Requirements on Fuel Control Systems

For vehicle applications with more stringent legal exhaust emissions limits, a closed-loop fuel control system with a catalytic converter may be required. To ensure that the catalytic converter is operating at maximum HC, CO and NOx conversion efficiency, the warm engine air/fuel ratio must be very accurately controlled to stoichiometry.

Added control of the air/fuel ratio is made possible through feedback from the oxygen sensor (see Figure 2-6), which measures oxygen concentration in the exhaust. The maximum benefits of both the added air/fuel ratio control and the conversion of emissions in the catalyst are only realized after both the oxygen sensor and the catalyst are within their respective operating temperature ranges. Refer to Figure 2-7.

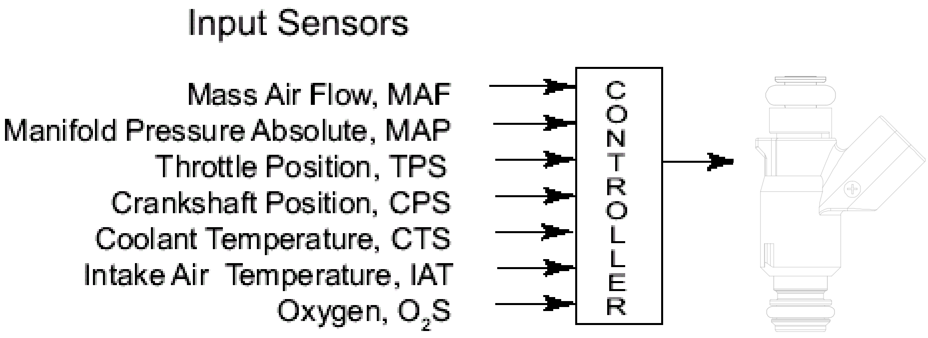


Figure 2-6 - Engine Management System Open Loop vs Closed Loop System Architecture

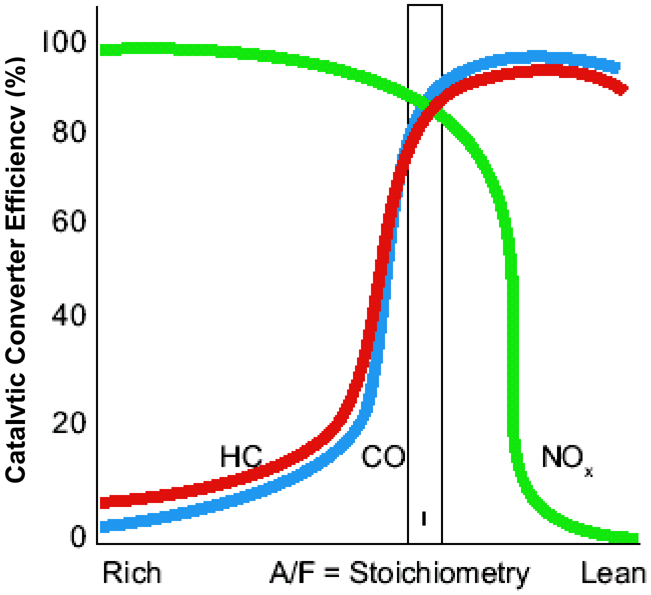


Figure 2-7 - Catalytic Converter Efficiency vs Air/Fuel Ratio

The fuel rail assembly should provide controlled pressure and a steady flow of fuel to the injectors. The fuel rail assembly must provide the correct amount of fuel to each cylinder. Each fuel injector in the fuel rail assembly should provide the correct amount of fuel, at the correct time and place. Some compensation can be made within the engine software to correct consistent cylinder-to-cylinder air/fuel ratio imbalances.

The evolution of US exhaust emissions legal limit is shown in Figure 2-8. The continual reduction in legal exhaust emission limits places ever greater demands on fuel delivery and control.

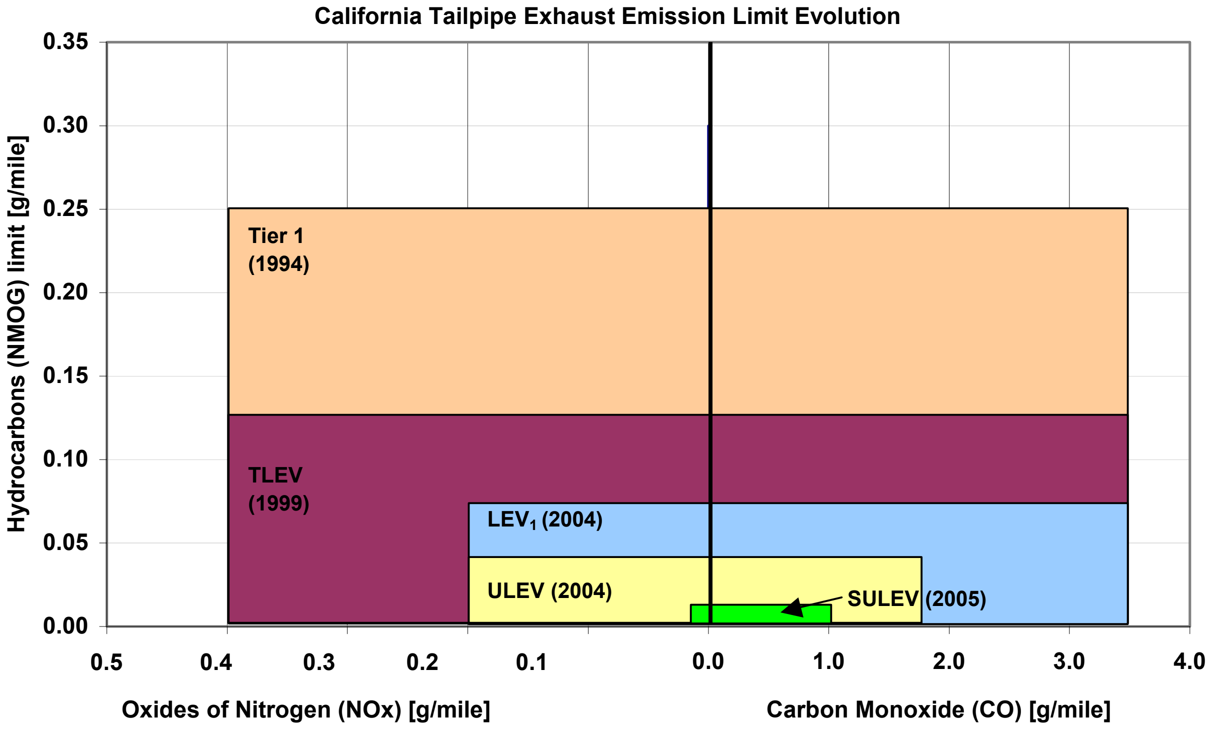


Figure 2-8 California Tailpipe Emissions Limits

2.4.2 Fuel Injector Design Effects on Evaporative Emissions

Many countries regulate evaporative HC emissions from the vehicle. While there are many contributors to the total vehicle evaporative emission quantity, the impact to the fuel injector will be in permeation and leakage requirements. Injector tip leakage and permeation through seal rings must be considered in fuel system design and seal ring selection.

Increasingly stringent evaporative emissions requirements place additional demands on the sealing capabilities of the fuel system (see Figure 2-9).

The Multec 3.5 Injector contributes to reduced evaporative emissions by:

1. Reduced injector tip leakage

2. Elimination of internal seal rings which can be a source of permeation.

3. Availability of a reduced cross section injector to rail seal ring to minimize permeation.

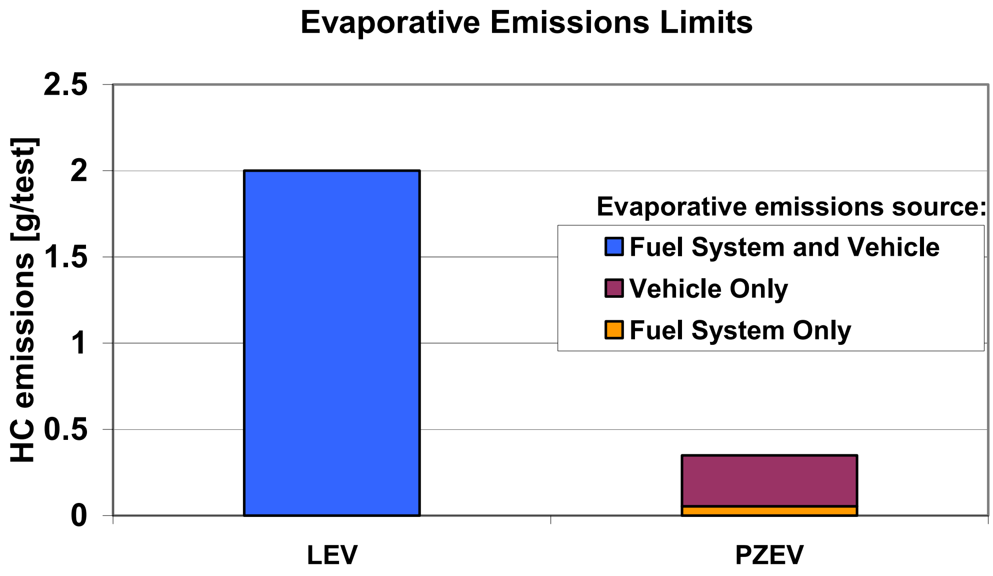


Figure 2-9 - Evaporative Emissions Regulations

2.4.3 Impact of Canister Purge on Engine Fueling

To reduce the amount of vehicle evaporative emissions, a contained fuel storage and supply system is used to minimize the escape of fuel vapors from the fuel tank to the atmosphere. This is accomplished by trapping vapors formed in the fuel tank within a carbon canister connected to the fuel tank. The amount of vapor to be contained increases with fuel temperature and fuel volatility. The vapors trapped in the canister are then drawn by engine vacuum through a hose to the intake manifold during engine operation. This fuel must be accounted for in the combustion process to prevent a rich air/fuel ratio and increased emissions. The engine controller will reduce the amount of fuel being metered by the injectors when canister purge is taking place, based on feedback from the oxygen sensor. The impact of canister purge flow rates on the fuel injector is greatest when purge is active at idle. Since the injector is normally at a low pulse width at idle, canister purge can reduce the required flow rate of the injector and lead to very small commanded pulse widths. These pulse widths may be beyond the working flow range of the injector (see section 3.10.2.) The potential impact of these low pulse widths on flow variation must be considered when setting up the fuel system calibration. Any negative impacts of canister purge can be minimized by proper size selection of the fuel injector and/ or use of a low pulse width correction table.

See Section 3.9.1- Minimum pulse-width

Note: *Canister purge should not be so excessive as to lower the injector commanded pulse-width to the point of inaccurate operation. Refer to Section 3.9.1- Minimum Pulse-Width.*

2.4.4 Impact of EGR and PCV on engine fueling

As with canister purge, EGR (exhaust gas recirculation) and PCV (positive crankcase ventilation) can affect the amount of fuel required during a given cycle. The method of compensating for EGR and PCV is not identical to canister purge, however, and methods of compensating must be considered separately from canister purge.

EGR has the impact of displacing fresh air in the intake manifold, reducing the fuel requirement for a given set of engine speed and load conditions. EGR is considered an inert gas (consisting mostly of combustion products and water vapor), and does not burn when added to the combustion process. The effect of EGR can typically be compensated for by measuring actual intake airflow (if a mass airflow meter is used) or via the change in manifold pressure caused by the EGR.

While PCV contains some fuel vapor (similar to canister purge), it also contains a large amount of water vapor. While the water vapor is inert (like EGR), the fuel vapor can be combusted and thus must be compensated for in a manner similar to canister purge.

2.4.5 Injector Flow Characterization

Refer to Fuel Rail Applications Manual

Once the correct fuel injector (including fuel rail assembly) and fuel pump supply systems are determined, flow data used for characterizing injector performance can be generated. Flow characterization requirements will depend on the type of fuel system (for example, vacuum biased recirculating or returnless) and the sophistication of the engine controller software package. Typically, the complexity of the data required for the fuel system calibration is dependent on the emissions requirements. Some of the more important fuel system calibration parameters, as well as a suggestions for obtaining the most relevant data, are listed below:

Delphi suggests collecting fuel calibration data with the entire fuel system – fuel rail conduits, fuel injectors and fuel pressure regulator. This will allow the fuel calibration to compensate for fuel distribution variation and fuel pressure regulator gain.

Injector Slope & Intercept	Injector slope and intercept of pulse width vs flow rate will form the base fuel flow curve. Typically, this base fuel flow curve is a linear regression of the data collected.

Voltage Sensitivity/ Offset	Used to adjust the flow curve to account for system voltage variation
Vacuum Effects	Typically used for non-vacuum biased systems, such as returnless fuel systems. Compensates for flow shifts as manifold vacuum changes. Delphi can provide slope & intercept values for each vacuum point of relevance to the customer.
Fuel Pressure Sensitivity	Typically a function of regulator gain. Can be minimized by using rail flow data for recirculating systems. For Demand fuel systems Delphi normally provides flow data at a constant rail fuel pressure. Any regulator gain correction must be done as part of the fuel pump correction.
Temperature Sensitivity	Usually applied as an offset to the base fuel flow curve, if required.
Low Pulse Width Correction	As the injector operates at very small pulse widths, the actual flow curve will deviate from the linear regression predicted flow. Although Multec 3.5 maintains linearity to very low pulse widths, some applications may still require low pulse correction.
Injector-to-Injector Variation	Multec 3.5 Fuel Injectors are manufactured to very tight tolerances. Using rail calibration flow data will further help minimize the effects of individual injector variation by averaging the injector flows.
Pulse-to-pulse repeatability	Typical calibration flows are provided as the average of several data points at a given pulse width to minimize any pulse to pulse issues.
Durability Shifts	The fuel system may be required to compensate not only for internal shifts, but also for shifts in other parts of the engine. This is typically done by ensuring enough dynamic range exists in the closed-loop feedback control of the fuel system.
Fuel Properties	Consideration must be given to the types of fuel the vehicle might be exposed to over the life of the vehicle. Differences in the distillation curves, volatility, specific gravity, etc. will impact the flow curve. The type of fuel that the injector calibration data is generated from will need to be considered based upon customer requirements. If the vehicle is designed to operate on fuels with high alcohol fuel content, increases to the commanded injector pulse width must be made to account for the lower energy content of the alcohol fuels. (See sections 2.2.1.1 and 3.6.4)

3.0 Product Description

3.1 Scope

The Multec 3.5 injector was developed to provide high levels of performance and durability to meet increasingly stringent emissions-control legislation. Engineering efforts to enhance injector component design and construction are ongoing. This section addresses these topics.

Note

Due to the unique requirements of individual fuel system applications for different customers, the process of determining optimum fuel injector characteristics requires a joint effort between the responsible Delphi Application Engineer and the customer engineer(s). The information presented in this section provides technical guidance only. Detailed product specifications result from the collaboration of Delphi with customer engineering and design teams.

3.2 General Description

In simplest terms, the purpose of fuel injection is to deliver fuel to achieve the desired air/fuel mass ratio to the engine. Fuel atomization and injector targeting play critical roles in achieving this ratio. The accuracy of the air/fuel mass ratio has a direct effect on emissions, fuel economy, power, driveability, start quality and idle quality.

The Multec 3.5 Fuel Injector is a top-feed design for port fuel injection systems (Figure 3-1). Depending on the application, one or more Multec 3.5 Fuel Injectors can be used for each cylinder.

The Multec 3.5 Fuel Injector is an electromechanical device. A magnetic field is generated as voltage is applied to the solenoid coil. The resulting magnetic force lifts the valve assembly, overcoming manifold vacuum, spring force, and fuel pressure, allowing fuel to pass through the ball and seat interface to the director. As the fuel passes through the director, an atomized spray is developed. The injector closes when the voltage is removed, cutting off the fuel flow.

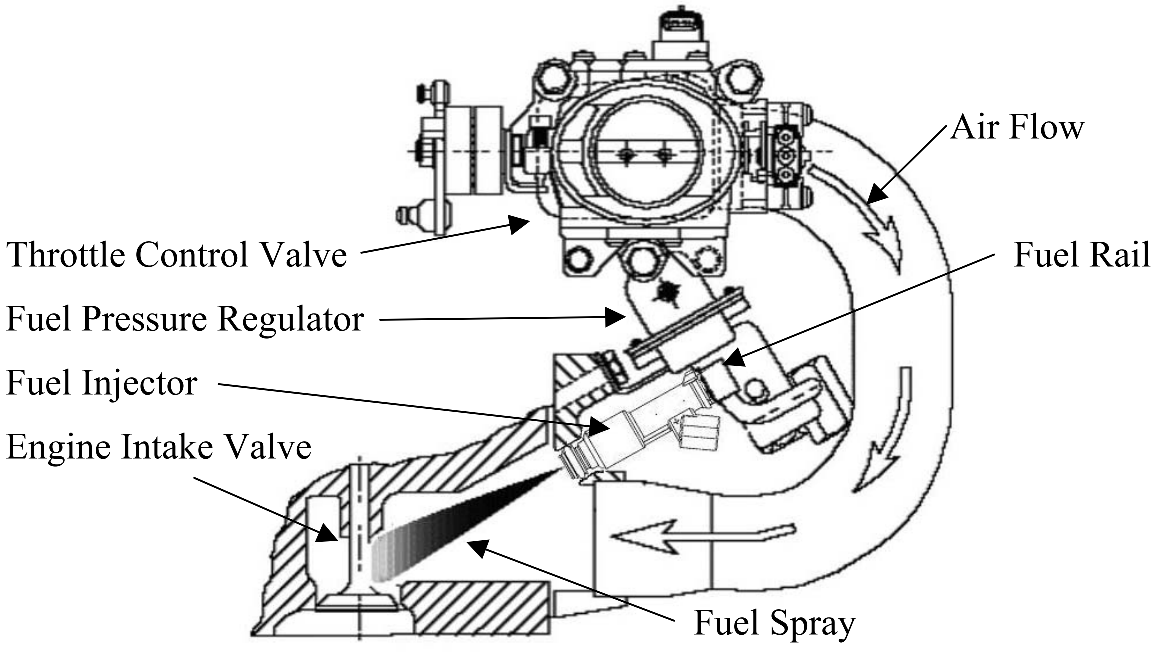


Figure 3-1 - Top Feed Port Fuel Injection

The Multec 3.5 injector is currently designed with either

- Upper and lower seal rings (Figure 3-2)
- Upper seal ring and lower face seal. (Figure 3-3)

The upper seal ring provides a seal between the rail conduit and the injector to prevent fuel leakage. The lower seal ring or face seal (at the discharge end of the fuel injector) prevents the leakage of engine vacuum. Other functions of the seals are as follows:

- Center the top end of the injector into the fuel rail and the bottom end into the intake manifold or cylinder head
- Reduce fuel rail and intake or cylinder head thermal conductivity
- Isolate the injector from engine vibration
- Reduce transmission of injector operation noise

Note

Solid contact between the injector and the rail or manifold transfers noise, vibration, and heat and should be avoided.

- Control fuel system HC permeation

See Section 3.3.5

The injector is typically retained in the fuel rail with a clip. The internal components of the fuel injector are non-serviceable.

3.2.1 Appearance

The standard Multec 3.5 Fuel Injector has a black plastic upper body, with a stainless steel (silver color) lower body.

3.2.2 Exterior Outline

The injector exterior outline meets underhood packaging constraints per vehicle specifications. These requirements shall be defined in approved engine/induction layouts from the customer.

The Multec 3.5 injector is offered in two lengths. The "long" Multec 3.5 version simulates the industry standard injector length allowing easy application of the Multec 3.5 in existing engine configurations. The "mini" Multec 3.5 version was developed to provide fuel system packaging advantages. The mini version is offered with an extended tip option which places the spray origin closer to the intake valve when required for spray targeting.

The Multec 3.5 injector is available with two electrical connector styles (see Section 4.4.4). Other connector designs can be made available as required.

3.2.3 Usage Definition

The Multec 3.5 Fuel Injector is designed to be used as a hydrocarbon-based liquid-fuel port fuel injector for spark ignition engines.

3.2.4 Failure Diagnostics

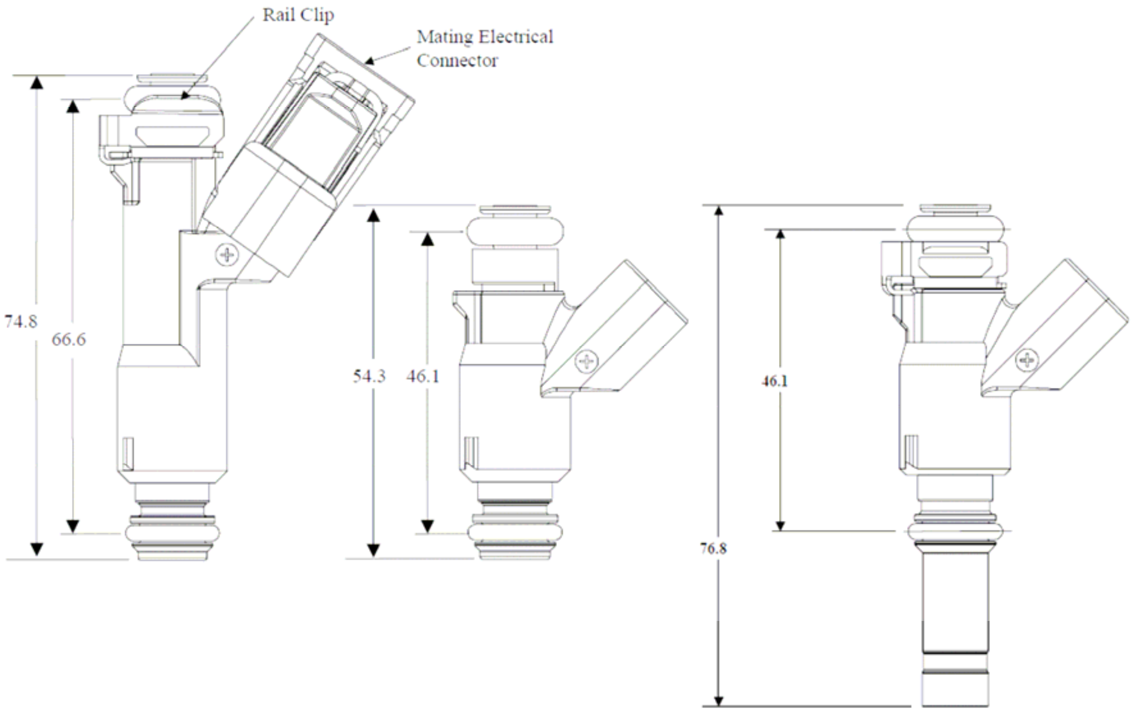
Refer to Section 5

Current and voltage levels to the fuel injector can be monitored in specific applications by the engine controller. Mechanical malfunctions must be inferred from other engine operating parameters. Specific diagnostic recommendations are discussed in Section 5 — Software.

3.3 Physical Specifications

3.3.1 Dimensions

The physical dimensions of the Multec 3.5 Fuel Injector are presented in Figure 3-2 and Figure 3-3 (For reference only).



Long Injector Mini Injector Extended Tip Injector

Figure 3-2 - Multec 3.5 Fuel Injector Dimensions – Seal ring design. (For exact dimensions, refer to Delphi Injector Outline Drawing).

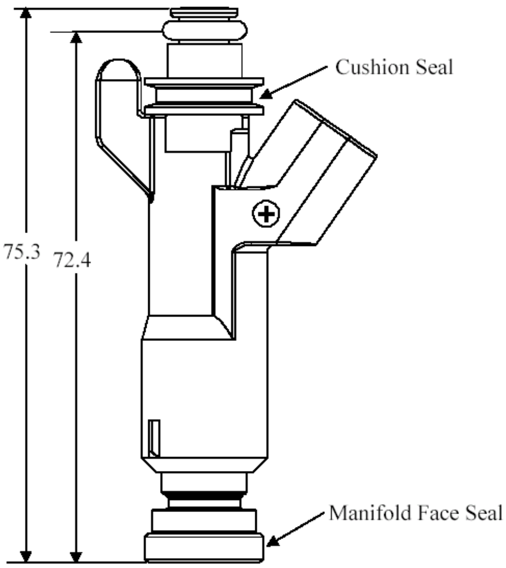


Figure 3-3 – Multec 3.5 Fuel Injector Dimensions – Cushion seal / Face seal design (For exact dimensions, refer to Delphi Injector Outline Drawing.

3.3.2 Mass

The mass of the Multec 3.5 Fuel Injector varies slightly with fuel injector length and type. An approximate value for mass is 35.2 grams for a "long" version, and 31.5 grams for a "mini" version (includes clip and seal rings).

3.3.3 Identification and Markings

Each injector is identified with permanent markings for traceability that include the date code, build location identification, and the Delphi or customer part number see Figure 3-4 below).

The 2D symbology pattern provides a machine readable version of the part number and build information.

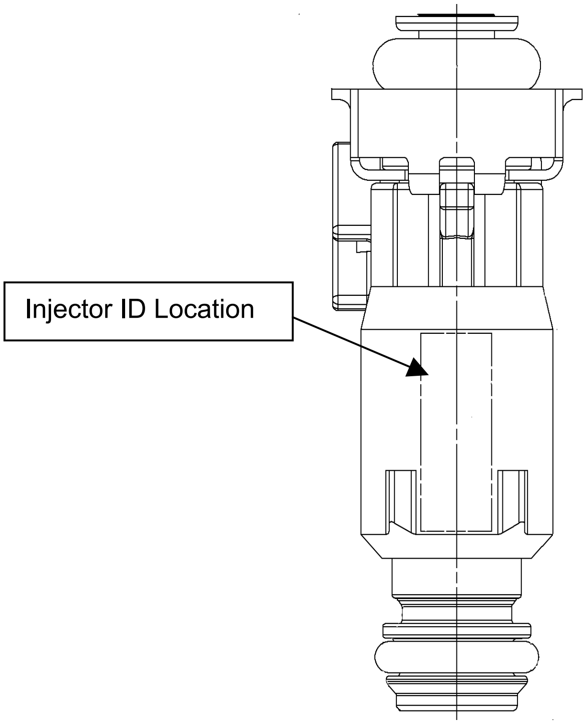


Figure 3-4 - Injector Identification and Markings

3.3.4 Internal Components

Internal components of the Multec 3.5 Fuel Injector are shown in Figure 3-5.

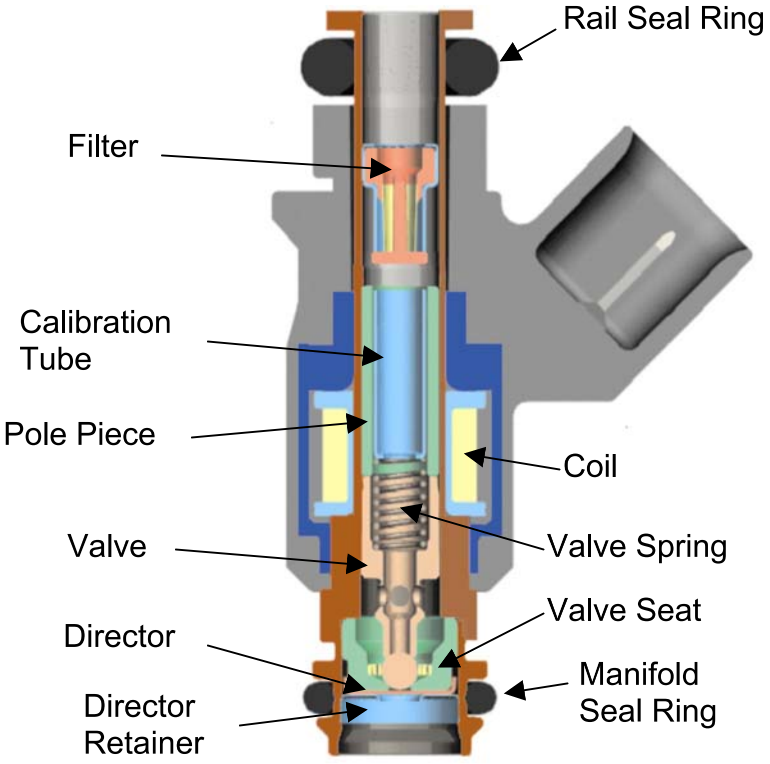


Figure 3-5 Multec 3.5 Internal Components

3.3.5 Injector Retaining Clip

The injector clip (refer to Figure 3-6) is typically supplied as part of the injector assembly and provides the following functions:

- Retains the injector to the rail prior to assembly to the engine.
- Allows the rail assembly (including injectors) to be removed from the manifold as a unit, enabling fuel to be retained in the rail. This also applies if the rail is impacted and moved relative to its normal mounted position.
- Positions the injector during normal operation, preventing solid contact with the manifold/head. Solid contact affects noise and heat transfer to the injector, and possibly injector durability.
- Provides a method for rotational orientation of the injector with respect to the rail. This is especially important for the dual-spray injector design to maintain spray proper targeting relative to the intake valves.

Note: *The injector retaining clip is designed to engage the encapsulation post and maintain rotational orientation of the injector in the fuel rail socket.*

- Two injector retaining clip styles are available. The revised design shown in Figure 3-6 improves assembly of the injector and clip to the fuel rail and is therefore preferred over the original clip design.

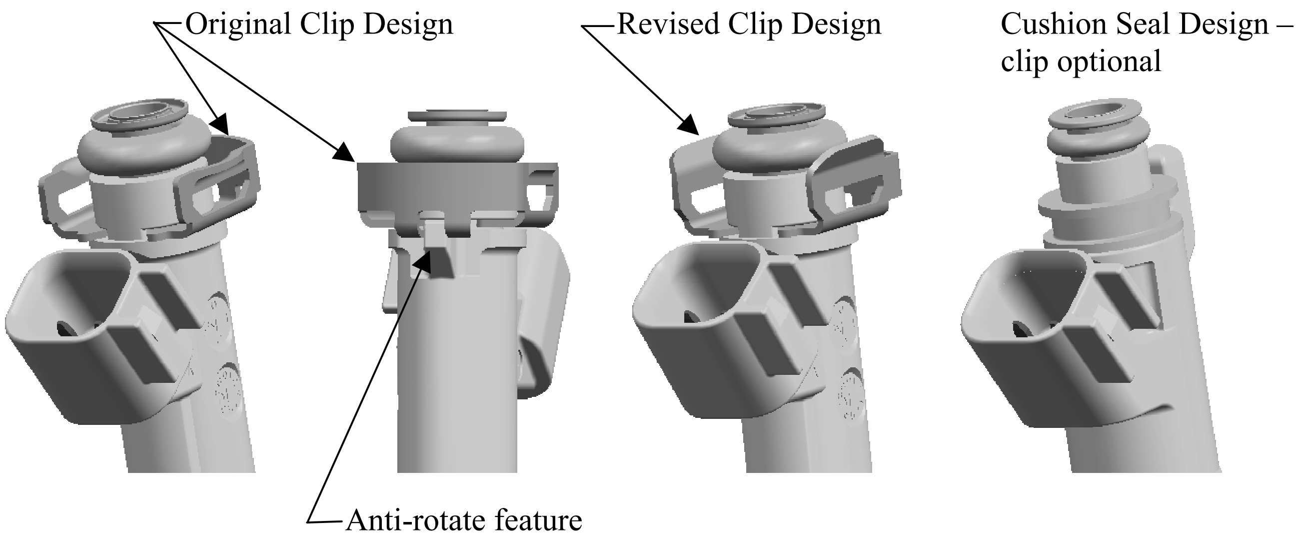


Figure 3-6 -Injector Retaining Clip Designs

3.3.6 Seal rings

Seal rings for injectors (refer to Figure 3-5) are made to withstand temperatures ranging from -40° C to 150° C (-40 to 302° F) without leakage or seeping. They must also be resistant to varying amounts of fuel additives to fuel (i.e., ethanol, etc.). The following are currently available seal rings designs. Please contact a Delphi representative if the specific sealing requirements are not met by these designs:

Injector to fuel rail seal ring

- Dimensions:
  - ID. : 6.35 mm
  - OD. : 14.85 mm
  - Cross-section: 4.25 mm
- Materials
  - Viton® GLT (blue color). For low temperature applications
  - Viton® A (black). All other applications.

Injector to manifold

- Dimensions:
  - ID: 9.61 mm
  - OD: 14.49 mm
  - Cross-section: 2.44 mm
- Materials:
  - Viton® A (black or brown other applications.)

3.4 Cushion Seal Injector Design

An alternate injector mounting scheme utilizes a face seal at the manifold interface and a seal ring at the rail interface. A retaining clip is optional in this design. The rail traps the injector in place and provides the axial force to maintain the face sealing at the manifold. See Figure 3-3

3.5 Injector Design

Injector design is driven by more stringent emission regulations as well as increased engine performance. The injector is required to deliver fuel flow at higher (static) and lower (minimum) flow rates and higher pressures with improved fueling accuracy. Specific design considerations are required for non-standard fuels such as E-85 (85% ethanol blend) to meet engine performance and injector corrosion resistance requirements.

The standard Multec 3.5 injector will satisfy most applications. Special component treatments are used in an **E-85 compatible** injector. **Dual-cone** spray and skewed spray options are available.

The magnetic circuit and flow path in the Multec 3.5 injector is optimized to allow one injector configuration to satisfy static flow rates from 1 to 4 g/s at 300 to 400 kPa. (See Figure 3-7 and Figure 3-8). Higher flow rates are possible at increased flow tolerances.

Flow and spray configurations are tailored via the director plate design to meet individual customer requirements.

Note: *Delphi has many developed Multec 3.5 injector models to satisfy various levels of flow and spray type. Please consult a Delphi representative to determine if a model is already developed that meets requirements.*

The fuel injector meters fuel to the engine based on the duration of the voltage signal received from the engine controller drive circuit. During each cylinder cycle the injector receives a voltage signal energizing the coil and creating a magnetic field. The magnetic field lifts the armature valve off the seal seat allowing fuel to flow to the director plate. When the voltage is terminated, the magnetic field diminishes and the valve spring returns the armature valve to the closed position ending fuel flow. See Figure 3-7.

Pressurized fuel enters the injector at the top via its connection to the fuel rail. The fuel passes through the center of the injector. A filter at the injector inlet protects the injector valve from particulate contamination present in the fuel system between the chassis filter and the injector. (The chassis filter is intended as the primary filtration point in the fuel system. The injector internal filter is non-serviceable.) The fuel passes through the center of the armature valve, then radially outward through cross drillings before it reaches the seat seal area. When the armature valve lifts (less than 0.10 mm) fuel is allowed to flow past the valve and seat to the director plate which meters the flow rate and generates the spray pattern via the size, number and orientation of holes. See Figure 3-8.

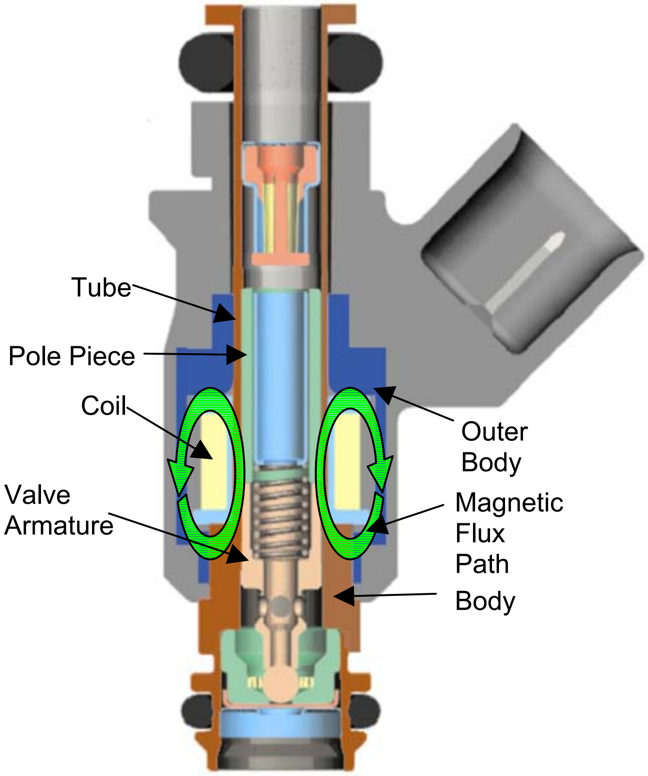


Figure 3-7 - Multec 3.5 Magnetic Circuit

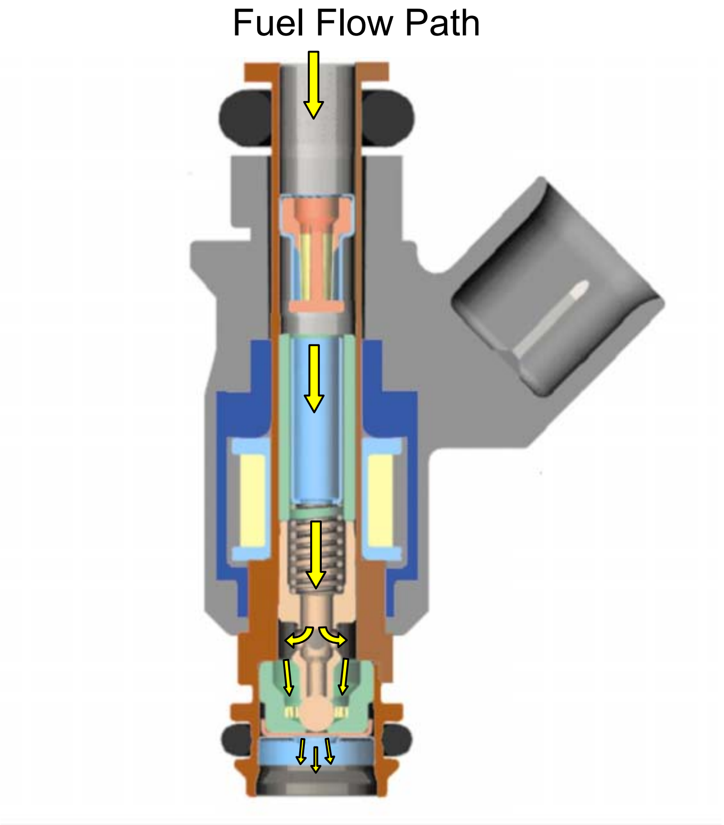


Figure 3-8 - Multec 3.5 Fuel Flow Path

3.5.1 Dual Spray Fuel Injector

The dual spray injector is designed for applications with two intake valves per cylinder. (See Figure 3-9). The dual spray design allows fuel to be targeted at each intake valve, enhancing fuel control due to the potential to reduce wall wetting. A locating device is required to ensure correct injector orientation. Various cone and separation angles are available to meet application specifics.

See Section 3.3.5

All Multec 3.5 injectors incorporate a locating post in the encapsulation for orientation. The injector retaining clip is designed to engage the encapsulation post and control rotational orientation of the injector in the fuel rail socket to maintain the proper spray targeting to intake valve relationship.

Note

A dual intake valve arrangement does not necessarily require a dual spray injector.

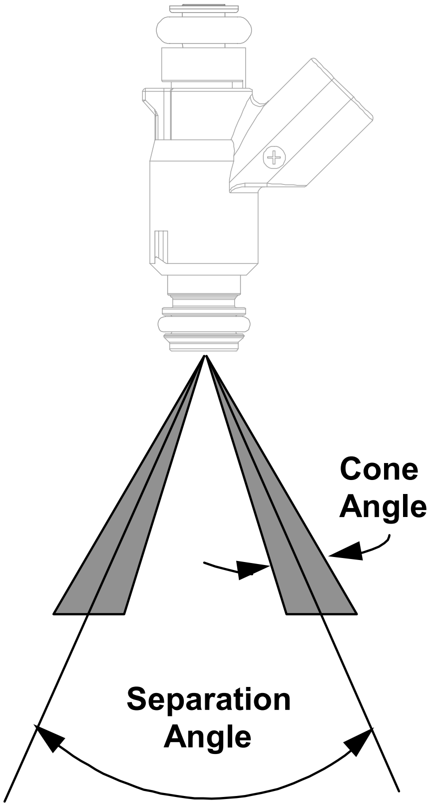


Figure 3-9 - Dual Spray Injector

3.6 Injector Controls – Controller Drive Circuit

There are two principal types of injector drivers: saturated switch and peak-and-hold. All Multec 3.5 injectors are designed to use the saturated switch driver.

A saturated switch drive circuit is used with injectors having relatively high resistance, generally 11 to 16 ohms.

- **Multec 3.5 injector resistance is nominally 12.0 Ohms at 20° C (68° F) [Test current not to exceed 10 mA]**

Maximum current is limited by the circuit resistance: I=V/R. When the injector driver is de-energized, return spring force and fuel pressure push the ball on its seat and shut off fuel flow. A saturated switch driver is a low-cost driver with low injector energy dissipation rates.

3.6.1 Minimum Operating Voltage (MOV)

Injectors need to function reliably and predictably at low battery voltage conditions. Low battery voltage conditions are caused by low temperatures, battery/alternator malfunctions, engine cranking and high temperature/high load conditions.

Minimum operating voltage is the lowest voltage that will provide fuel flow (i.e., open valve).

Static minimum operating voltage (SMOV) is defined as the minimum level of applied voltage level where actuation of the injector first occurs. (See SAE J1832 Section 4.1.23.1.1 for SMOV measurement procedure.)

Dynamic minimum operating voltage (DMOV) is defined as the applied voltage where the injector dynamic flow rate (at a duty cycle of 10.0 / 20.0 ms PW/RR) is 50% of the injector dynamic flow rate at normal operating voltage. (See SAE J1832 Section 4.1.23.2.1 for DMOV measurement procedure.)

Note *Minimum operating voltage, system pressure, and linear range are injector performance trade-offs.*

3.6.2 Driver Considerations

In high percentage alcohol fuel applications, it is necessary to completely remove power from the injector when the vehicle is not running to avoid potential internal corrosion. This can be accomplished by using a “high side” drive circuit, or powering the injector from ignition rather than battery with the normal “low side” drive circuit. (A “low side” driver circuit switches the ground side of the driver circuit to control the injector operation.)

3.6.3 Driver Circuit Clamping Voltage

When the injector driver circuit switches off the injector, the collapse of the magnetic field in the solenoid coil generates a return voltage spike in the circuit that must be dissipated. A Zener diode is used to limit EMI radiation. Zener diodes with a breakdown voltages ranging from 56V to 100V can be used for injector performance characterization at Delphi. Injector dynamic flow rate will vary with driver circuits set at different clamping voltages. The Zener diode breakdown voltage used by the vehicle controller should be employed for injector flow testing used to generate vehicle calibration tables

3.6.4 Injector Polarity

See section 4.4.3.

3.7 Injector Flow Rate Sizing

The injector flow rate must be sized to provide adequate fuel flow for all anticipated vehicle operating conditions. This will require knowledge of the engine and platform performance requirements. In selecting the proper injector flow rate, a balance must be maintained between the maximum and minimum fuel rate requirements for the engine. To size the injector, the following performance specifications must be determined:

1. **Fuel system pressure**
    - Fuel system pressure information will be used to determine director hole size.
    - The Multec 3.5 injector magnetic circuit is designed for system operating pressures of 300 kPa to 500 kPa (43.5 psi to 72.5 psi.)
    - The fuel supply system should be designed to include pressure relief to prevent the injector from being exposed to pressures greater than 1000 kPa (145 psi.) Pressure in excess of 1000 kPa may cause temporary loss of function, and possible permanent damage.

Often it is desirable to determine the impact of a change in fuel system pressure on flow. The following equation is given as an approximation for estimating static flow at a given pressure drop when the static flow at a different pressure drop is already known:

- $m_2 = m_1\sqrt{\frac{\Delta p_2}{\Delta p_1}}$

Note: *The following calculations assume an ideal constant fuel supply for pressure vs. injector flow. Any fuel pressure control deviations from the set point must be taken into consideration in the following calculations. (The fuel pressure regulator gain will tend to increase pressure at very low injector flows and decrease flow at very high injector flows. (See Section 5.2.3.14 for fuel pump flow compensation).*

Note: *In addition, the following calculations assume that the fuel supply system is vacuum biased, meaning that the pressure drop across the injectors is held constant regardless of the manifold vacuum level at the tip. This is usually achieved by connecting the dry side of the regulator diaphragm to manifold vacuum.*

In a non-vacuum biased system for a normally aspirated system, the pressure drop across the injectors increases with higher manifold vacuum. Low engine fuel demands typically occur during conditions of high manifold vacuums: idle and deceleration. This situation increases the flow range requirement demands on the injector.

Injector Pressure Drop = inlet fuel pressure + manifold vacuum

Note: *For a turbocharged or supercharged system the intake manifold pressure will increase during boost conditions, reducing the pressure drop across the injector. (For boost, use negative vacuum (pressure) in above equation.)*

2. **Engine horsepower rating**

   - To size fuel injector flow rate, the design engineer must determine the engine condition where the maximum amount of fuel is required. Initially, two conditions should be considered, peak torque fueling and peak horsepower fueling. (Calibration specific issues may increase these requirements – see below.)
   - At peak torque, the engine requires the greatest amount of air and fuel per cylinder event. At peak horsepower, the engine typically requires less air and fuel than peak torque but delivery time per cylinder event is greatly reduced due to the higher rpm.
   - Data analysis has shown that if an injector can provide enough fuel per cylinder event to cover the peak horsepower point there will be sufficient fuel to cover the peak torque condition as well. For these reasons peak horsepower is usually chosen for baseline fuel injector flow design.

3. **Engine's Brake Specific Fuel Consumption (BSFC) ratio**
   - BSFC is the ratio of measured engine fuel flow to engine horsepower output (Lb_m/HP*Hour). It is determined on a dynamometer and is a function of RPM. If data is available, the engineer should use the BSFC value at peak horsepower RPM. If data is not available, 0.55 Lb_m/HP*Hour can be used for initial estimates. The BSFC used should comprehend the alternate fuel requirements for the application. Higher concentrations of alcohols will have higher BSFC requirements.

4. **Number of cylinders**
   - The number of engine cylinders information will be required to convert required engine fuel flow to required injector fuel flow. (Assuming a one injector/cylinder design.)

5. **Minimum fuel flow rate**

See Section 3.10.1

   - The ratio of the minimum flow rate and the maximum flow rate determined from this procedure will determine the required linear flow range for the injector. The linear flow range calculation will help determine which injector design would meet the vehicle requirements. To determine the minimum fuel flow rate, four conditions should be considered.
     - **Idle** (The minimum fuel rate required by the engine is based on a no load idle of a warm fully broken in engine at altitude. No load implies a charged battery, no air conditioning, no steering wheel motion and vehicle in neutral. Testing at altitude decreases the pumping work. If the minimum required flow rate is not measured at altitude, then an additional safety factor of 10% to 15% should be used to account for the effects of altitude.
     - If the vehicle calibration requires **make-up pulses**. Make-up pulse requirements could be one tenth of the idle flow requirement. (A make-up pulse is a fuel injection pulse delivered after the normal injection pulse, but before the intake valve opens. The make-up pulse is calculated in response to increased engine power requirements occurring after the normal pulse was calculated and delivered.)
     - Any **deceleration fueling requirements**. The fuel flow rate required during steady state decel is a function of the engine speed and manifold pressure during decel.
     - Any idle **purge requirements**. The amount, if any, of evaporative canister fuel vapor recirculation must be determined as a percentage of the fuel supplied to the engine, reducing the fuel flow rate requirements of the injector.

6. Vehicle Calibration Dependent Issues

- When sizing injector flow rate for any engine/vehicle application, the engineer should also consult the fuel calibration engineer for calibration specific fuel concerns. An example list is:
  - Piston Protection
  - Power Enrichment
  - Converter Over-temperature Protection
  - Cold Start Requirements
  - Any application injector duty cycle limitations

Some calibrators desire that the injector should be sized to meet an A/F ratio range of 9.0 to 10.0 A/F [equivalence ratio (ϕ) = 1.63 to 1.47] at the maximum horsepower point. However, the resulting required linear flow range might warrant a flow compromise.

Once the preceding specifications are determined, proceed with the following calculation to obtain maximum fuel flow per injector.

Example:

Engine Rated Horsepower (HP) @ 4500 RPM	300 HP
BSFC (Lb_m/HP*Hour) @ 4500 RPM	0.53 Lb_m/HP*Hour
Number of Cylinders	8
Minimum fuel flow per injector (Make up pulses) @ 600 RPM	0.023 gm/sec
Calibration Specific Issues (Values are guidelines)	
Power Enrichment	11.5 A/F Ratio = 1.25 Equivalence Ratio (ϕ)
Converter Over temperature	11.0 A/F Ratio = 1.33 Equivalence Ratio (ϕ)
Cold Start Requirement	10.5 A/F Ratio = 1.40 Equivalence Ratio (ϕ)
Fuel Pump Compensation	Compensation for lower pump pressure at high flow

1. Multiply the maximum engine horsepower by the brake specific fuel consumption to obtain required fuel flow per hour.

(300 Hp) * (0.53 Lb_m/HP*Hour) = 159 Lb_m/Hour

2. Convert to grams/second.

(159 Lb_m/Hr) * (454 grams/ Lb_m) * 1 hr/3600 sec) = 20.0 gm/sec

See Section 3.9.2

3. Adjust the value to eliminate injector operation in the tail-biting region (if required). (Assume a 5% adjustment.)

(20.0 gm/sec) * 1.05 = 21.0 gm/sec

See Section 7.2

4. Adjust the value to account for possible injector durability flow shift (lean). Durability flow tolerances for a specific injector model are provided on the injector outline drawing.

(21.0 gm/sec) * 1.05 = 22.1 gm/sec

5. Divide the value by the number of cylinders to obtain maximum flow per injector.

(22.1 gm/sec) / 8 = 2.7625 gm/sec per injector

6. Adjust value for calibration specific issues beyond enrichment at maximum power (assume max power at 11.5 A/F).

   For this example, the calibration specific issues are not additive (i.e. they occur at different operating conditions). Therefore the worst case will be chosen.

Power Enrichment:	(2.7625 gm/sec) * (11.5/11.5) = 2.7625 gm/sec
Converter OT:	(2.7625 gm/sec) * (11.5/11.0) = 2.89 gm/sec
Cold Start Req.:	(2.7625 gm/sec) * (11.5/10.5) = 3.03 gm/sec

Final injector size (maximum injector flow) = 3.03 gm/sec

Note: *Make sure to specify fuel type that the engine data is based on when sizing injector (i.e. CARB Phase III, etc). For flexible fuel vehicles the maximum flow requirements should be determined with the fuel of lowest specific heating value (i.e.* alcohol fuel blends) *and the minimum flow requirement with fuels of highest heating value (i.e. gasoline). See section 2.2.1.1.*

7. Calculate required injector linear and working flow range. To calculate the required flow range, engine derived maximum and minimum injector flows must be converted to flows at test stand repetition rates (rr). This is done by multiplying the flows by the ratio of the engine speed to the test stand repetition rates and then compensate for any duty cycle differences. For most applications the following assumption will be true:

   - The calculated max. fuel point occurs at static flow on both the engine and test stand. (i.e. repetition rate and duty cycle differences don't apply.)

Additional assumptions for the following calculation

- One injector per cylinder
- Sequential injector firing

Engine repetition rate = [1/ RPM] * [(60 sec/min)* (2 rev/inject)* (1000msec/sec)

Example @ 600 RPM:

Engine rep rate = [1/600 RPM]*120,000 msec/inject
= 200 msec

Injector test stand repetition rate is normally 10 msec.

Required fuel flows at test repetition rates:

Minimum fuel flow = 0.023 gm/sec * [200 msec/10 msec]
= 0.46 gm/sec (on test stand at 10 ms period)

Maximum fuel flow = 3.68 gm/sec

Required Flow Range = Max flow / Min flow
= 3.68 / 0.46

Required Injector Linear and/or Working Flow Range = 8

Sections 3.10.1 and 3.10.2 describe the differences between linear and working flow range. The engine control algorithms available for a particular application will determine whether the system flow range requirement calculated above will impact the linear or working flow range requirements for the injector. The different calibration control algorithms are described in section 5.2.

Note: *These calculations assume constant injector pressure drop. For non-vacuum biased fuel systems, the flow rate calculations will need to be adjusted to compensate for the non-constant pressure drop between idle and maximum power operating conditions due to varying manifold vacuum.*

In other words, the minimum engine fuel flow rate calculated above will occur at a higher injector pressure drop than the maximum fuel flow rate for a vacuum biased fuel system. The max and min flow rates should be normalized to the same injector pressure drop before making the flow range calculation.

Example:

Min flow = 0.46 gm/sec @ (400 kPa fuel pressure + 50 kPa Vac=450 kPa injector pressure drop.)

Max flow = 3.68 g/s @ (400 kPa fuel pressure – 0 kPa Vac = 400 kPa injector pressure drop.)

Min flow adjusted = $0.46*\sqrt{\frac{400}{450}} = 0.434$

Adjusted flow range requirement = 3.68/0.434 = 8.5

Injector Flow Worksheet

Program Name:

The following values must be determined before calculating maximum fuel flow per injector.

- Engine horsepower rating (HP) _________
  - @ Engine RPM _________
- Brake Specific Fuel Consumption (BSFC)
  - (Comprehend alternate fuel requirements) _________
  - @ Engine RPM _________
- Number of Cylinders _________
- Minimum Fuel Rate _________
- Calibration Specific Issues
  - List: _________________ _________
  - List: _________________ _________

Use the following formula to determine maximum fuel flow per injector.

1. Multiply max. engine horsepower by the brake specific fuel consumption to obtain required fuel flow per hour.

   (________ HP) * (________ BSFC) = ________ Lb_m/Hour

2. Convert to grams/second.

   (_______ Lb_m/Hr)*(454 grams/ Lb_m)*1 hr/3600 sec)=________ gm/sec

3. Adjust the value to eliminate injector operation in the tailbiting region (if required). (Assume a 5% adjustment.)

   (________ gm/sec) * 1.05 = ________ gm/sec

4. Adjust value for durability flow shift limit (see injector outline drawing for values)

   (________ gm/sec) * 1.xx = ________ gm/sec

5. Divide the value by the number of cylinders to obtain maximum flow per injector.

   (________ gm/sec) / (_____ cylinders) = ________ gm/sec per injector

6. Adjust value for calibration specific issues.

   (________ gm/sec) * 1.xx = ________ gm/sec

Final injector size (maximum injector flow) = _____________ gm/sec

7. Calculate required injector linear flow range.

   Engine rep rate =[1/(Engine RPM)] * [(60 sec/min)* (2 rev/inject)* (1000 mSec/sec)

   @ Engine Idle RPM = ________

   Engine rep rate = [1/_____ RPM]*120,000 mSec/inject

   Required fuel flows at test repetition rates:

   Minimum fuel flow = _____ gm/sec*[_____ mSec/10 mSec]

   Maximum fuel flow = _________ gm/sec

   Adjust min and max flow rates for constant injector pressure drop: $m_2 = m_1\sqrt{\frac{\Delta p_2}{\Delta p_1}}$

Required Flow Range = Max flow / Min. flow

Required Injector Flow Range = _________

3.8 Injector Targeting, Placement and Cone Angle

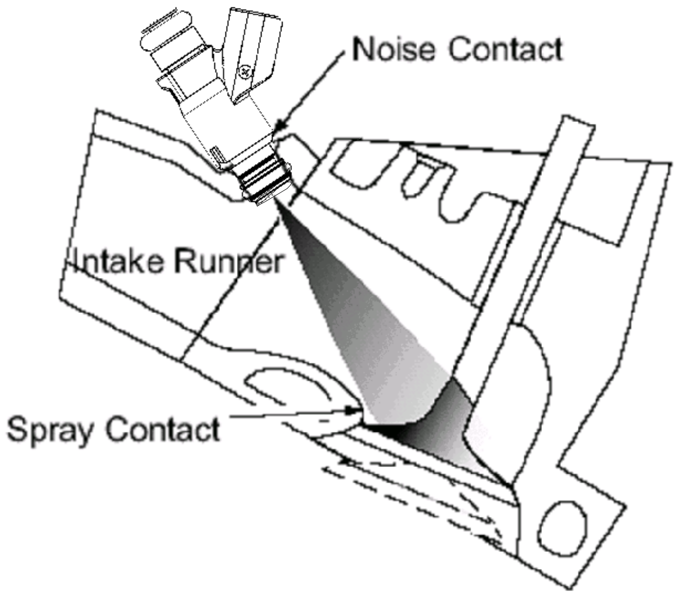


Figure 3-10 - Injector Targeting

This section is intended as a guideline to proper injector placement and spray selection. These guidelines are general recommendations that may not apply to all applications. An injector spray development plan including engine emissions, and driveability should be performed in order to confirm the injector selection performs optimally in the intended application. More detailed information about injector spray measurement can be found in the SAE recommended practice for injector spray (J-2715) which was in the approval process at time of writing and may currently be available.

3.8.1 Targeting

Generally, the goal is to target the fuel spray so that it uniformly covers the intake valve with little or no wall wetting within the target path. Spray impinging on the hot intake valve of a warmed up engine will readily vaporize. Cold start strategies for reduced emissions may require alternate spray targeting schemes. Delphi has extensive spray visualization and measurement capabilities to help determine the optimum spray targeting for an application. Involvement early in the engine / intake design process provides the maximum flexibility to locate the injector tip for best spray targeting. See your Delphi representative for details.

The customer should define any specific limits on the wetted manifold and valve area. (Reference Figure 3-10 for typical injector spray targeting.)

Positioning of the injector must take into account the amount of time required to vaporize the fuel (transport + residence time), the impact of wall wetting and the impact on the tip temperature of the injector. Shorter distances will reduce fuel transport delays and aid in calibrating optimum injection timing. Longer distances allow the injector fuel spray to spread out, contacting the walls around the intake valve. Typical injector to valve distances for MPFI systems are 70 to 120 mm.

***Note**: The placement of the injector in the head versus the intake manifold or too close to the intake valve can significantly increase the injector tip temperatures (especially during hot soaks) and lead to hot start and driveability problems. Maximum allowed injector tip temperatures are dependent on fuel system pressure and test fuel volatility. See section 8.4.1.*

3.8.2 Cone Angle

The injector spray cone angle is a measure of the included angle containing a specified percentage of the fuel. At Delphi spray cone angles are measured using a spray patternator consisting of a grid of hex shaped cells that collect the fuel spray and measure the volume distribution.

- **Single spray injectors**: The spray patternator is located 100 to 143 mm from the injector tip. N-Heptane at system pressure is supplied to the injector, which is pulsed at 5 ms PW, and 40 ms period. The included angle which contains 90% of the spray volume is calculated as the single spray cone angle.
- **Dual spray injectors:** The spray patternator is located 100 mm from the injector tip. The spray centroids are located from the volume distribution of each spray cone. The included angle which contains 90% of the spray volume is calculated for each spray cone and reported as the dual spray cone angle. The location of he spray centroids is used to calculate the dual spray separation angle and orientation angle (see Figure 3-11.) Examples of spray patternator data for single and dual spray injectors are shown in Figure 3-12. Actual injector fuel delivery rates and engine operating conditions (MAP and port air flow rates) also affect the injector cone angle.
- Placement of the injector within the manifold or head area must comply with the interface requirements found in section 4 and should minimize the potential for fuel from previous injection events puddling at the interface. Puddled fuel will eventually dislocate from the interface, causing an excess fuel condition. This will effectively lead to a less stable combustion event or in the extreme case, a cylinder misfire.

  - Retracting the injector long distances inside the manifold/head bore increases the potential for fuel at the fringes of the spray to collect in the bore and shelters the injector tip from fuel stripping forces generated by the inlet air flow velocity.

  - Positioning the injector tip out into the inlet air stream reduces the risk of fuel puddling but also provides surfaces for water to condense on the injector tip. This can lead to injector icing (see section 2.2.7.4) and poor or no start conditions on some applications. Intake manifolds made of low thermally conductive materials (i.e. plastic) may increase the risk of icing (for injector tip in manifold designs). Vehicle level icing tests should be conducted to validate proper operation.

- Injection timing within the engine cycle can have a significant effect on fuel targeting and puddling of fuel.

- For dual intake-valve engines, dual spray injectors may provide some benefits, especially in meeting more stringent emissions requirements. With the appropriate intake/cylinder head design, a single spray injector may also be acceptable for dual intake-valve engines.

- The interaction of the injector spray with intake mixture motion control devices need to be considered. Specific injector spray parameters may be required to take advantage of intake mixture motion control.

- Systems testing with Delphi support may be necessary to determine the optimum spray configuration to meet specific engine performance and emissions goals. This may include high speed video recording of fuel injection events in the running application engine, cold start emissions, steady state emissions, and transient response.

3.8.3 Spray Atomization

Spray atomization is defined by the droplet size distribution of the fuel spray. Small fuel spray particles will increase the percentage of fuel vaporized in the cylinder improving combustion of the fuel. Vaporization can also be improved by increasing the heat input to the fuel: This is achieved by targeting the fuel at the hotter intake valve area, and by maximizing the fuel residence time in the port prior to the intake valve opening.

Spray atomization parameters typically used to describe the distribution of droplet sizes are the Sauter Mean Diameter (D_{32}), and DV_{90}. D_{32} describes the ratio of volume to surface area for the entire spray. It relates to the physics of droplet evaporation and is useful in the study of combustion.

$$D_{32} = \frac{\sum N_i D_i^3}{\sum N_i D_i^2} = 6 * \frac{Volume}{Surface}$$

DV_{90} describes the droplet size which 90% of the spray volume is smaller than. This parameter is useful in understanding the overall droplet size distribution spread.

Spray atomization measurements at Delphi are typically performed with a Laser Diffraction instrument. The beam is located 100 mm from the injector tip which is actuated at pulse width to deliver 15 mg/pulse of N-Heptane.

Injector spray atomization is influenced by the following design parameters:

- Cone angle (wider cones tend to have better atomization.)
- Flow rate (higher flows tend to have larger droplets.)
- Director design (atomization can improve with the number of holes.)
- Valve design (flow upstream of the injector affects atomization.)
- Fuel pressure (higher fuel pressure provides better atomization)

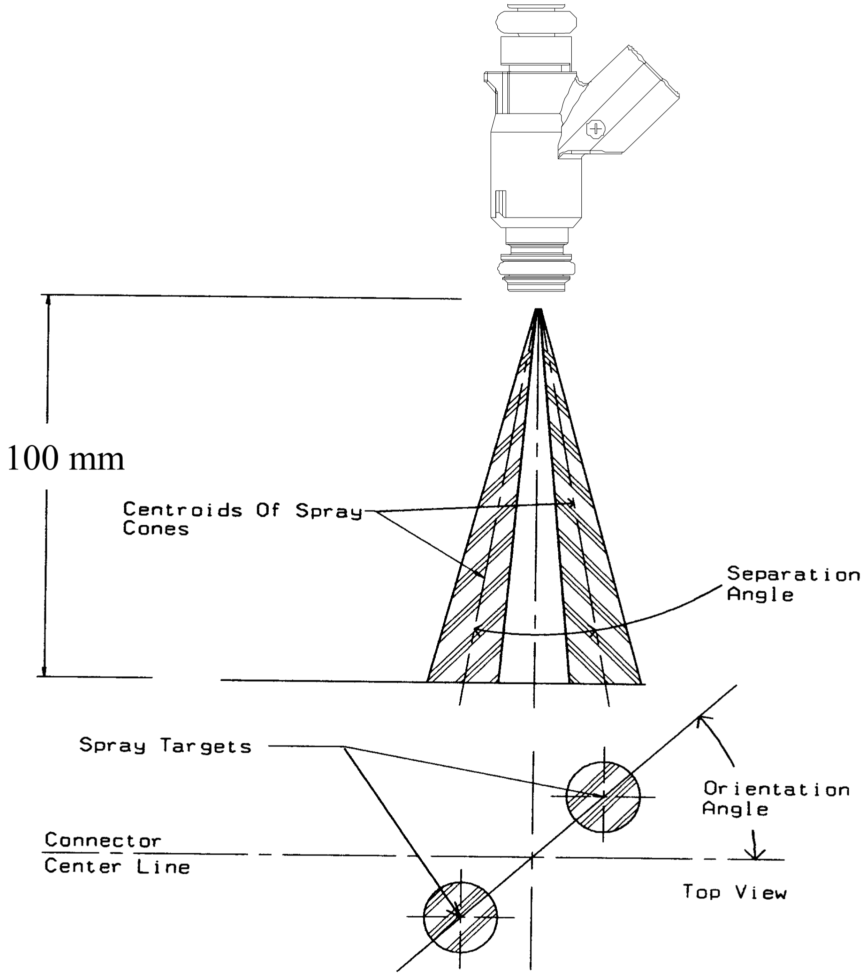
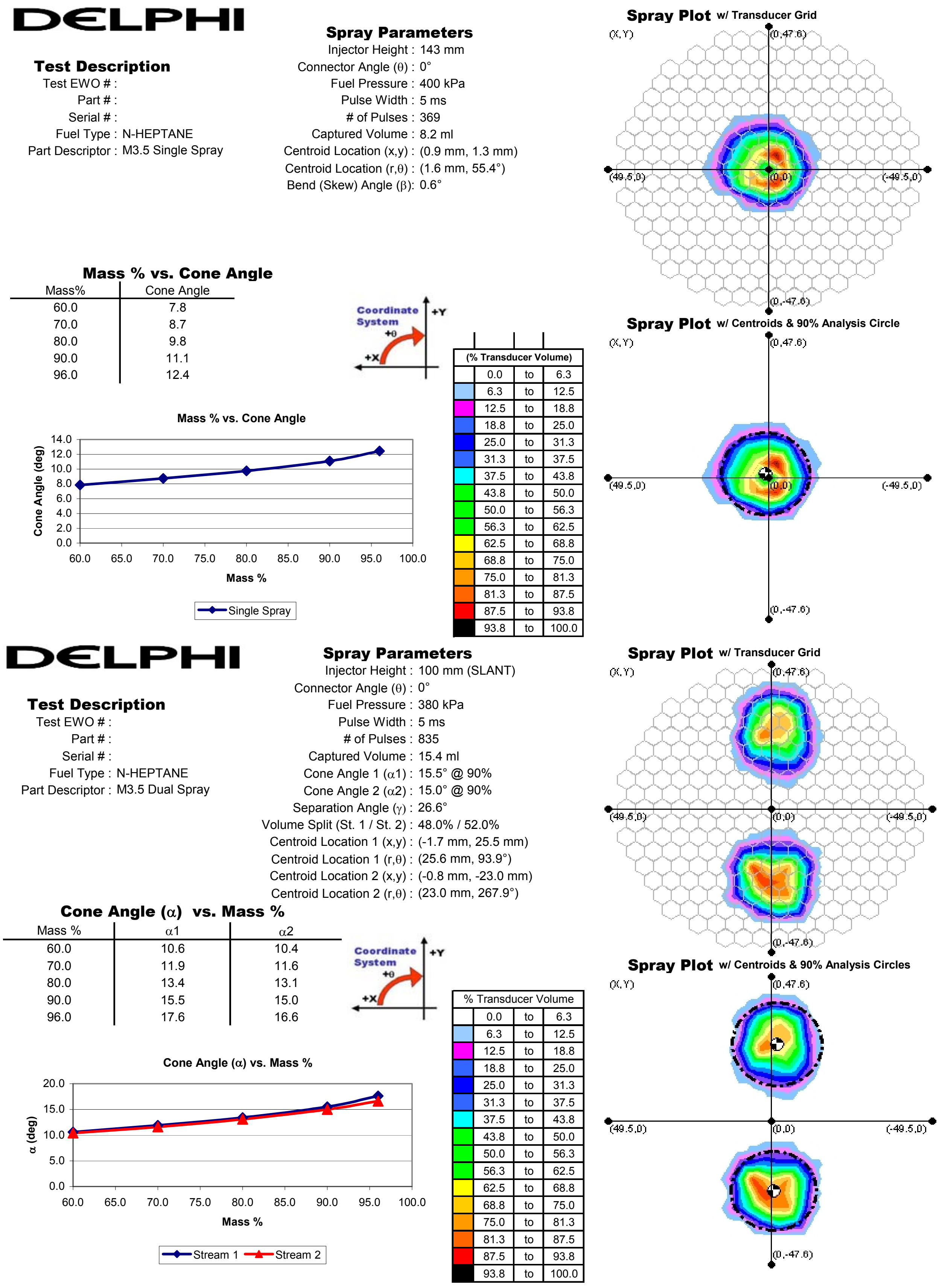


Figure 3-11 - Dual Spray Injector Separation and Orientation Angle



Test Description

Test EWO # :
Part # :
Serial # :
Fuel Type : N-HEPTANE
Part Descriptor : M3.5 Single Spray

Spray Parameters

Injector Height : 143 mm
Connector Angle (θ) : 0°
Fuel Pressure : 400 kPa
Pulse Width : 5 ms
# of Pulses : 369
Captured Volume : 8.2 ml
Centroid Location (x,y) : (0.9 mm, 1.3 mm)
Centroid Location (r,θ) : (1.6 mm, 55.4°)
Bend (Skew) Angle (β): 0.6°

Spray Plot w/ Transducer Grid

Mass % vs. Cone Angle

Mass%	Cone Angle
60.0	7.8
70.0	8.7
80.0	9.8
90.0	11.1
96.0	12.4

(% Transducer Volume)				
⬜	0.0	to	6.3
🟦	6.3	to	12.5
🟪	12.5	to	18.8
🟦	18.8	to	25.0
🟦	25.0	to	31.3
🟦	31.3	to	37.5
🟦	37.5	to	43.8
🟩	43.8	to	50.0
🟩	50.0	to	56.3
🟩	56.3	to	62.5
🟨	62.5	to	68.8
🟨	68.8	to	75.0
🟧	75.0	to	81.3
🟧	81.3	to	87.5
🟥	87.5	to	93.8
⬛	93.8	to	100.0

Spray Plot w/ Centroids & 90% Analysis Circle

Test Description

Test EWO # :
Part # :
Serial # :
Fuel Type : N-HEPTANE
Part Descriptor : M3.5 Dual Spray

Spray Parameters

Injector Height : 100 mm (SLANT)
Connector Angle (θ) : 0°
Fuel Pressure : 380 kPa
Pulse Width : 5 ms
# of Pulses : 835
Captured Volume : 15.4 ml
Cone Angle 1 (α1) : 15.5° @ 90%
Cone Angle 2 (α2) : 15.0° @ 90%
Separation Angle (γ) : 26.6°
Volume Split (St. 1 / St. 2) : 48.0% / 52.0%
Centroid Location 1 (x,y) : (-1.7 mm, 25.5 mm)
Centroid Location 1 (r,θ) : (25.6 mm, 93.9°)
Centroid Location 2 (x,y) : (-0.8 mm, -23.0 mm)
Centroid Location 2 (r,θ) : (23.0 mm, 267.9°)

Spray Plot w/ Transducer Grid

Cone Angle (α) vs. Mass %

Mass %	α1	α2
60.0	10.6	10.4
70.0	11.9	11.6
80.0	13.4	13.1
90.0	15.5	15.0
96.0	17.6	16.6

% Transducer Volume				
⬜	0.0	to	6.3
🟦	6.3	to	12.5
🟪	12.5	to	18.8
🟦	18.8	to	25.0
🟦	25.0	to	31.3
🟦	31.3	to	37.5
🟦	37.5	to	43.8
🟩	43.8	to	50.0
🟩	50.0	to	56.3
🟩	56.3	to	62.5
🟨	62.5	to	68.8
🟨	68.8	to	75.0
🟧	75.0	to	81.3
🟧	81.3	to	87.5
🟥	87.5	to	93.8
⬛	93.8	to	100.0

Spray Plot w/ Centroids & 90% Analysis Circles

Figure 3-12 - Sample Single and Dual Spray Injector Patternator Results

3.9 Pulse-Width Limits

Fuel delivery becomes unpredictable at high duty cycles (>95%) and very low pulse-widths due to unstable opening and closing times.

Opening response (O.R.) is the time it takes the magnetic circuit to build up sufficient force to overcome loads from the fuel pressure and valve spring on the injector valve and move it from the fully closed position to the fully open position.

Closing response (C.R.) is the time it takes for the magnetic circuit to decay to a level at which the loads from the valve spring and fuel pressure can move the valve from the fully open position to the fully closed position.

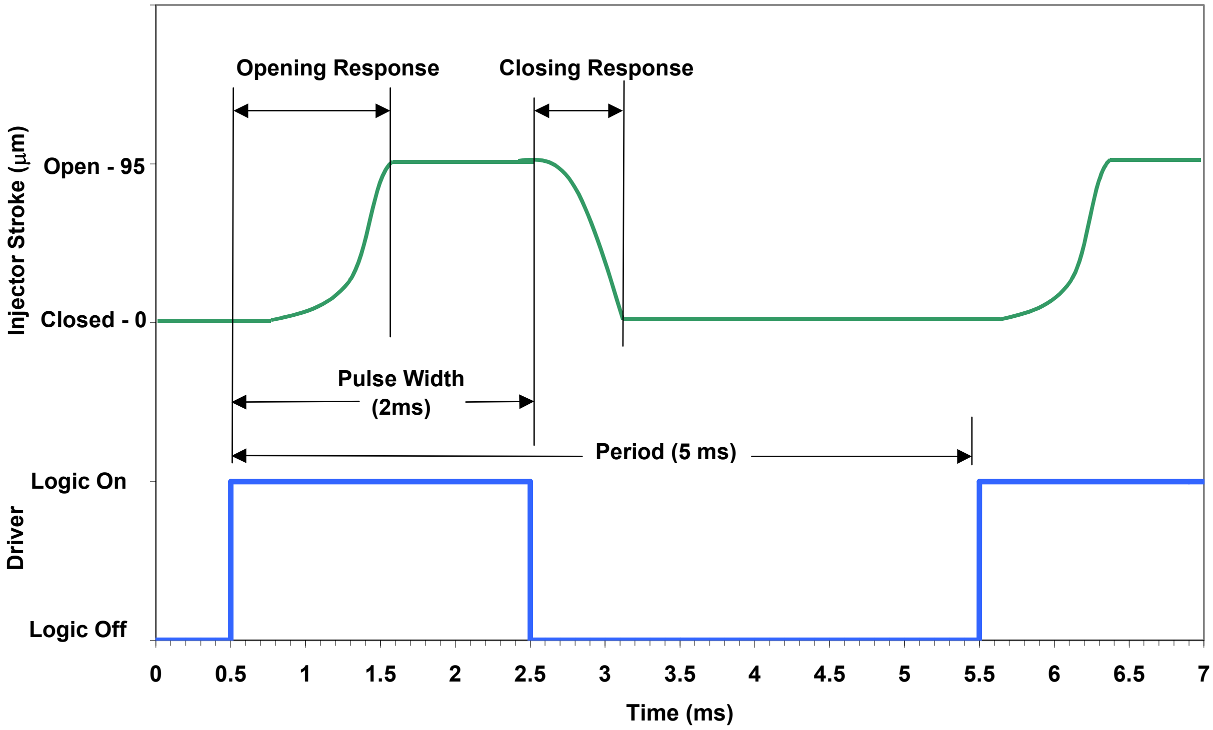


Figure 3-13 Injector Opening and Closing Response

Inertial forces must be considered when determining opening response and closing response. Other factors that contribute to injector opening and closing responses include:

- System voltage
- Injector body temperature (affects coil resistance)
- Fuel lubricity
- Injector flow calibration
- Internal injector friction
- System pressure**Error! Bookmark not defined.**
- Wiring resistance and connector resistance
- Injector part-to-part tolerances
- Driver characteristics
- Magnetic material properties

Injector flow deviates lean from the ideal linear line at very low pulse widths due to the inability of the valve to open within the command pulse time. Conversely, at very high pulse widths the injector has insufficient time to close before the start of the next pulse and deviates rich from the ideal linear flow line.

Additionally, injector opening and closing response times become less repeatable at very low pulse-widths. As a result, fuel delivery also becomes less repeatable. Refer to Figure 3-14 and Figure 3-15 for graphical representations of high and low pulse-width flow effects.

Note: *The lowest useable pulse width is independent of injection frequency (or engine rpm). The highest useable pulse width is a function of injection frequency.*

3.9.1 Minimum Pulse-Width (MPW)

Minimum pulse-width is the least amount of injector "on" time required to achieve consistent fuel flow. During a single pulse event, the flow of an injector does not stabilize until after the current rise-time effects are complete. If the pulse time is less than an the opening event time, inaccurate fuel flow results in the following ways:

- A lean shift occurs at low pulse-widths in the minimum pulse-width region
- Flow rates in the minimum pulse-width region of the flow curve are subject to larger pulse-to-pulse and part-to-part variations than in the linear portion of the flow curve.

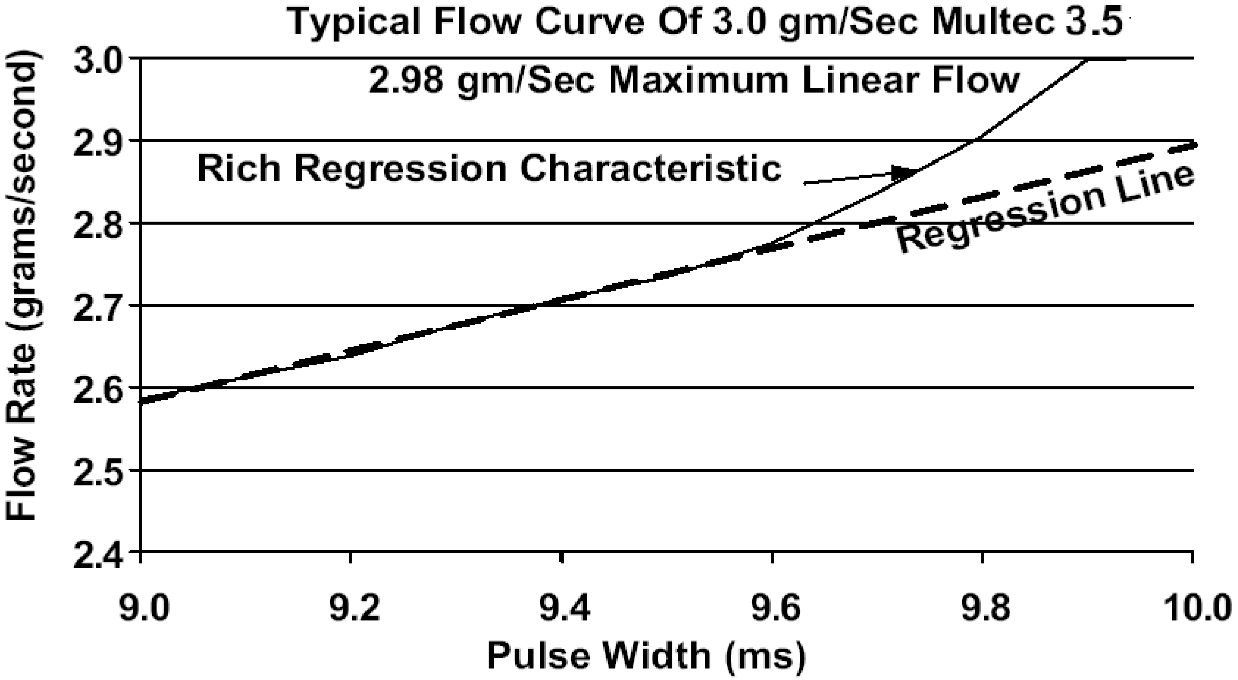


Figure 3-14 - High Pulse-Width Flow Effects. Static Occurs at 10 msec (rep. rate = 10 msec)

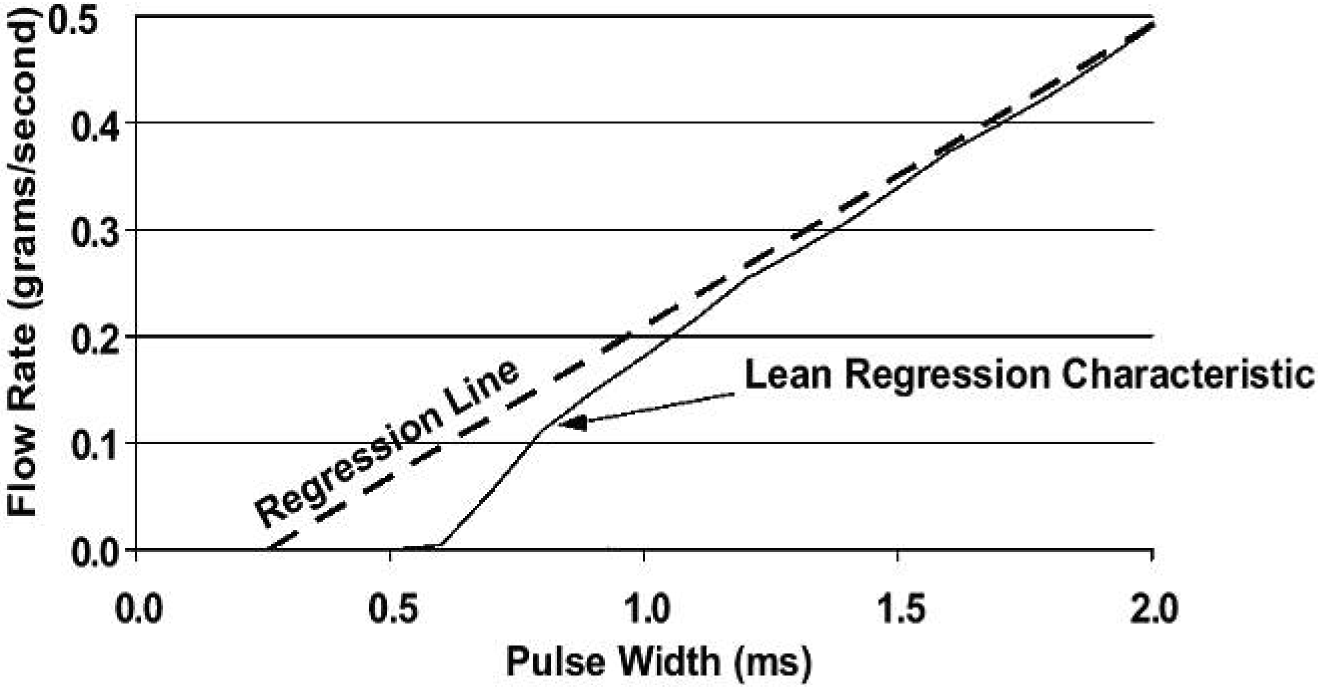


Figure 3-15 - Low Pulse-Width Flow Effects. (Rep. rate = 10msec)

3.9.2 Tailbiting

Refer to Figure 3-16. The trace for driver logic represents the commanded signal to the injector. The trace for injector valve stroke is an example of the actual response of the injector to this input. This trace represents the result of commanding the injector to open before the injector has fully closed from the previous input signal. This phenomenon is often referred to as "tailbiting", and will occur when the injector is operated at a pulse width just below the static (fully open) operating point of the injector. The following are characteristics of tailbiting:

- A rich shift occurs at high pulse-widths approaching static flow (100% duty cycle)

- Flow rates in the tailbiting portion of the fuel flow curve have a large part-to-part variation

While this does not cause any damage to the injector, it will have an impact on fuel system performance, especially emissions. The maximum useable pulse width can be estimated as:

Engine injection period – injector closing response time

Thus the maximum useable pulse width is a function of injection frequency. The engine injection period is determined by the injection scheme (see Section 5.2.1) and the engine rpm.

See Section 3.6.4	***Note**: It is important to consider the impact of tailbiting when sizing the injector flow rate for a vehicle application. It is desirable to have approximately 5% more injector flow than is required for maximum fueling conditions on the vehicle.*

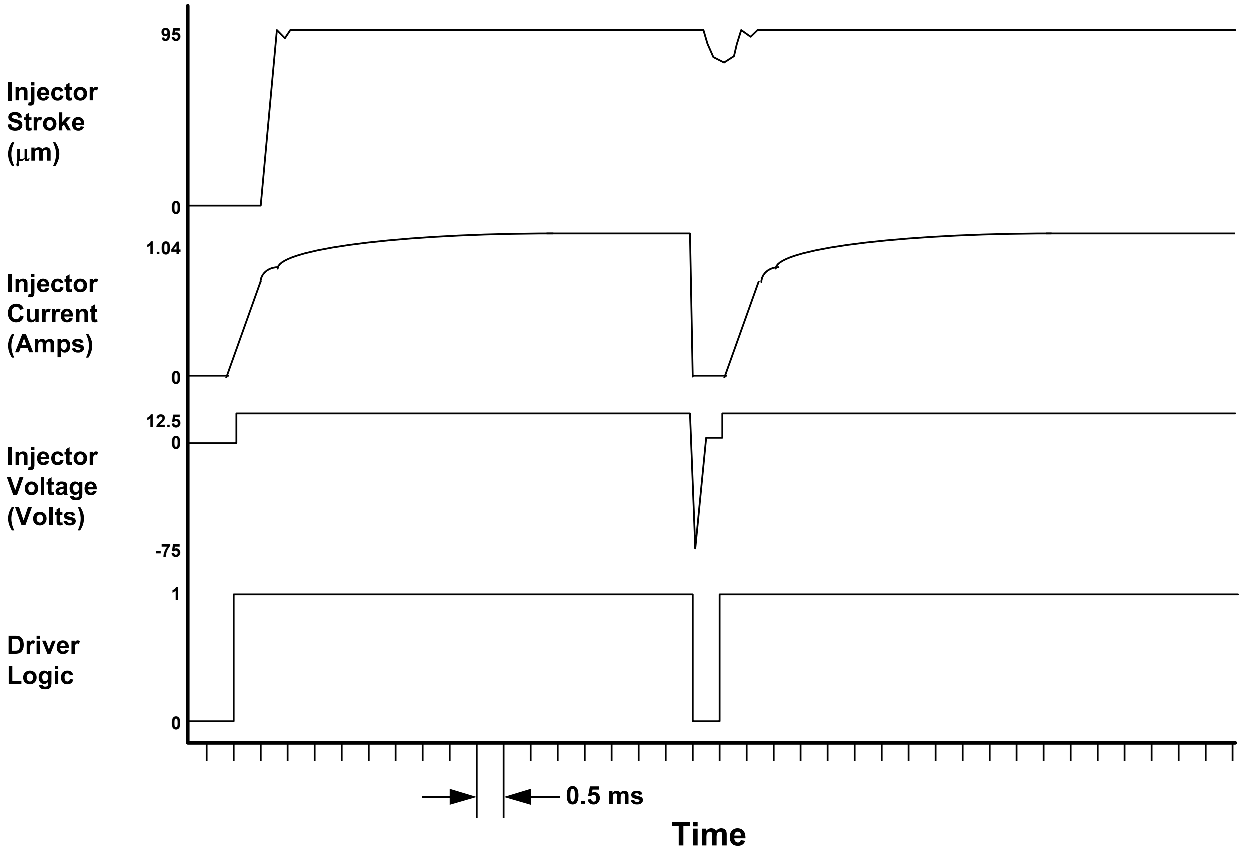


Figure 3-16 - Injector Flow Curve Tailbiting

3.10 Linear and Working Flow Range

3.10.1 Linear Range

Linear Range is a measure of the portion of an injector flow curve that is linear. It is a function of opening and closing response times. The SAE J1832 standard test period is 10 ms.

Linear Range = Maximum regression flow divided by the minimum regression flow where actual flow falls within +/-5% of the linear regression line determined by the 3.0, 4.0, 5.0, 6.0, and 7.0 ms pulse-widths and a 10.0 ms repetition rate. Refer to Figure 3-17.

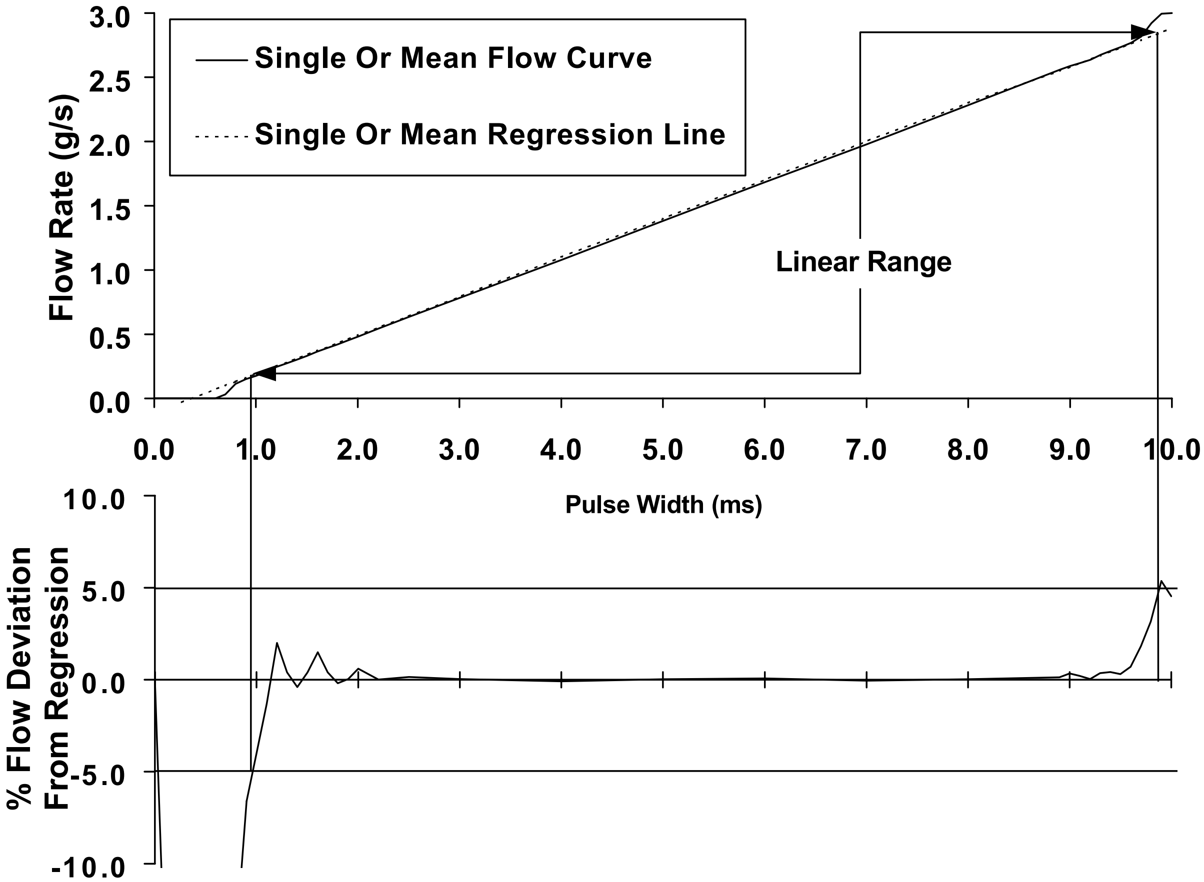


Figure 3-17 - Linear Range

Note

The 5% limit for linear flow range is an SAE J1832 standard to allow comparison of injector data. Using values other than 5% may be more appropriate depending on the fueling accuracy needs of the engine control system.

Linear range can apply to a single injector or an average of a population of injectors (this must be specified when reporting the linear range value.) A high linear range is desirable for the following reasons:

- Allows accurate fueling at lower idle and higher peak engine speeds.
- Better low pulse-width performance combined with higher maximum flow. (Important for high specific output engines and turbocharged or supercharged engines).
- Aids in engine controller calibration accuracy.
- Can allow for one injector model to be used for multiple engine applications.

3.10.2 Working Flow Range

Working Flow Range is a measure of injector-to-injector flow variation based on a production population of at least 24 injectors. It impacts cylinder-to-cylinder air/fuel ratio.

Working Flow Range = Maximum flow divided by the minimum flow where all injectors are within +/- 5% of the mean flow curve at 3 standard deviations. Refer to Figure 3-18.

Note

For vehicle calibration, the working flow range and linear flow range should be obtained from the fuel rail assembly flow.

Both linear flow range and working flow range need to be understood to predict the injector behavior at a commanded pulse width. Some calibration schemes can compensate for the non-linearity of the injector with a low pulse width correction table. This assumes the injector working flow range low pulse width is less than the linear flow range lower pulse width.

The 5% value used for the calculation is a standard based on the SAE J1832 specification. The percent deviation value used in the calculation can be varied based on the recommendation of the vehicle calibrator for the maximum acceptable cylinder-to-cylinder fuel variation. The injector working flow range in combination with the rail round robin test to measure cylinder-to-cylinder rail flow effects, can be used to calculate the fuel system cylinder-to-cylinder fueling error. Unless the engine control system has individual cylinder fuel control capability, this cylinder-to-cylinder fueling error cannot be compensated for by the engine control system. (Using the +/-5% standard limits translates into ~ 1.5 A/F ratio total variation worst case.)

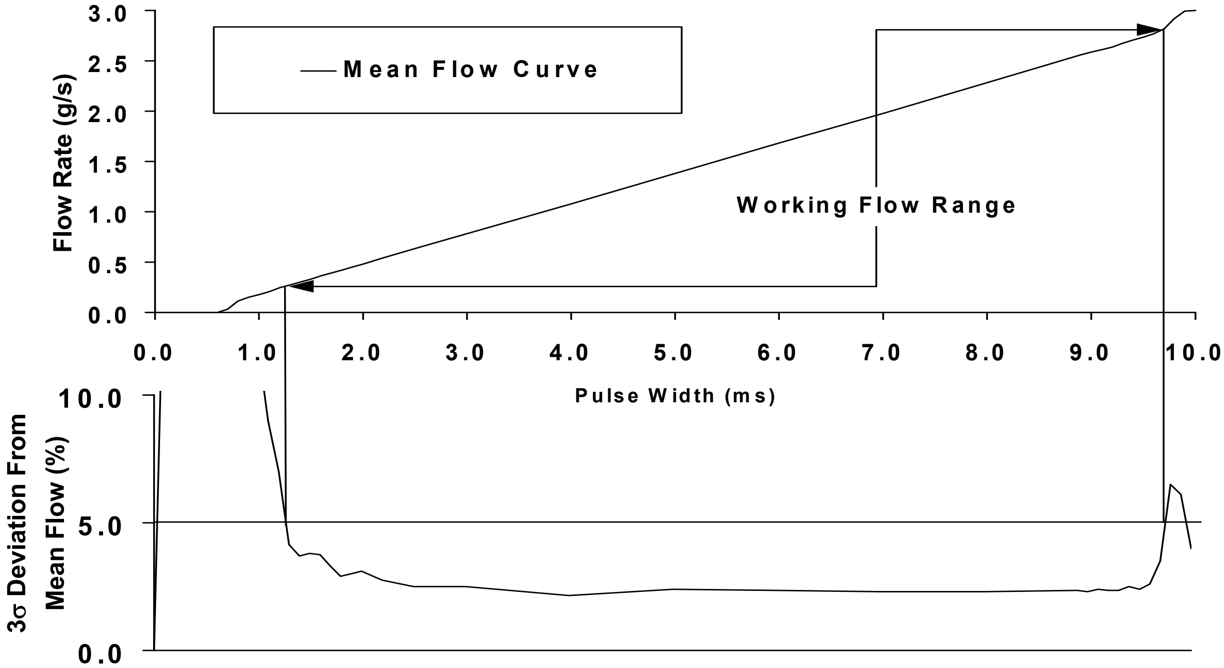


Figure 3-18 - Injector Working Flow Range

3.11 Tip Leakage

Tip leakage is defined as unmetered fuel that leaks from the injector tip due to imperfect sealing in the closed valve position. The injector valve seals through metal-to-metal contact between the valve and seat for cycling wear durability reasons. The design and manufacture of this interface controls the tip leak rate.

Loss of fuel pressure during engine shutdown due to injector tip leak can result in fuel vapor formation in the fuel system. This may lead to long engine restart times and possible stalling.

In addition, injector tip leakage has been identified as a source of evaporative hydrocarbon (HC) emission during engine shutdown and tailpipe HC emissions during engine restart. As government regulations further restrict these emissions, injector tip leakage requirements are becoming more stringent.

Injector tip leak rate is normally specified using a gaseous medium such as Nitrogen. This is to avoid the limitations of fluid leak test equipment in the manufacturing environment. Vehicle testing with limit leak rate injectors is recommended to verify that the tip leak design specification provides the expected level of performance.

When using gaseous leak check techniques (bubble, pressure decay, or mass flow), it is imperative to perform an injector internal drying procedure by cycling the injector with pressurized clean dry air prior to leak test. All liquid must be cleared from the valve area in order to obtain a valid leak rate. The presence of liquid, which is an order of magnitude more viscous than a gas, may produce a false low leakage measurement. To obtain accurate injector tip leakage measurements, adequate time must be allowed for the injector to cool following the purge procedure prior to performing the leak test.

Note Injector leak is normally the last functional test performed during injector manufacturing. Therefore the injectors are delivered to the customer in the dry state. If a functional gaseous leak test is to be performed on the injector, rail or fuel system prior to introducing fuel into the system, the injector may produce a false leak. This may be due to the injector valve becoming unseated in the dry state during shipping and handling. If this occurs, a momentary pulse of the fuel injector is recommended to reseat the valve and correct the false leak. (See section 6 – Product Handling.)

Note While changes in tip leakage could effect crank times, evaporative emissions and exhaust emissions, it is important to properly diagnose such problems as tip leakage may not be a factor. Other possible causes include a malfunctioning pump check valve, regulator leakage, etc.

3.11.1 Total Fuel System Tip Leakage Monte Carlo Analysis

At a vehicle level the total tip leakage from all the injectors in a fuel system is of more significance than the individual injector tip leak rates. A portion of the total vehicle evaporative HC emissions can be allocated to fuel system injector tip leakage.

Rather than specify a stringent maximum leak rate for each injector to ensure an assembly made up of worst case specification limit tip leak injectors does not exceed the fuel system limits, a Monte Carlo analysis of total fuel system leakage can be performed. The Monte Carlo analysis determines the cumulative percentage of rail assemblies vs total leak for a given distribution of injector tip leakages.

For example, if maximum total fuel system tip leak for a 4 cylinder rail is specified at 1.6 cc/min, an injector maximum tip leakage specification of 0.40 cc/min could be used to guarantee all fuel systems meet the 1.6 cc/min specification. Alternatively, the distribution of tip leak rates from a production lot of injectors can be used in a Monte Carlo analysis to simulate 5000 rail builds and determine the total tip leak distribution. The total tip leakage for the rail is determined by selecting 4 injectors at random from the production injector tip leak distribution and adding the tip leakages. The cumulative percentage of rails with a total tip leak rate less than the specified value is calculated. Typically a compliance level is specified for the total rail tip leak that allows a very small percentage of rails to exceed the limit. See Figure 3-19 for a sample rail tip leak Monte Carlo distribution.

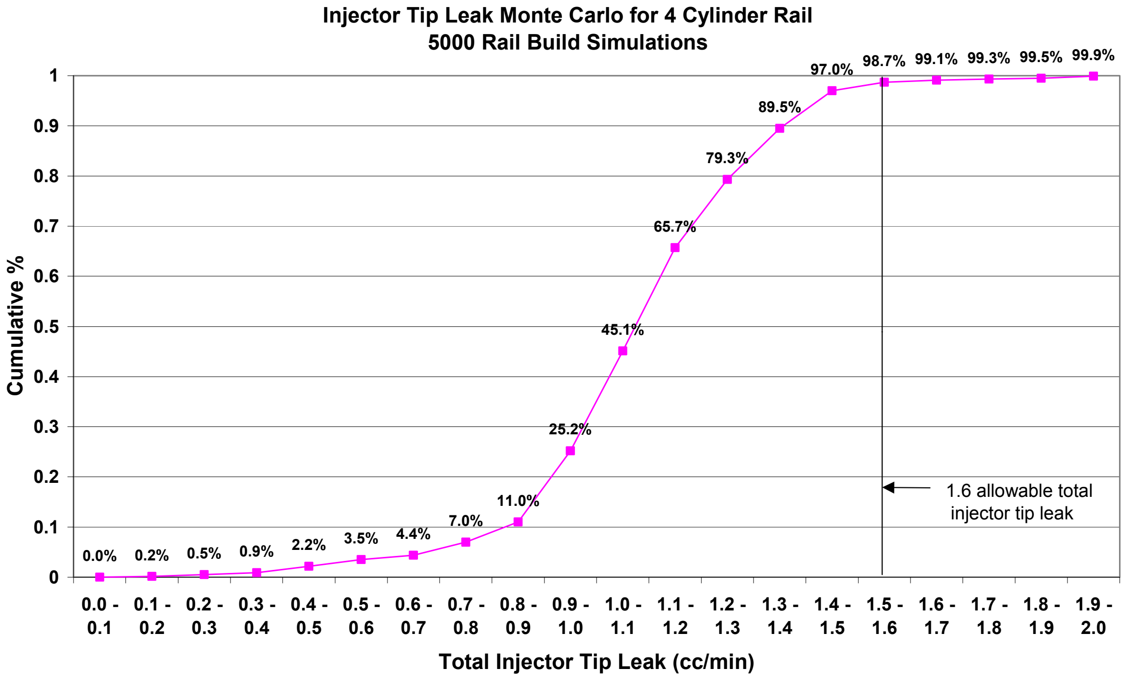


Figure 3-19 Fuel Rail Total Tip Leak Monte Carlo Simulation Example (4 cylinder)

3.12 Contamination Resistance

See Section 7.3.4

The injector fuel inlet filter protects the fuel injector from initial build fuel contamination as well as from fuel system assembly contamination. Filtration is extremely important because particle contaminants can cause an injector to stick open, flow shift or tip leak.

The injector inlet filter mesh size is 30 microns. Smaller filter mesh sizes can lead to a higher likelihood of premature vaporization of highly volatile fuels under high temperature conditions.

The injector inlet filter is not a serviceable component and is designed only to trap potential built-in contamination between the chassis fuel filter and injector. A chassis fuel filter with a 10 micron rating is required to protect the injector from long term contamination damage.

3.13 Dynamic and Static Fuel Flow Specifications

For injector model specification on engineering drawings and in the manufacturing process, flow is specified at two calibration points: dynamic and static.

Dynamic fuel flow is a measure of dynamic injector performance. It is typically measured at a 2.0 ms pulse-width and a 10 ms repetition rate for Multec 3.5 port fuel injectors. The 2.0 ms pulse-width was chosen to maximize low pulse-width flow accuracy. Dynamic fuel flow is affected by opening response, closing response, and static flow. The following design factors directly determine opening and closing response (see section 3.9).

- Magnetic circuit design (including stroke)
- Core spring load
- Differential fuel pressure
- Sealing diameter
- Friction/fluid damping effects

Static fuel flow is a measure of maximum flow capacity and is measured at 100% duty cycle. The following design factors affect static flow:

- Sealing diameter
- Seat geometry
- Fuel pressure
- Director hole size
- Valve Stroke

The injector is set for both static and dynamic flow during the manufacturing process.

Multec 3.5 injectors are capable of static flow rates from 1.3 to 4.0 g/s at 400kPa (58 psi.) Static flow rates above 4 g/s are feasible, but may require relaxed flow tolerances due to increased pressure sensitivity.

The injector set point flow rate is normally determined for each static flow rate to optimize low voltage and low pulse width performance.

3.13.1 Flow Test Fluid Specification

All production and audit injector flow rate measurements will be made with the following fluid unless otherwise specified:

Stoddard Solvent (Delphi Materials Specification Number M52625)
Specific gravity – 0.788 +/- 0.25% @ 15.56°C
Absolute viscosity – 0.997+/- 0.20% cP @ 20°C

Note: Production injector flow values are specified in Stoddard Solvent only. Any flow values provided in gasoline are for reference.

As an approximation, injector flows in gasoline will be 1.0 to 2.5% less than those in Stoddard Solvent.

3.14 Noise

Injector noise is generated by valve impact when opening and closing on the seat and pole piece stop. Injector noise is perceived as a “ticking” sound. See Figure 3-5

Other engine noise is often attributed to the injector (valve train noise and the fuel line ‘hammer’ noise generated by the injector on/off fuel flow interruptions interacting with the fuel rail and fuel lines). Proper hydraulic damping of the fuel system is recommended to prevent the propagation of fuel flow induced noise.

Refer to Section 5.2.1.4

A sequential firing scheme will generally reduce injector noise. Injector noise can also be reduced by improving injector noise absorption (i.e., an engine cover).

3.15 Electrical Specifications

3.15.1 Solenoid Coil Specifications

Solenoid electrical specifications for the Multec 3.5 Fuel Injector are presented in Table 3-1.

3.15.2 Avalanche Energy

Avalanche Energy supplements inductance as a solenoid specification parameter relevant to injector driver requirements. Avalanche Energy is the inductive energy stored in the magnetic field of the solenoid that is released back into the driver circuit when voltage is switched off.

Current in the injector coil generates a magnetic field when the injector is energized. This field breaks down as the current decays when the injector is turned off inducing a voltage spike in the injector coil (much like an ignition coil). However, instead of generating a spark, the voltage spike known as “flyback voltage” is limited by the Zener diode avalanche voltage in the injector driver. (See section 4.4.5.1.)

Energy from the magnetic field measured as avalanche energy must be dissipated in the engine controller. The engine controller must be configured to absorb or dissipate appropriate amounts of avalanche energy.

$$Avalanche\,Energy = \int_t I * V_{Zener}$$

SOLENOID COIL SPECIFICATIONS (Nominal)

Coil resistance (ohms @ 20°C and 100 μA)	12.0
Temperature coefficient of resistance (1/°C)	0.00393
Inductance	6.6 mH @ 1 kHz
Avalanche Energy (steady state)	2.8 mJ @16 V
Maximum intermittent operating voltage at 85°C (100 ms PW / 200 ms Period for 1 minute while flowing pressurized fuel)	26.5 V

***Note**: Operation can be temporarily compromised during an over voltage condition.*

Table 3-1 Solenoid Electrical Properties

3.16 Environmental Conditions

The Multec 3.5 Fuel Injector is designed to operate in a certain range of conditions but can withstand extreme operating conditions for short periods of time. Table 3-2 lists typical examples of normal and extreme operating conditions. Refer to the Engineering Product Specification for the application for exact values and conditions. Values shown are for example purposes only. Specific application values may vary. Extreme operating conditions are for short durations only with possible degraded performance.

OPERATING CONDITIONS

	Normal	**Extreme***
Ambient air temperature	-40 to +50°C	-40 to 66°C
Underbody air temperature	-30 to +90°C	
Underhood air temperature	-40 to +125°C	-40 to 150°C
Relative humidity	0 to 95% @ 85°C	
Barometric pressure	55 to 105 kPa	
Fuel system pressure (nominal)	200* to 500 kPa	
Fuel temperature	-40 to +65°C	
Engine intake manifold absolute pressure	5 to 105 kPa	

Table 3-2 - Injector Environmental Operating Conditions

Note: ** Dependent on high temperature performance requirements.*

3.16.1 Hot Fuel Handling

See Section 8.4.1 for details on injector hot fuel handling testing and injector performance.

3.16.2 Environmental Exposure

The Multec 3.5 Fuel Injector meets performance and physical requirements for environmental conditions it may be exposed to, as defined by Delphi Validation Plans (see section 9.) The fuel injector is compatible with specifications for:

Ozone
Salt Spray
Structural Loads
Humidity
Contamination
Shock
Pressure
Vibration
Temperature
Fuel Compatibility

4.0 System Interface

4.1 General

The Multec 3.5 Fuel Injector interfaces with the other Engine & Vehicle Subsystems as described in this section and shown in Figure 4-1.

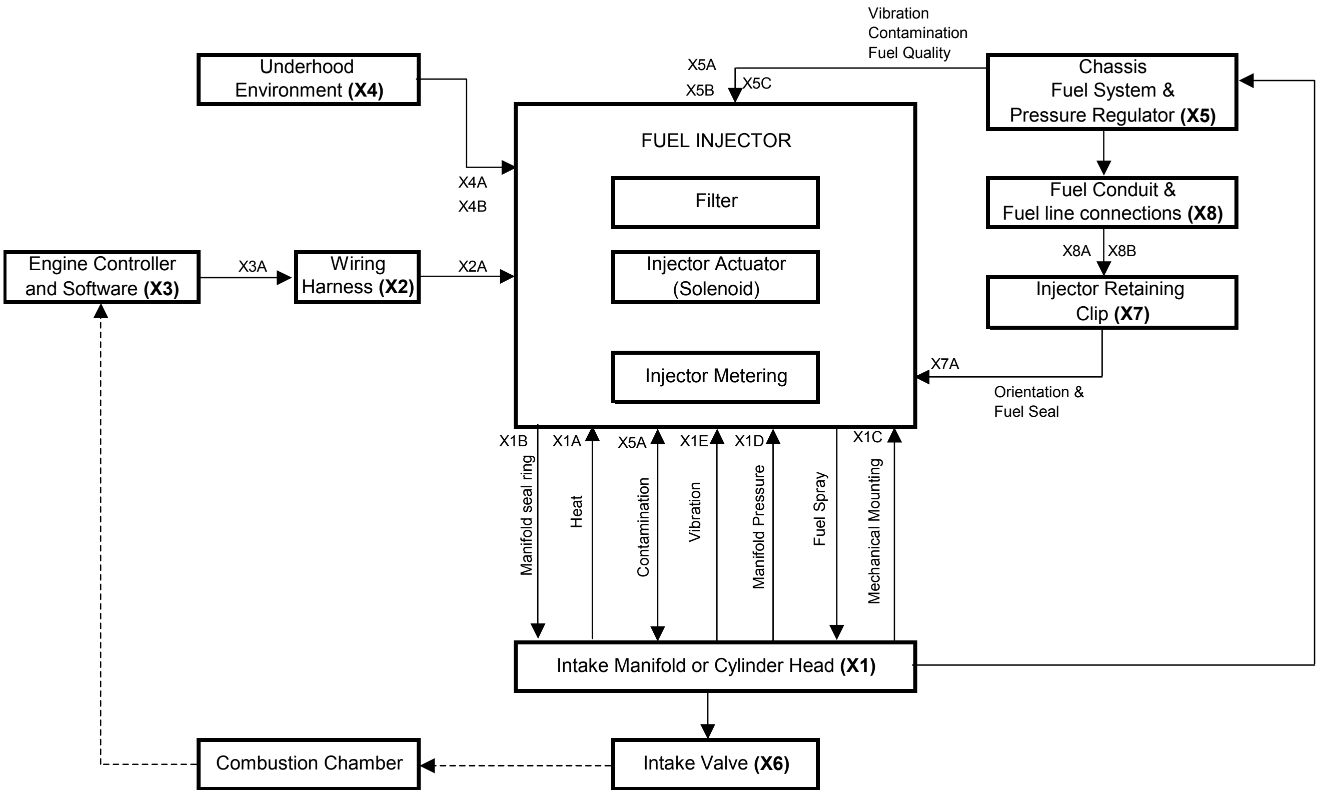


Figure 4-1 - Block Diagram

4.1.1 Interface Control Document

<table>
<tr><th colspan="5">INTERFACE CONTROL DOCUMENT</th></tr>
<tr><th>TO/FROM</th><th>INTERFACE NAME</th><th>INTERFACE ID</th><th>INTERFACE DESCRIPTION</th><th>SEE SECTION</th></tr>
<tr><td>To:
Vehicle Harness
X2</td><td>Wiring</td><td>X2A</td><td>Required for attachment, available from Delphi-P
• Refer to Section 4.4.2</td><td>4.4</td></tr>
<tr><td>To:
Engine Controller and Software
X3</td><td>Control</td><td>X3A</td><td>Provide interface for injector coil operation</td><td>4.4</td></tr>
<tr><td></td><td>Software</td><td>X3A</td><td>Software requirements:
A. Block-learn
B. Enable/Disable criteria
C. Injector scheduling
D. PWM output to injector
E. Diagnostics</td><td>5.2
5.3</td></tr>
<tr><td>To:
Manifold or cylinder head
X1</td><td>Orientation</td><td>X7A</td><td>Angle to direct fuel to intake valve</td><td>4.2.2</td></tr>
<tr><td></td><td>Seal ring seal or face seal</td><td>X1B</td><td>Provide seal between fuel injector body and engine vacuum</td><td>3.3.6
3.4</td></tr>
<tr><td></td><td>Mechanical Mounting</td><td>X1C</td><td>Provide mounting of injector in cylinder head of intake manifold</td><td>4.2.1</td></tr>
<tr><td>From:
Manifold or cylinder head
X1</td><td>Vibration</td><td>X1E</td><td>Verify vibration levels remain within component specifications</td><td>4.2.3</td></tr>
<tr><td></td><td>Vacuum Single</td><td>X1D</td><td>Fuel pressure regulator manifold pressure biasing</td><td>5.2.3.2</td></tr>
<tr><td></td><td>Contamination</td><td>X5A</td><td>Passages to and from the fuel injector must be clean and free from debris</td><td>7.3.4</td></tr>
<tr><td></td><td>Heat</td><td>X1A</td><td>Verify heat and temperature levels remain within component specifications</td><td>7.1</td></tr>
</table>

Interface Control Document continued				
To: Chassis fuel storage and handling subsystem X5	Vibration	X5C	Verify vibration levels and noise transmission paths to chassis	4.2.3
	Orientation	X8B	Packaging requirements must be met for design layout	4.2.2
From: Chassis fuel storage and handling subsystem X5	Fuel seal – injector to rail seal ring	X8A	Provide for fuel seal integrity for all applicable temperatures and pressures between fuel rail and fuel injector inlet	3.3.6
			Fuel validation for compatibility and calibration requirements	
	Fuel composition	X5B	Provisions must be made for minimization of fuel contamination	2.2.6
	Contamination	X5A		7.3.4
From: Underhood Environment X4	Ambient air flow	X4A	Provide sufficient ambient air flow for injector cooling	4.2.1
	Road splash	X4B	Provide protection from road splash	

4.2 Mechanical Interfaces

4.2.1 Locating the Fuel Injector

Properly locating the Multec 3.5 Fuel Injector on the engine contributes to satisfactory long-term operation. The recommendations provided below should serve as a guide for hardware planning.

Clearance

- To provide adequate air circulation to cool the injector and prevent heat transfer from the surrounding components, e.g., fuel rails and the intake manifold. (See Figure 4-2)

Road Splash

- Avoid mounting the fuel injector in a location where it will be exposed to excessive road splash or where water puddling can occur.

Vibration

- Avoid metal-to-metal or plastic-to-plastic contact between the injector and the intake manifold or fuel rail to prevent audible noise. (See Figure 3-10)

Temperature

- Locating the fuel injector tip in the cylinder head will significantly increase injector tip temperature, impacting hot restart performance.

Tip Location

- To prevent fuel collection at the injector tip and surrounding port surfaces do not recess the injector tip from the airflow.

4.2.1.1 Limits on Injector Position

The fuel injector should be located to meet the following requirements when analyzed at worst-case dimensional conditions for rail injector and engine:

- No injector interference when seated into the manifold / head.
- With the injector clip removed, no loss of fuel seal with rail socket.

Multec 3.5	**“A” Ref**
Long	**54.60**
Mini	**33.60**

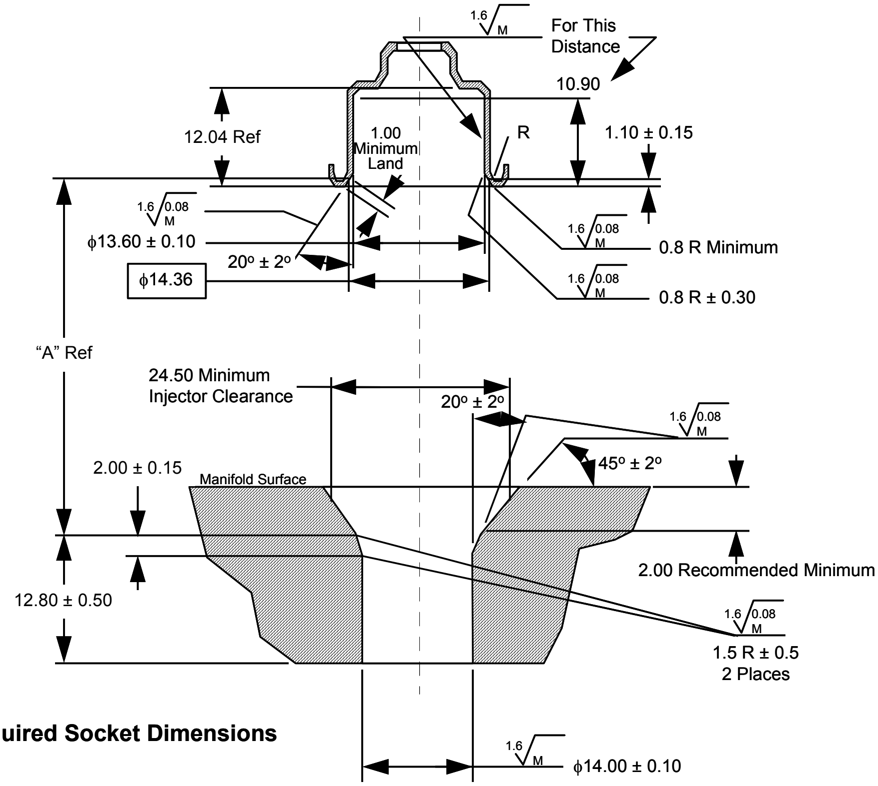


Figure 4-2 - Example of Recommended Mounting Feature Dimensions

4.2.2 Orienting the Injector

Injector spray targeting and combustion quality are interrelated and must be evaluated in the specific application (refer to Section 3.8 for information on injector targeting, placement and cone angle). An orientation tab on the injector solenoid engages the injector clip and allows the injector to be oriented rotationally relative the fuel rail. The fuel rail then supplies the specific feature for orienting the injector clip. See Figure 3-6.

4.2.3 Vibration Levels

4.2.3.1 Vibration Durability Requirements

Component vibration levels should be measured as soon as proper hardware is available to ensure that engine vibration is within acceptable limits.

Before a validation statement can be completed, the vibration levels need to be analyzed for each application.

If resistance to dynamometer engine vibration levels (usually higher than vehicle levels) is required, this should be communicated to the Delphi Design Engineer.

4.2.3.2 Vibration Measurement Techniques

The following vibration measurement procedure is recommended:

1. Use accelerometers to take vibration measurements in three orthogonal directions with respect to the injector — the axis through the mounting is longitudinal, perpendicular to the mounting axis is lateral, and through the injector is vertical. Sketch or photograph the accelerometers and locations, identifying the axis orientations with the data. To eliminate confusion when comparing data, it is imperative that a sketch of the part with the axis be included with the data sets.

2. Place the accelerometer on an appropriate mount. (Usually the fuel rail mounting bolt.)

3. If possible, attach a second accelerometer on the injector body to measure the response of the unit.

4. Once accelerometers with the proper charge amplification or signal conditioning are set up, run the engine and acquire data. Tape record measurements for later laboratory analysis.

   When tape recording data, set the recorder to a tape speed such that the minimum usable frequency range is 20-2500 Hz. Because engine vibration can be classified as stationary random, data must be taken and averaged. Twenty to 30 seconds of data are needed to get a true picture of the environment. Data should be at steady-state operating conditions, with the engine loaded as it typically would be during operation. A tachometer signal should be monitored and recorded to correlate engine rpm to the data.

   Steady state rpm data is necessary at idle, 1000, 1500, 2000… through redline. A slow speed sweep (three to five minutes in duration) from idle to redline should be made as well.

5. Data can be compared if they are presented in the format typically used at Delphi. RPM spectral maps and power spectra are needed. Use the following parameters for analyzing the data:

    - Hanning window
    - Narrow band analysis
    - Frequency band from 20-2500 Hz
    - Stable averaging and peak hold averaging for a minimum of 50 events
    - Overall RMS Level in a 20-2500 Hz frequency band
    - Identification of peak frequencies and level
    - Display graphs in Power Spectral Density (PSD in g^2/Hz) vs. Frequency (linear frequency axis and both log and linear axis for amplitudes).

    This procedure should be performed for each operating condition and axis. Figure 4-3 shows an example of how the data should be presented for steady state rpm conditions. Figure 4-4 shows a typical spectral map.

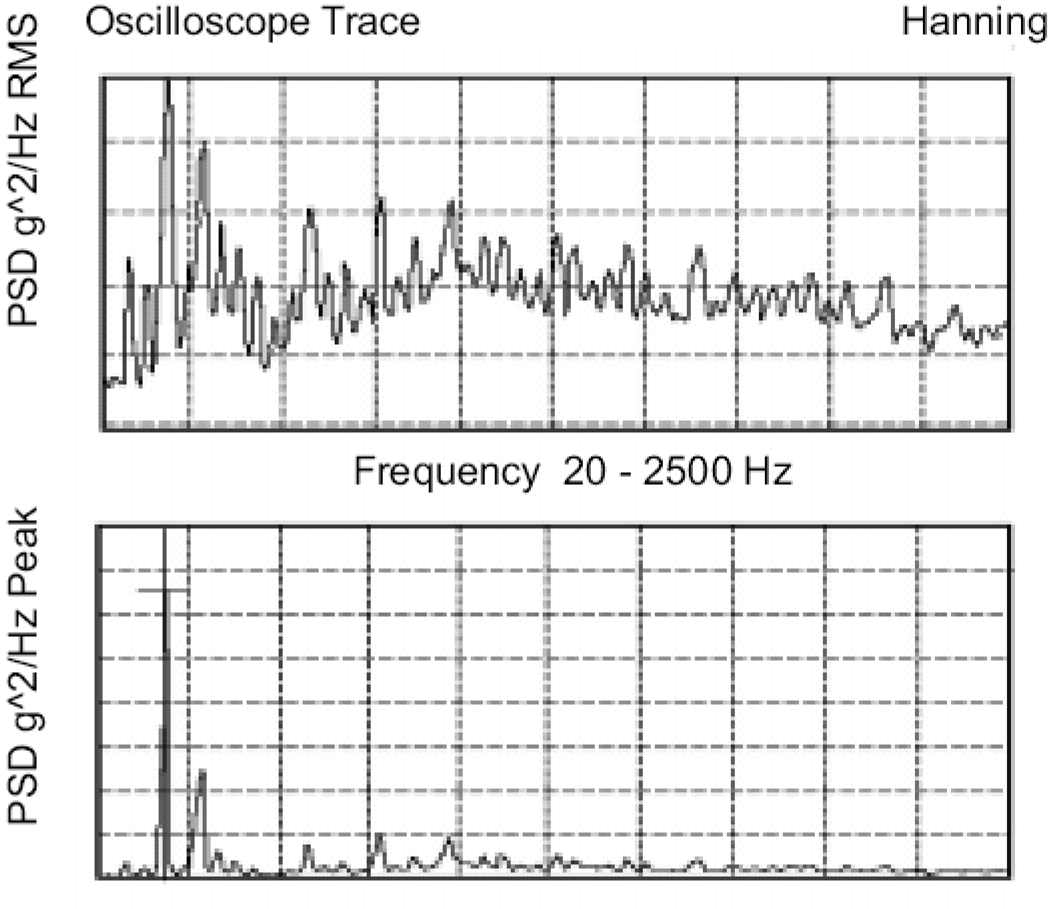


Figure 4-3 - Example of data presentation for steady state rpm.

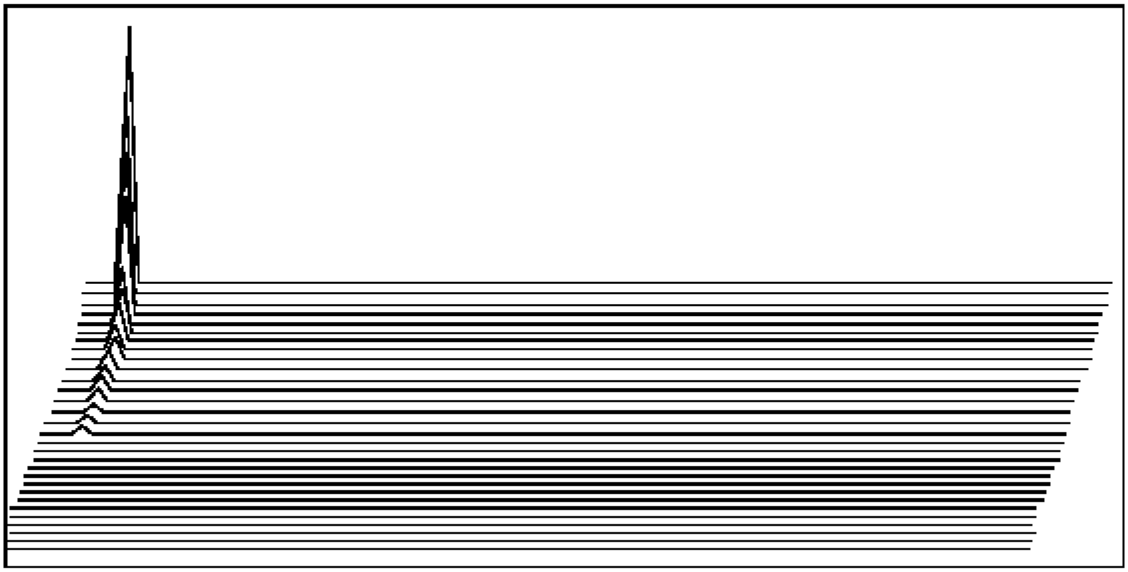


Figure 4-4 - Typical Spectral Map

4.2.4 Fuel Supply System Interface

Fuel is normally supplied to the injector by a fuel rail, which should be designed with the following characteristics in mind:

- Minimize pressure drop to injectors at maximum required engine flow rate.
- Minimize pressure variation between injectors during all operating conditions.
- Minimize pressure disturbances created by the injector opening and closing events, which may in some cases result in port-to-port flow variations.
- Consist of conduit of sufficient volume to temporarily store fuel vapor generated during hot soaks to prevent vapor from being ingested in the injector during engine re-start.
- Constructed of materials suitable for fuel / environment compatibility which will not degrade over time and contaminate the injector.

The chassis fuel supply system should be designed to supply adequate fuel flow and pressure over the intended operating range of the engine. Refer to section 2.3.

4.3 Seal rings

Seal ring seals are supplied with each injector. If replacement seals are required, use only Delphi-supplied replacement seal rings. Reference section 3.3.6

Note

Lubricate the seal rings with an approved lubricant or equivalent (see Table 6-2*) The lubricant application process must prevent lubricant from contacting the director plate, which could possibly restrict the injector flow.*

Caution

Do not use lubricant that will cause harm to oxygen sensors, (such as those based upon or containing silicone). Reference Delphi Oxygen Sensor Application Manual.

Warning

It is preferred to not reuse the seal rings when re-installing an injector. If re-use is necessary, carefully inspect each seal ring for any signs of damage, as even minor defects can lead to fuel / vacuum leakage. Always install injectors and seal rings using the recommended service procedures to avoid the possibility of a safety hazard. Seal ring lubricant is required to prevent tearing the seal during installation in its mating component.

Warning

When installing seal rings to the injector inlet, take extra care not to damage the seal on the injector top flange. See Figure 6-1.

4.4 Electrical Interface

4.4.1 Electromagnetic Compatibility

Generation:

The Multec 3.5 Fuel Injector should not produce any objectionable RFI in AM, FM, and CB bands. EMI/RFI can occur in two ways: radiated through surrounding air and conducted through connecting wires. Suppression of the EMI occurs in the injector driver circuit Zener diode.

Susceptibility:

The fuel injector should be isolated in such a manner that other electrical components cannot induce excess interference (EMI/RFI) levels into the injector's controls.

EMI/RFI measurements should be made at the vehicle level using the appropriate engine controller, injector drivers, and wiring.

4.4.2 Wire Routing

Electrical wiring to the injector should be routed so that conductors are protected from excessive heat, damage, and wear.

Avoid unnecessary handling (disconnecting and connecting) of the electrical connector.

The wiring should be of a gauge sufficient to handle the required injector current without causing a significant voltage drop over its length.

Caution

Wire lengths should be sized appropriately to prevent side loading the connector which can cause electrical disconnects:

- Strain on the connector due to wires that are too short
- Excess length that could allow alternate unintended wire routings that could place strain on the connector.
- Wiring that could become pinched between components during assembly possibly leading to a short circuit and full-on injector condition.

Caution

Do not share injector wiring with other components. Dedicated wiring is required. For other types of applications consult a Delphi application engineer.

4.4.3 Fuel Injector Polarity

The Multec 3.5 Fuel Injector utilizes a 2 terminal electrical connector. The terminals correspond to power and ground and are not polarity dependent for injector performance, yet a polarity has been established to reduce the severity of a coil short to the injector body from a full-on condition to a blown fuse. See Figure 4-5.

Best practice is to maintain consistent polarity during all injector testing and evaluation to minimize potential performance variation.

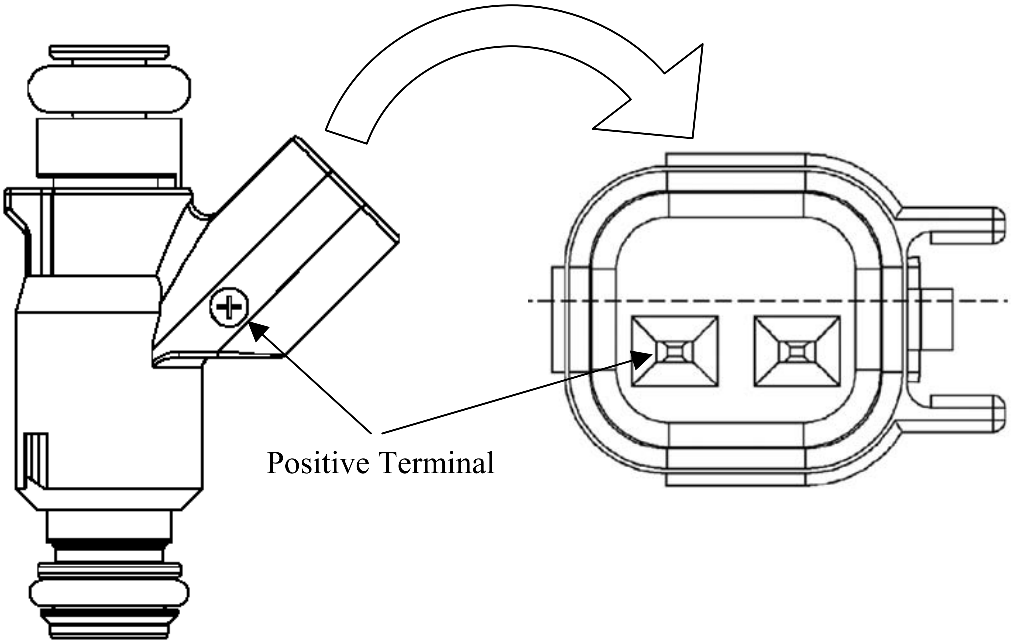
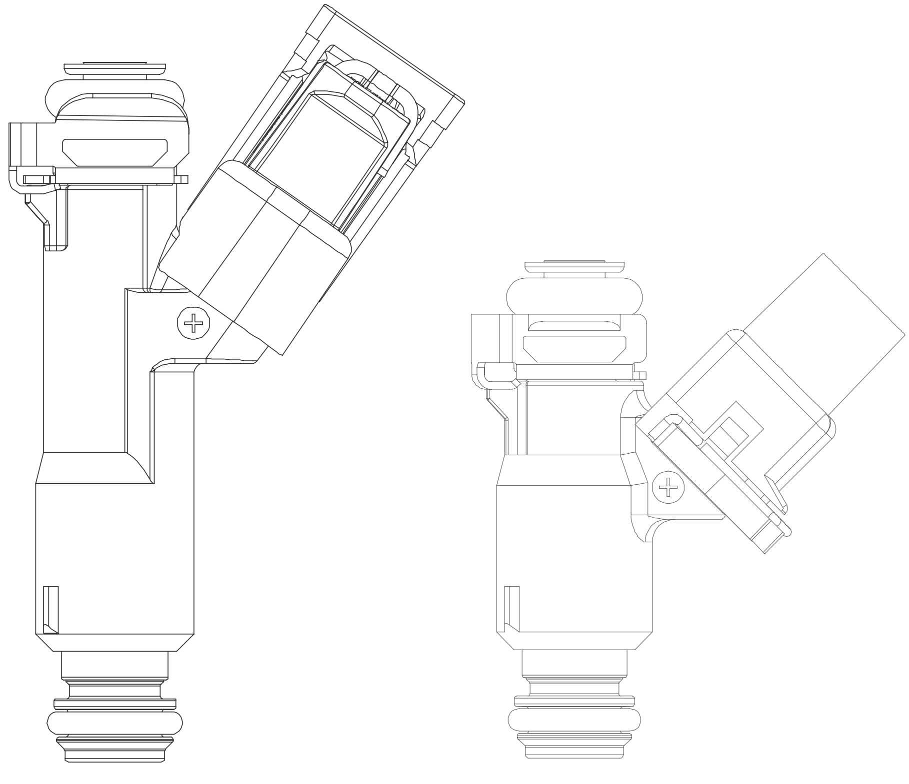


Figure 4-5 Injector Connector Polarity '+'

4.4.4 Fuel Injector Connector

- The Multec 3.5 injector is available with two electrical connector styles:
- "Metri-Pack" splash-proof type design
- USCAR standard connector design (immersion-proof)

The USCAR connector design is more robust to environmental exposure and is therefore recommended over the metri-pack design. Engine control systems that monitor the injector circuit continuity as part of on-board-diagnostics will benefit from the improved environmental resistance of the USCAR connection system.



USCAR Connector Metri-Pack Connector

Figure 4-6 - Injector Electrical Connectors

Metri-Pack design:

Component	Part Number	Description
Electrical Connector & Seal	12110179 or 12129140 or equivalent	Splash proof connector
Terminal	12077939 or equivalent	

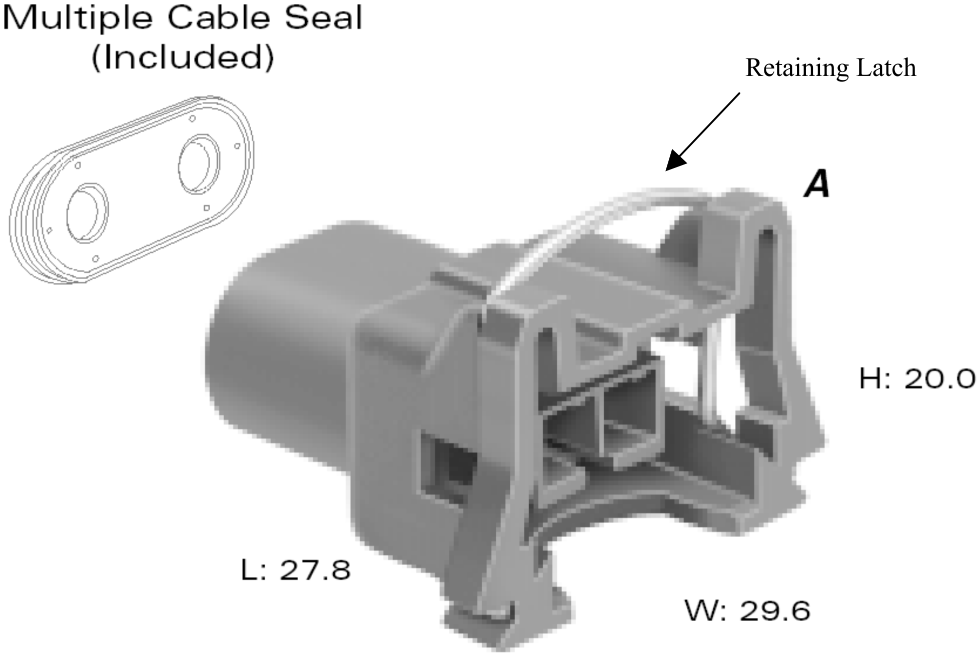


Figure 4-7 - Metri-Pack Harness Connector

USCAR 1.5 mm terminal connector design (SAE/USCAR-12 design guideline).

Component	Part Number	Description
Electrical Connector & Seal	15355226	USCAR mating connector
Cable Seal	12176807	Or equivalent
Terminal	12176636	
TPA	15326238	Terminal Position Assurance feature
CPA	15355227	Connector Position Assurance feature

Or Alternate:

USCAR 1.5 mm terminal connector design (SAE/USCAR-12 design guideline).

Component	Part Number	Description
Electrical Connector & Seal	15419715	USCAR mating connector
Cable Seal	15366021	Or equivalent
Terminal	12191818	Terminal supplied with Nyosil lubricant
TPA	15423278	Terminal Position Assurance feature
CPA	15423276	Connector Position Assurance feature

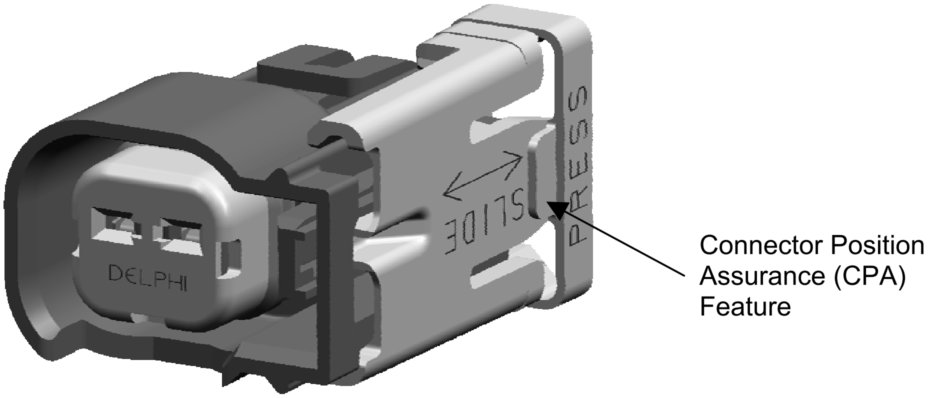


Figure 4-8 - USCAR Harness Connector

Note *It is recommended to use a non-wicking grade cable on the wires leading to the injectors. This is a commercially available product from Delphi - Packard Electric Systems. This is to address the failure mode of fuel wicking from the injector to the engine control module.*

Caution *Use of the Connector Position Assurance (CPA) feature on the USCAR version of the mating connector is recommended. The CPA is a secondary lock that provides verification that the mating connector is properly latched. This prevents false connections in which electrical contact is made, but the mechanical latching of the connector to the injector is incomplete allowing it to disconnect during usage.*

Note *Connector terminal lubricant is recommended to prevent fretting corrosion (see section 7.5)*

4.4.5 Controller

The engine controller calculates a pulse-width (PW) based on inputs from the various sensors, and delivers the signal to the fuel injector through an injector driver synchronously with the engine. There are two principal types of injector drivers: saturated switch and peak-and-hold. These circuits must be compatible with injector resistance and inductance. The Multec 3.5 injector utilizes the saturated switch injector driver.

See Section 3.6

The fuel injector driver circuit for the saturated switch injectors is pictured in Figure 4-9. Refer to Section 3.6 for additional injector driver information.

The types of electronic components used and the component specifications will affect the electrical output of the injector driver. Subtle changes in electrical output characteristics can have an effect on injector flow.

Where the vehicle application driver circuit differs from the standard Delphi recommendation, the differences should documented and understood relative to the injector flow calibration generated by Delphi on the standard driver. In some cases, the flow calibration data will need to be adjusted to compensate for the driver differences.

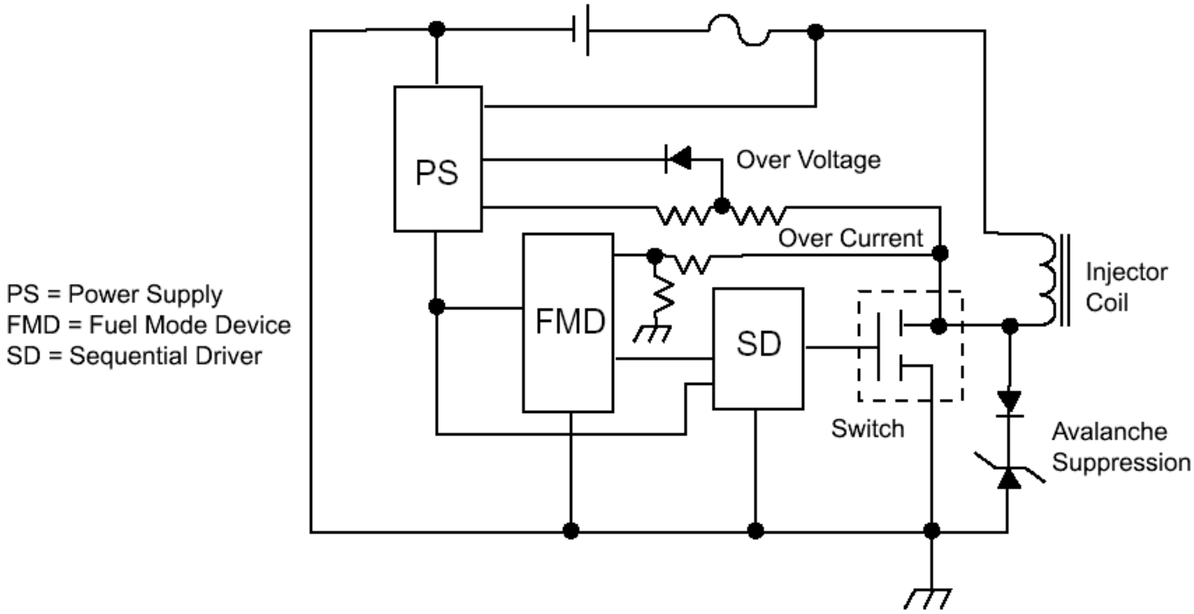


Figure 4-9 - Electrical schematic of saturated switch injector driver circuit

4.4.5.1 Avalanche Energy

A magnetic field is generated by the injector coil when the injector is turned on. This field breaks down when the injector is turned off inducing voltage into the injector coil (much like an ignition coil). However, instead of generating a spark, a voltage spike known as avalanche energy is created which must be absorbed by the injector driver creating heat. The energy the driver needs to dissipate when the inductive load is turned off is one of the most important factors limiting driver life. The engine controller must be configured to absorb or dissipate appropriate amounts of avalanche energy.

Injector avalanche energy is typically evaluated at the minimum and maximum operating temperatures and voltages. Typically, maximum single event avalanche energy and repetitive avalanche energy values are required for the controller. The avalanche energy for the Multec 3.5 injector is the same for all injector applications due to the common coil design. (See section 3.15.2.)

The avalanche energy is calculated using an oscilloscope to measure the voltage across and current through the driver during the injector shut-off transient. These curves are multiplied together and integrated over time to obtain the avalanche energy of the transient. (See Figure 4-10.)

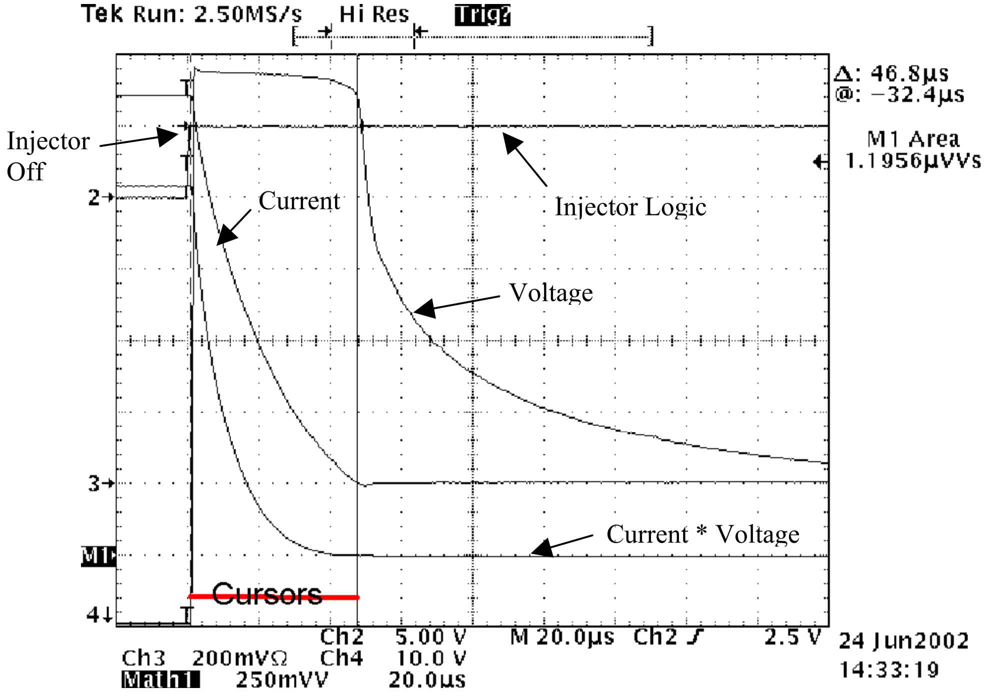


Figure 4-10 - Oscilloscope trace of injector avalanche energy measurement

5.0 Software

5.1 General

Refer to Section 2.2.1.1

An ideal air fuel (A/F) ratio provides minimum emissions and maximum fuel economy and driveability. For any given engine and vehicle operating condition, there is an optimum A/F ratio. It is the function of the engine controller's software to calculate the optimum A/F ratio for the existing conditions. The engine controller monitors the output of the engine and vehicle sensors, and uses this data to determine the correct fuel delivery requirements for the existing conditions. An injector pulse width is calculated from the fuel delivery requirements through a series of look-up tables and modifiers based on the injector flow performance at the current engine operating state. Pulse-width is a function of the following:

- Desired air/fuel ratio
- Air flow
- Corrections, sensor inputs (i.e., TPS, O2S, ECT, MAF, etc.)
- Injector flow characterization

Desired Air/Fuel Ratio

The desired air/fuel ratio is stoichiometric for steady state operation and normal operating temperatures during the emission test procedure for a closed loop system. As previously mentioned, stoichiometric is dependent on fuel — for gasoline it is approximately 14.7 to 1 (See Table 2-1). At this ratio, the fuel and air are in correct theoretical proportion for complete combustion, providing optimum fuel efficiency and a minimum of emissions. Stoichiometric operation provides the optimum trade-off in catalytic conversion efficiency for HC, CO and NOx (refer to Figure 2-2).

Air Flow

Airflow must be determined in order to achieve the desired air/fuel ratio and calculate pulse-width. The two methods used by the engine management system to determine airflow are speed density and mass airflow.

- **The speed density system** estimates airflow by calculating the amount of air through the cylinders. It uses Manifold Absolute Pressure (MAP) to determine density, engine speed (rpm), temperature of the A/F mix, volume per cylinder, calculated EGR flow, and volumetric efficiency (see section 5.2.3.1).

- **The mass airflow system** directly measures the airflow into the cylinders using a mass airflow sensor normally placed at the at the throttle body inlet.

5.2 Control Algorithms

The following closed-loop and open-loop software sections briefly describe engine and engine management system components that typically influence air/fuel control and thereby impact control of the fuel injector.

The system software has control algorithms to make corrections to injector pulse-width. Corrections are determined using closed-loop and open-loop feedback. Each correction has its own algorithm within the performance characteristics of the application specific software.

Note

The complexity and size of control system software and algorithms are driven by emissions and diagnostic requirements. The use of the following algorithms is dependent on government and customer requirements (some systems do not require closed-loop correction to meet performance and emissions goals).

5.2.1 Injection Methods

Refer to Section 5.2.5

There are four fuel injection timing methods. (See Figure 5-1.) Cost and emissions output play key roles in determining which of the four methods is used.

5.2.1.1 Simultaneous Single Fire (SSF)

Injectors are pulsed simultaneously once per engine cycle (i.e. once every two crankshaft revolutions). SSF is used during transitions to and from Deceleration Fuel Cut Off to avoid going below the minimum injector pulse-width. It is not recommended for use during idle or driving modes because it can cause problems with engine combustion stability.

5.2.1.2 Simultaneous Double Fire (SDF)

SDF pulses the injectors twice every engine cycle, or once per crankshaft revolution. But rather than alternately pulsing injector groups like ASDF, SDF pulses all the injectors at once. Each pulse-width is shortened, dispensing half the required fuel per engine event. SDF results in even more variation in fuel vaporization entering the cylinder, but is less costly than ASDF because there is only one injector driver.

5.2.1.3 Alternating Simultaneous Double Fire (ASDF)

Injectors are pulsed in groups twice every combustion cycle, once every crankshaft revolution (the amount of injectors in each group usually equals 1/2 of the number of cylinders). One half the required fuel for each combustion event is injected with each injector pulse. Compared to SFI, ASDF has more variation in fuel delivery to the cylinder, because of variations in when the fuel is injected relative to each cylinder event. It is less costly; since each injector group shares an injector driver, only two drivers are required. Also, a cam position sensor is not always required.

5.2.1.4 Sequential Fuel Injection (SFI)

The injectors pulse in sequence to the engine's firing order, one time every two crankshaft revolutions. This assures that each injector is pulsed in the same relative position to the cylinder event and prevents the spraying of fuel into an open intake valve. SFI does require a cam position input to correctly pair respective injectors and cylinders. Fuel injection is timed relative to the opening of the intake valve. This system provides the best cylinder-to-cylinder consistency in fuel delivery.

Note *System dynamic range is affected by the injector firing method.*

5.2.1.4.1 Make-up (Trim) Fuel Pulses

When SFI is utilized, make-up fuel pulses may be added to the commanded fuel pulse to more accurately fuel a cylinder for a given event if sufficient time is available prior to the intake valve opening. The benefit is better air/fuel control resulting in improved emissions.

Note The make-up fuel pulses are usually small in amount resulting in very low pulse widths – increasing the performance requirements of the injector.

Note Software schemes using make up fuel pulses increase the durability requirements of the injector. Normally injector cycles are directly related to the number of engine revolutions. Make-up pulses increase the number of injector cycles beyond this.

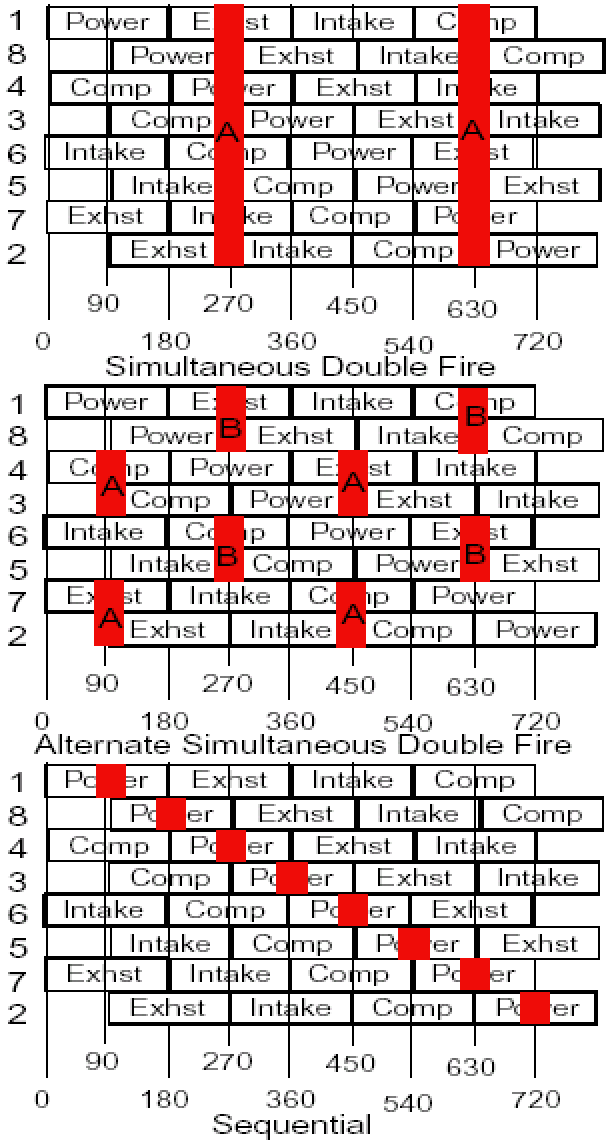


Figure 5-1 - Injector Firing Schemes (red bar = injection event)

5.2.2 Open Loop Injector and Fuel Rail Characterization

For ease of calculation and calibration, the engine controller's software assumes the injector is a linear device. As a linear device, the injector can be characterized by the slope in the traditional Y = M*X + B equation of a line.

In most fuel systems, fuel flow rate varies linearly and proportionally with injector on-time. Y = M*X + B can be used to effectively model "fuel flow" vs. "on-time."

Y = Fuel flow (grams/sec)

M = Slope (grams/sec/msec)

X = Pulse-width (msec)

B = Y intercept (grams/sec)

Note It is best if the slope and intercept are determined by flowing a fuel rail assembly. This will then include pressure regulator effects (for a recirculating fuel system) and rail pressure dynamic effects. Injector only flow data can only be used for initial approximation.

Note More sophisticated models of the injector flow curve can be developed from the empirical flow data to include the non-linear nature of the curve at very low pulse widths.

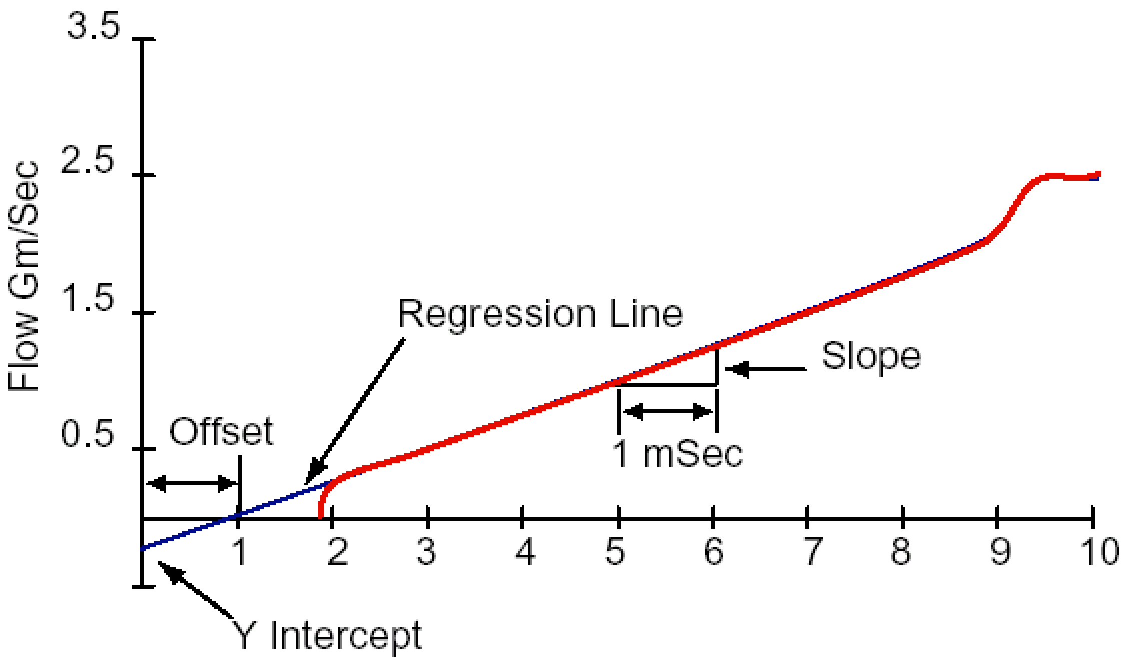


Figure 5-2 - Slope and intercept graph (Flow vs. Pulse Width)

The actual calculation process in the engine controller is as follows:

1. The offset is assumed to be zero and the desired injector pulse-width is calculated from the inverse slope (msec/gram/sec). This is called the intermediate Base Pulse-width (BPW).

2. For software sets including low pulse-width correction, if the BPW is less than specification, then the low pulse-width correction is applied.

3. The BPW is then compared to the minimum PW. If the BPW is less than the minimum allowable PW, the BPW is set to the minimum PW, or the injector firing scheme is altered, to increase the PW above the minimum.

4. The X intercept (injector offset) is then added to the final BPW, forming the total PW that is delivered by the engine controller.

Note: Demand (or returnless) fuel systems where fuel pressure is not biased for manifold vacuum require the injector slope and intercept to be measured as a function of injector tip vacuum at a constant fuel gauge pressure. (Vacuum levels of 0 to 80 kPa in 20 kPa increments are typically used.)

5.2.2.1 Injector Slope

The injector slope characterizes the maximum injector flow. The slope term correlates very closely to static flow and is constant over a wide range of battery voltages, although it does vary with pressure — the higher the pressure, the steeper the slope. The slope term is obtained using the following method:

1. A flow curve for the fuel rail assembly that measures each port's flow is taken at 13.5v at a constant repetition rate. Flow points are determined by the injector firing scheme.

2. A linear regression is done for the flow based on the points determined in step 1.

3. The linear regression is then used to determine the slope and offset (which is used in section 5.2.2.2).

Note

Do not use the actual static flow point from the flow curve because most injectors deviate rich near static flow (see Figure 3-14). Also, do not use the "offset" from the flow curve. The engine controller initially assumes a zero offset and then makes corrections later.

4. If the flow data is a measurement of total rail flow rate rather than individual cylinder flow rate, divide the slope by the number of cylinders.

Note

It is a good practice to use an average of several fuel systems' flows (minimum 3) to calculate the fuel system slope and offset.

5.2.2.2 Injector Offset

Since the injector flow curve does not go through the origin, an "offset" is needed (See Figure 5-2). "Offset" refers to the amount of time that is added to (or subtracted from) the engine controller-calculated pulse-width. It is a function of voltage and pressure.

Offset can be determined by doing the following:

Method 1

- Flow the fuel system at the same voltages (and manifold vacuums for non vacuum biased fuel systems) as in the offset table in the vehicle software. Calculate a linear regression at each test condition.
- Note the points where the regression line intersects the time-axis at each voltage and vacuum (x-intercepts) and enter them into the table (refer to Figure 5-2).

Method 2

- Use the average regression line slope at 13.5 injector volts. Intersect this slope with the average per cylinder flow at each voltage and a specified pulse-width. The pulse-width selected should represent a typical, highly used injector pulse-width during the vehicle emissions test procedure, and falls within the linear portion of the flow curve.
- Extrapolate the regression line until it intersects the time axis at each voltage and enter them in the table.

Note It is only necessary to use voltages that cover the operating range of the engine controller.

Note For systems using a vacuum biased regulator, the pressure drop across the injector and resulting slope term is typically constant. A single set of injector offsets can be used independent of engine vacuum.

Note For non-vacuum biased systems, the injector slope varies with the pressure drop across the injector. Injector offsets will be affected by this change in slope. Fuel rail flow characterization will include measuring the offset change vs. both injector voltage and manifold vacuum.

5.2.2.3 Low Pulse-Width Correction

The Low Pulse-Width Correction table is used to compensate for the difference between the linear approximation of the fuel flow and the actual fuel flow at small pulse-widths. The correction effectively extends the dynamic range of the fuel system by decreasing the minimum usable pulse-width. (See section 3.10.2)

Most software can correct pulse-widths of approximately 3.9 ms and lower. (This correction varies with the control software.) Some software contains a table bias term, which is another variable that allows the table to correct for rich, lean, or rich and lean flow deviations.

Note Cylinder to cylinder flow variation increases as pulse-widths become very short.

A very low pulse-width, such as during hot idle, is non-linear but it can be corrected, using the low pulse-width correction. Low pulse-width corrections are independent of voltage corrections.

Values for the correction table are obtained by flowing an average system or several systems at the values of the table plus the injector offset using characterized, mean-limit injectors (Flow point = table value + X intercept @ 13.5v). For non-vacuum biased systems, this flow test should be made at a manifold vacuum that is representative of injector low pulse width operation conditions.

Note This is necessary because the table corrects the BPW and not the total pulse-width. In other words, the low pulse-width correction is done before the injector offset is added-in, and this is done to correct the total output pulse-width.

5.2.2.4 Low Voltage Correction

Low voltage correction is required as system operating voltages decrease below the normal operating range. As operating voltage decreases, injector opening response increases resulting in reduced fuel flow. Pulse-width (PW) is increased to compensate. A software correction table is calibrated for this use.

Flow changes due to voltage change are converted through the offset value (refer to Figure 5-2). These flow changes are a non-predicted deviation from the actual regression line, which become a simple table of correction versus predicted values. It is necessary to normalize pulse-widths to assure a smooth transition. Several spreadsheet programs have been written to automate this entire process and are highly recommended.

5.2.2.5 Minimum Pulse-Width (MPW)

Minimum BPW is a user-defined point below which the injector will not be operated. This is typically defined as a point where the actual injector flow deviates significantly from the predicted linear flow through either non-linearity or excessive variation.

- For control software that has low pulse width correction (see section 5.2.2.3), compensation can be made for the non-linearity, so the injector population variation is the determining criteria for minimum pulse-width. Injector to injector flow variation increases as pulse widths decrease from the set point (2.0 ms PW.) The working flow range calculation quantifies the 3-sigma variation vs. pulse width (see section 3.10.2.) SAE J1832 defines the 5% variation value as the criteria to calculate the working flow rage value. For use in the vehicle calibration, the variation limit should be determined in conjunction with the system calibrator. Injector to injector flow variation will result in cylinder-to-cylinder A/F deviation. (For example, at 14.7 A/F nominal a +/- 7 % flow variation will result in a +/- 1 A/F variation cylinder to cylinder.)

- For control software that does not have low pulse width correction, both the non-linearity of the injector (LFR) resulting in a mean shift, and the part-to-part variation (WFR) resulting in cylinder-to-cylinder A/F variation should be taken into account when determining the minimum pulse width to use for the application.

The minimum BPW is typically a 2-byte variable referred to in software for synchronous and asynchronous operation.

Note *Minimum PW is expressed in terms of BPW and does not include the injector offset term.*

If the system requires operation below the minimum operating pulse-width, the following is recommended:

- A double-fire system may switch to single-fire or asynchronous operation.
- Deliver minimum pulse width calibration value.

5.2.3 Open-Loop Characterization

Open-loop characterizations are based on fixed, predetermined engine and fuel system characteristics. Error driven feedback loops do not exist in open-loop characterizations; instead, characterizations are based on what happens in an average engine and vehicle with average components during expected operating ranges. The goals of optimum open-loop characterization are to: attain the required air/fuel ratio with the least amount of closed-loop correction, and to provide best driveability and minimum emissions during warm up before closed-loop feedback is possible. When air/fuel ratios need to be rich or lean of stoichiometric, open-loop characterization determines the accuracy of the actual delivered air/fuel ratio.

5.2.3.1 Volumetric Efficiency (VE)

Volumetric Efficiency corrects the base pulse-width for pumping inefficiencies and various errors inherent in the system. The speed density equation assumes perfect induction, combustion, and exhaust. Since this is impossible, the VE correction is used to model system flaws based on engine speed and load.

The VE calibration is the basic building block for fuel delivery.

The VE table is calibrated to achieve a stoichiometric air fuel ratio at all conditions.

5.2.3.2 Vacuum Biasing

For ease of fuel calibration, it is desirable to maintain a constant pressure differential across the injector. This is achieved through referencing the fuel pressure regulator to manifold vacuum. This maintains a constant pressure differential across the injector, keeping slope constant. This makes injector "on" time (and flow) become a simple prediction based upon the injector slope.

Newer demand fuel systems (returnless) locate the pressure regulator at the fuel tank where vacuum biasing is not practical. For demand fuel systems the pressure drop across the injector pressure changes with engine vacuum. Correction tables for slope and injector offset vs. engine vacuum are required. See section 5.2.2 for notes on Demand Fuel Systems.

Note *Useable injector dynamic range is reduced without vacuum biasing. (See section 3.6.4 for pressure compensation.)*

5.2.3.3 Variable Fuel Pressure Compensation

Fuel systems capable of variable fuel pressure control will require injector flow data over a wider range of injector pressure differentials (pressure differential = fuel pressure + engine vacuum). The control system will typically use the differential pressure to look up the injector slope and intercept for the current operating point.

Variable fuel pressure can be used to enhance injector flow range by reducing pressure at low fuel consumption conditions to increase minimum commanded pulse widths. Likewise, during maximum power conditions the fuel pressure can be temporarily boosted to increase injector flow if the pump has sufficient capacity.

5.2.3.4 Altitude/Barometer Correction

Altitude/barometer correction is used to compensate for changes in air density at different altitudes.

5.2.3.5 Engine Coolant Temperature (ECT)

The engine coolant temperature signal is used to compensate fueling during warm-up. Due to the lower fuel vapor formation rates at cooler temperatures, the ECT signal schedules richer air/fuel ratios to achieve a combustible mixture in the cylinder. ECT can be used alone or in conjunction with intake air temperature (IAT).

5.2.3.6 Intake Air Temperature (IAT)

Early systems did not use IAT but relied strictly on ECT. Air density varies with air temperature (i.e., hot air is less dense than cold air), and air density changes directly affect the air/fuel ratio. On speed density systems, intake air temperature is used to determine changes in air density so injector pulse-widths can be adjusted to achieve the required air/fuel ratio.

Certain conditions reduce the effectiveness of the ECT in predicting charge temperature (i.e., when the engine is warm and ambient air temperature is cold). In these situations, the IAT gives a better indication of the condition of incoming air temperature.

5.2.3.7 Manifold Absolute Pressure (MAP)

MAP is used to measure air density in speed density fuel systems. Air density is an indication of air mass going into the cylinder and is used to adjust fueling.

5.2.3.8 Power Enrichment Mode (PE)

To obtain maximum power, it is necessary to enrich the A/F to a value rich of stoichiometric. This ensures that all cylinders have sufficient fuel for maximum power. PE is typically based on TPS and can vary with rpm, altitude, etc. Rich A/F ratios result in increased emissions; therefore it is critical to avoid PE during the emissions test schedule.

Final PE A/F ratios may be affected by the need to further enrich the mixture to reduce exhaust temperatures to protect pistons, exhaust valves, etc., from damage.

5.2.3.9 Catalytic Converter Protection Mode

Under certain conditions, catalytic converter temperatures can exceed manufacturer recommendations. An option to reduce temperature in the converter is to add additional fuel (catalytic converter protection mode). Resulting A/F ratios may be richer than power enrichment A/F ratios. Injector flow rates must be sized to include this factor.

5.2.3.10 Individual Cylinder Fuel Trim vs. Adaptive Multipliers

Often times there are cylinder-to-cylinder A/F imbalances. These imbalances can be compensated for through development work and incorporation into the software of individual cylinder fuel trim constants.

5.2.3.11 Steady State Conditions

Steady state conditions are engine changes that occur slowly, (i.e., stabilized operation with no or extremely slow changes in speed, load, temperature, etc.). Steady state conditions are easiest to predict.

5.2.3.12 Transient Conditions

Transient conditions are those conditions that require an adjustment of fueling based on larger or more rapid changes in throttle position or engine RPM than can be accommodated through the normal closed-loop control.

Acceleration Enrichment (AE)

During acceleration, the change in airflow rate to the cylinder is faster than the control system's corresponding adjustment to the fuel flow rate. In addition, the decrease in manifold vacuum (increase in MAP) causes fuel to be deposited on the manifold walls. Extra fuel is added during acceleration to compensate for and maintain the proper A/F ratio in the cylinder

Deceleration Fuel Enleanment (DE)

During deceleration, the fuel on the intake manifold walls is evaporated due to the reduction of pressure (decrease in MAP), resulting in more fuel to the cylinder. To compensate, a correction factor causes less fuel to be pulsed from the injectors to maintain the proper A/F ratio.

Deceleration Fuel Cut Off (DFCO)

During more extended overrun (low MAP) conditions, such as going down a long hill, it is desirable to completely turn off the injectors. This is necessary, as combustion at extremely low MAP's is unstable, which can result in high emissions and potentially high converter temperatures. Added benefits of DFCO can be reduced fuel consumption and lower emissions. Transitions from fuel-off to fuel-on must occur smoothly.

Wall Wetting, Fuel Puddling

Even with careful injector targeting, a certain amount of fuel overlaps the intake valve and hits the walls, reducing the amount of fuel for that pulse. Fuel may also accumulate and puddle on the walls during rapid changes in intake manifold vacuum and airflow. Accumulation of fuel will also occur at high manifold pressure (low vacuum). When vacuum increases, this accumulated fuel vaporizes and is drawn into the combustion chamber, increasing the amount of fuel for each pulse. Algorithms are used to compensate for these conditions.

5.2.3.13 Engine Starting Conditions

Certain requirements during engine start-up need to be met in order for the engine to start. For example, fuel does not vaporize well at low temperatures such as in a cold engine, so more fuel is needed to achieve combustible air vapor ratios in the cylinder to start the engine. During hot start, fuel vapor is excessive and may require compensation. Also, oxygen sensors are inactive at start-up and cannot monitor the air/fuel mixture. Various corrections are used to address these starting conditions.

Prime Pulse

In some applications, a prime pulse of fuel is injected (based on coolant temperature) at the start of cranking to start the engine faster.

Crank Fuel

Crank fuel is delivered while cranking before the engine starts to run. The exact amount is determined by engine parameters.

Crank-to-Run Fuel Decay

Following start-up, the temperature of the engine increases and the air/fuel ratio is gradually enleaned. Crank-to-run fuel decay is essentially the transition between crank to run. Properly timed enleanment reduces emissions without causing engine stalls or acceleration sags.

5.2.3.14 Engine Protection

Engine Speed Limiters

Engine speed limiters shut off the fuel when the engine goes above a predetermined speed (RPM), to avoid engine damage. Hysteresis is recommended to minimize driveline backlash.

Top Speed Limiters

Top speed limiters shut off the fuel when the vehicle goes above a predetermined speed (MPH or KPH).

Fail Soft (Limp Home)

If a sensor fails, the vehicle will still operate by using the remaining sensors to predict the failed sensor's reading. However, driveability and emissions may be affected. As an example, if the mass air flow sensor fails, the system could switch to speed density operation.

Fuel Pump Correction

A decrease in fuel pressure causes a decrease in the flow from the injectors. As system voltage decreases, such as during a crank condition, voltage to the fuel pump is also reduced, resulting in reduced fuel flow and pressure to the injectors. A correction factor increases the pulse-width proportionally to compensate for the reduction in fuel pressure.

5.2.4 Closed-Loop Corrections

Oxygen sensors are located in the exhaust system and must be heated to 200 – 300°C (392 - 572°F) before they become active. Also, the catalytic converter's ability to remove hydrocarbons, carbon monoxide and oxides of nitrogen is reduced until the converter reaches operating temperature. Seventy percent or more of the total vehicle emissions during an EPA test cycle are generated before the catalytic converter reaches operating temperature. To reduce time to activity and improve emissions, some O_2 sensors are electrically heated internally. Also, spark timing can be retarded to help raise exhaust temperature and assist the O_2 sensor and catalytic converter in warming up.

Closed-loop systems use feedback from the oxygen sensors to maintain the correct air/fuel ratio. Most automotive oxygen sensors are made of zirconia. This ceramic material will produce a voltage in response to the amount of unused oxygen in the exhaust stream. It does this by comparing the amount of oxygen in the exhaust to the amount of oxygen in the air. When the exhaust is lean (excess air), the sensor produces a low voltage (near zero volts). When the exhaust is rich (excess fuel), it produces a high voltage (up to one volt). V6 and V8 engines with a split exhaust system may have separate oxygen sensors for each bank. Under these conditions, the air/fuel ratios for each bank are controlled separately.

Closed-Loop Correction is a system for fast correction of air/fuel ratio variations. <u>Proportional correction</u> is a calibrated step change in BPW (faster) each time a rich or lean error occurs. The size of the correction is intended to toggle the oxygen sensor between rich and lean conditions when the air/fuel ratio is close to stoichiometric. Integral correction is a slower (several milliseconds and smaller) step change. The amount of correction increases in relation to the length of time that the error exists. The ability of both of these systems to correct and control the air/fuel ratio depends on the control system's loop time, the optimization of calibration and the performance of the components.

The adaptive multiplier, also called the long-term fuel trim, corrects durability, engine tolerance, system tolerance and flow or output shifts that occur over time, such as changes caused by wear. The corrections are based on a block-partitioned graph of engine speed (RPM) versus engine load (throttle position). The long-term fuel trim has corrections for each block.

Note

Limits should exist on short term and long-term authority. The limits should be picked to avoid driveability or emission problems, while comprehending normal system tolerances. The customer must define the limits for each given application.

Fuel system component limit testing is encouraged to evaluate the control system response. Components with flow and pressure set at the limits of production and durability tolerances in order to create lean and rich limit conditions should be evaluated with the production engine control system as part of production validation. (See section 8.4.13)

In lieu of building limit components, modifications to the flow calibration software tables can be made to simulate these conditions.

5.2.5 Fuel Injection Timing

Previously, Figure 5-1 illustrated the different injector firing schemes. ASDF, SDF and SSF systems provide the greatest variation in fuel preparation and residence time. Open intake valve fuel injection cannot be avoided for these firing schemes.

Sequential firing schemes allow for optimizing fuel injection timing to maximize fuel at intake valve residence time and avoid most cases of open intake valve fuel injection. Figure 5-3 below is an example of optimum timing for a representative emissions test operating condition.

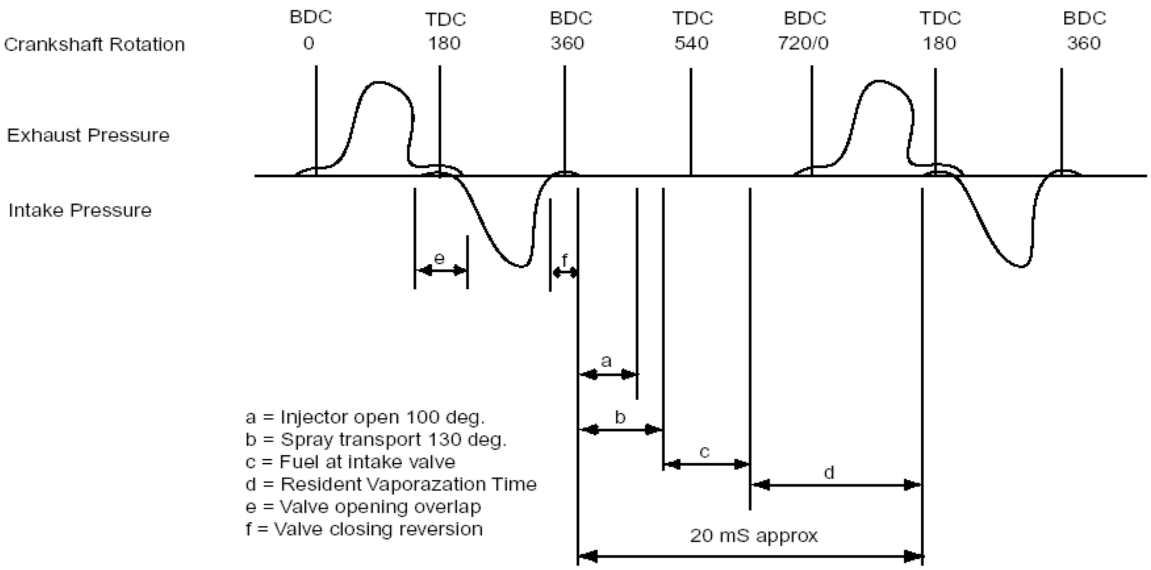


Figure 5-3 - Sequential injection timing considerations (4500 rpm)

The following factors affect fuel residence time in the manifold and need to be considered when calibrating injection timing:

- As RPM increases, the time available between valve open events decreases and the fuel pulse-width and fuel transport time in crank angle degrees increases. These effects combine to reduce the fuel residence time.
- Reversion air pulse occurs at valve closure. This can affect the injector spray geometry, causing increased manifold wall wetting. Delaying injection timing slightly can reduce disruption of the spray.
- During intake and exhaust valve overlap, exhaust gas will flow past the intake valve heating and displacing liquid fuel still on the intake valve. This will aide in fuel vaporization. If fuel spray timing is late, this back flow of exhaust can disrupt the spray geometry.
- Increasing fuel injector to valve distance will increase fuel transport times and reduce fuel residence time.
- the actual spray particle velocity varies throughout the cross section of the spray. Smaller particles slow down faster and take longer to get to the valve. For longer pulse-widths some of these smaller particles may arrive at the valve when the valve is open.

For some engine applications and conditions, the injection timing may require modification from the optimum fuel residence time goal. Airflow and reversion pulses from other cylinder valve actuations may displace fuel metered at the intended port. Occurrence of this is highly dependent on fundamental engine and intake port design (i.e. relative locations and sizes of port areas). In this case, delaying the arrival of fuel at the intake valve (closer to valve opening) may reduce port fueling errors.

5.3 Diagnostics

5.3.1 Fuel Trim Diagnostics

The long-term correction has defined limits on the amount of correction it can make to fuel injector flow. On some systems, if the flow has shifted to the extent that emissions will increase by a predetermined percentage, the Malfunction Indicator Lamp (Service Engine Soon) will illuminate, and a diagnostic trouble code will be stored in the engine controller. Shifts of this magnitude indicate that something in the engine control system is incorrect. Possible causes could be, but are not limited to, problems with the following:

- Injector
- Fuel pressure regulator
- Fuel pump
- MAP sensor
- Vacuum leaks
- O2 sensor
- Wiring
- Purge system

Note

Fuel injector limit-durability-parts need to be tested in conjunction with other air/fuel components impacting this diagnostic. On some software systems, limit-parts can be simulated through calibration changes to test diagnostics. Delphi can assist in guiding customers.

OBD II regulations require three specific types of diagnostic tests: component tests, systems tests, and ECM/PCM tests. A diagnostic test failure that results in more than an allowable increase in emissions is required to illuminate the MIL (Malfunction Indicator Lamp). The allowable emissions increase is set by the regulating authority.

A fuel injector flow rate shift may be diagnosed as a fuel trim too rich or too lean condition.

5.3.2 Oxygen Sensor Diagnostics

The signal of an oxygen sensor normally swings up and down between about 0.8 and 0.2 volts one or more times every second. A condition of mal-distribution can cause the pre-converter oxygen sensor to oscillate at the frequency of the engine (RPM). If the oxygen sensor oscillates above a certain limit, the Malfunction Indicator Lamp will illuminate and a diagnostic trouble code will be stored in the engine controller. Other potential oxygen sensor failure modes include: high sensor voltage output, low sensor voltage output, or no activity detected.

Note *Consult the oxygen sensor applications manual for additional details.*

5.3.3 Catalytic Converter Diagnostics

The oscillation of the oxygen sensors can also determine if the catalytic converter is working properly. The signal of the pre-converter oxygen sensor normally swings up and down between about 0.8 and 0.2 volts one or more times every second. When the converter is warmed up and operating correctly, the signal from the sensor behind the converter will switch over very slowly. It is not unusual for the signal from this sensor to stay at either high voltage (greater than 0.8 volts) or a low voltage (less than 0.2 volts) once the converter is at operating temperature. When it switches between high and low at a rate and amplitude similar to the pre-converter sensor, this can be an indication of a faulty catalytic converter.

5.3.4 Injector Driver Diagnostics

By looking at current flow to the injector, this diagnostic ensures that engine controller injector drivers, injectors, and wiring harnesses are working properly.

5.3.5 Engine Misfire Diagnostics

An excessive rich or lean shift of an injector may cause a rich or lean air/fuel ratio that is either non-combustible or very weak. This can ultimately result in engine misfires. Diagnostics detect engine misfires that exceed a predetermined percentage of combustion events. Engine misfire can be detected through crankshaft deceleration or ion sensing in the combustion chamber using the ignition circuit. Engine calibration engineers should determine what air/fuel ratio causes the onset of misfires, and calibrate diagnostics to recognize the fuel flow condition that causes misfiring.

Note *Rich or lean injectors are not the only potential cause of misfires. Other potential causes could be: base engine, ignition system, etc.*

5.3.6 Factors Affecting Engine Diagnostics

- Air calculations
- Temperature
- Manifold pressure
- System voltage errors (voltage drop due to vehicle wiring)
- Gain consideration (electrical and mechanical)
- Adequate fuel system capacity
- Actual volumetric efficiency may be different
- Canister purge rates
- Injector sensitivity
  - Spray
  - Targeting
  - Injector temperature
  - Manifold pressure
  - System pressure dynamics
  - Pressure gain of system (especially with remote mounted fuel pressure regulators)
  - Fuel type

6.0 Product Handling

The purpose of this section is to become familiar with the Delphi recommended handling procedures for the Multec 3.5 Fuel Injector. These recommendations cover storage practices and all handling that may occur from the time the injector enters until it leaves the customer's plant. Use this information as a guide for product handling.

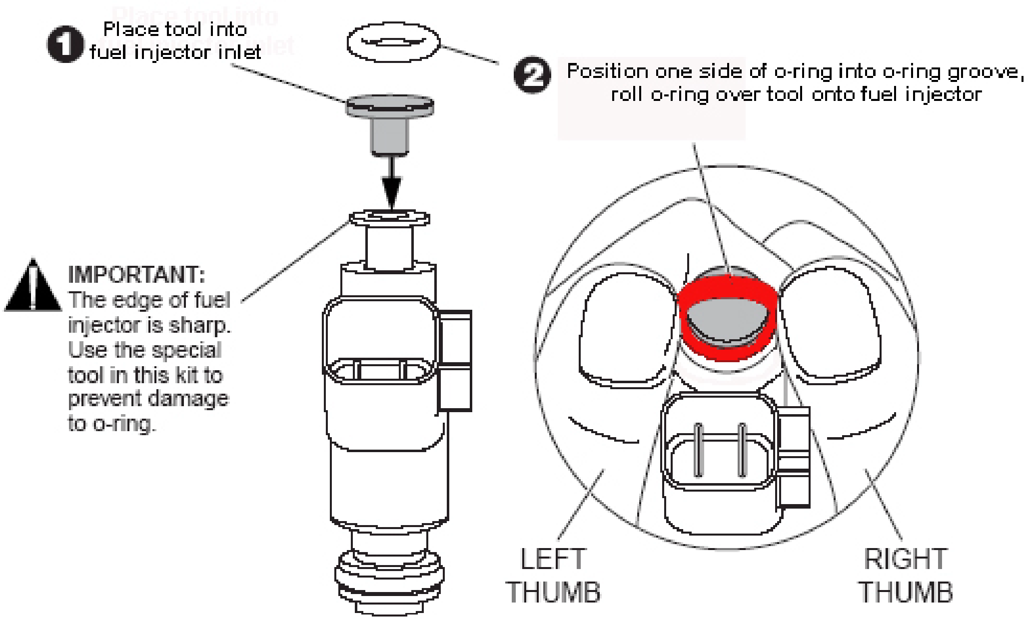
Table 6-1 lists recommendations for handling the Multec 3.5 Fuel Injector.

Table 6.1 — MULTEC 3.5 FUEL INJECTOR HANDLING

ACTION	REASON
DO NOT: Re-use injector seal rings if at all possible. If no other choice exists, take extra care in inspecting the seal rings for damage.	Leakage.
DO NOT: Interchange seal rings from Multec 1, Multec 2 and Multec 3.5 injectors. Use proper seal ring specified in parts listing for the application.	Seal rings are not the same size and are not interchangeable. Improper seal ring usage could result in fuel leakage.
DO: Take extra care when installing new fuel seal ring over injector inlet flange. See Figure 6-1.	Prevent tearing seal ring during installation.
DO: Use proper lubricants on seal ring surfaces to install injector in engine. Minimize time between applying lubricant and inserting injector / rail.	See section 6.5 for recommended lubricants. Avoid damage to seal ring during installation. Avoid contamination at seal.
DO NOT: Dip injector tips into lubricants.	Can plug injector spray orifices.
DO NOT: Apply voltage greater than 15V for testing. (Limit duration to 30 sec maximum while flowing fuel, or 10 sec max without flow).	Damage to solenoid could occur.
DO NOT: Cycle injector repeatedly without fuel pressure.	Damage to internal mechanical components.
DO: Pulse (actuate) stuck closed or tip-leak suspected injector (Actuate consists of one pulse <5 sec duration at 9 to 15V).	To verify the injector failure (See section 3.11).
DO NOT: Pulse (actuate) a suspected high leak rate injector (leak >50 sccm air).	Can dislodge internal contamination if present and preclude root cause analysis.
DO: Pulse (actuate) injectors prior to a dry fuel system leak test at engine/vehicle assembly to reseat injector valves.	Injector valves may not reseat without fuel after shipping and handling resulting in false leakage.
DO NOT: Use "snoop" or equivalent, to leak check injector.	Can cause soap deposits on injector. Use Stoddard solvent or Delphi approved equivalent.
DO NOT: Allow water to enter fuel system from air lines, etc. during leak checks.	Can damage injectors.
DO: Avoid any liquid contamination in the injector area.	Coil could short circuit.
DO NOT: Use any Dupanol™ or any material containing water on fittings on any area that could cause water to travel into the injector	Can cause injector to rust or stick.

DO NOT: Contact or apply load to the injector tip for installation.	Apply load to 45 deg angle on nylon over mold see Figure 6-2.
DO NOT: Pound injectors into manifold during assembly to engine. The force on the rail outline drawing must not be exceeded.	Can damage injectors, rail, or seal rings.
DO NOT: Seat rail by torquing the rail mounting fasteners.	May damage rail and injectors.
DO: Use care during connection of harness to injector.	Avoid terminal damage.
DO: Utilize Connector Position Assurance (CPA) feature on harness electrical connector.	Verification connector is properly latched and electrical continuity is maintained.
DO: Use recommended terminal lubricant on mating connector. (Section 7.5)	Minimize potential for terminal fretting corrosion.
DO NOT: Apply excessive side loads to electrical connectors.	May cause loss of electrical continuity.
DO NOT: Use any dropped unit.	Internal damage may have occurred.
DO NOT: Store injectors, rails, or subassemblies including engines on which the injectors have been installed in an unprotected environment.	External contamination can damage the injector electrically and/or mechanically.
DO: Return any dropped, damaged, or suspect material with a tag that describes the problem.	Ensure fast and correct diagnosis of root cause.
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 rails one at a time from packing trays.	Damage may be done to critical components.
DO NOT: Use the injector as a handle.	Do not use the injector to lift assemblies
DO NOT: Rack, stage, or handle parts in a manner that allows contact between parts.	Damage will occur.
DO NOT: Remove packing in a way that allows contact between parts.	Damage could occur due ton contact between parts.
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. Avoid potential warranty from use of questionable components.
DO NOT: Stack inventory skids more than two high.	Pallets or trays may flex or break causing damage to the contents.
DO NOT: Stack units on top of each other.	Damage may be done to critical components.
DO NOT: Tap on fuel injectors to correct any malfunction.	Can damage injector.

Table 6-1 – Multec 3.5 Injector Handling



1 Place tool into fuel injector inlet

2 Position one side of o-ring into o-ring groove, roll o-ring over tool onto fuel injector

IMPORTANT: The edge of fuel injector is sharp. Use the special tool in this kit to prevent damage to o-ring.

Figure 6-1 Injector Seal Ring Installation Precaution

6.1 Packing Procedures

The Multec 3.5 Fuel Injector is an electrical component and must be handled with reasonable care to prevent damage. Proper handling starts at the Delphi manufacturing operation where the packaging methods used help reduce the risk of damage due to impact, moisture, or contamination.

Note

Typically, injectors are delivered to the engine plant in a rail assembly. In this case, packaging issues are addressed at the rail assembly level (See Fuel Rail Assembly Applications Manual).

In cases where the injector is delivered to the customer as a discrete component, packaging requirements need to be defined early in the program. Packaging parameters to be considered should include:

- *Orientation of the injector in the packaging to facilitate handling at the customer location*
- *External dimension requirements of the packaging*
- *Quantity of injectors per layer, box, skid.*
- *Expendable or returnable packaging*

Caution

Injector packaging designs must provide adequate environmental protection to the injector taking into consideration the intended shipping method. Requirements include

- *Protection from vibration and shock*
- *Protection from external contamination*
- *Protection from shipping material generated contamination*

6.2 Receiving and Storage

The condition of each pallet or shipping container should be checked on receipt. Check the label attached to the pallet to verify the model number. Report any damage to Delphi.

Store the injector in a cool, dry, dust-free environment. Do not store injectors, rail assemblies, engines or partially assembled vehicles in an unprotected environment.

Caution

The Multec 3.5 Fuel Injector should never be exposed to liquid contamination. Should water enter the injector's solenoid assembly through the connector, fuel inlet or injector tip, damage could occur.

6.3 Movement Within the Plant

Exercise care to prevent damage and contamination when injectors are transported from storage to production lines or staging areas.

6.4 Installation in Fuel Rail

The injector should be installed in the fuel using the surface indicated in Figure 6-2. The injector tip should not be used for installation. The injector and socket axes should be aligned for installation using proper fixturing. Inadequate alignment will result in difficult assembly and possible damage to the injector seal ring or socket. Reference section 4.3 and Table 6-2 for seal ring installation lubrication requirements.

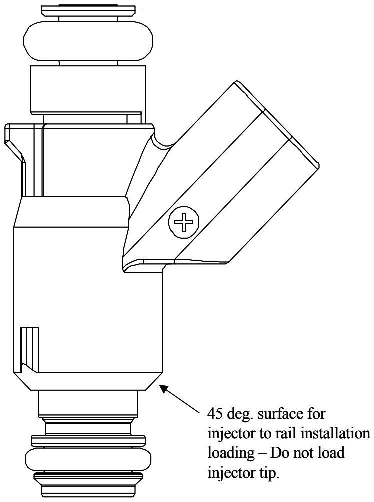


Figure 6-2 Injector Installation Surface

6.5 Installation on the Engine

Follow these guidelines to prevent damage to the injector and its electrical interface during the build process.

Lubrication

- Apply a light coating of lubricant to the lower injector seal ring. ISO 10 light mineral oil or equivalent is recommended. (See Table 6-2) Additional lubricants can be evaluated by Delphi for injector sticking and corrosion and added to the approved listing.
- The preferred technique is to apply the lubricant to the sockets the injectors are being installed into, rather than directly to the seal ring itself. This will help minimize the possibility of injector contamination.

Caution:

- *Avoid applying lubricant over the director plate holes – this may restrict injector flow. Do not dip the injector tip in lubricant.*

Fuel rail

- Rock the rail back and forth to seat the assembly.
- The maximum injector axial loading shall not exceed 800N.

***Warning**:*

- *Never hammer down on the fuel rail to install it.*

Avoid re-use of seal rings

- All Multec 3.5 injectors come from the factory with the seal rings attached. The re-use of seal rings is not preferred when replacing an injector. If an injector is to be re-used, and no new seal rings are available, take care to inspect each seal ring for signs of damage. Even minor defects in the seal ring can lead to leakage. Take extra care in installing seal ring over flange of injector inlet. (See Figure 6-1)

Warning:

- *Seal rings are not interchangeable between Multec 3, and Multec 2 and Multec 1 injectors. Consult service parts listing for proper replacement.*

Do not use the injector as a handle

- The Multec 3.5 Fuel Injector is not a handle. Do not use the injector to lift attached assemblies.

Leak Testing

- Prior to fuel system leak checks, a new fuel injector may need to be actuated to reseat the valve, which can unseat during shipping and handling. (Actuate consists of one pulse <5 sec in duration).

Use only system voltage for testing

- Never apply any voltage greater than 15V for testing purposes (See Section 8.0 for additional test precautions).

Caution:

- *Do not operate injector full on for more than 10 seconds without fuel and fuel pressure. (Or 30 seconds with fuel pressure).*

Harness connector

- Carefully installing the harness connector will prevent terminal damage. Listen for a positive audible click from the connector retention device — this ensures that it is fully engaged. If the connector is equipped with a Connector Position Assurance (CPA) feature, the CPA is pushed forward into the locked position after the main injector lock tab is engaged. The CPA is intended to verify the mating electrical connector is seated properly.
- Avoid unnecessarily disconnecting/reconnecting the harness connector.
- To remove the mating connector, first disengage the CPA (if present) to its staged position, and then depress the lock lever on the connector to disengage the mating connector from the injector. See Figure 4-6, Figure 4-7 ,
-
-
- Figure 4-8 and reference mating connector manufacturers' recommendations.
- The wiring harness must be designed with enough slack at worst case conditions to prevent tension on the wiring and injector connector, which could result in electrical, disconnects.
- Wiring routing diagrams should be provided to assembly personnel to document the proper wiring installation. Alternate wire routings, though feasible, may result in connector or wiring tension that could lead to electrical disconnects. Proper wiring routing and installation techniques should be reviewed during engine / vehicle pilot builds.
- Wires routed in a manner that can allow them to become pinched between components can result in a short circuit and a stuck open injector.
- For injectors that require orientation for spray pattern, do not rotate the injector in the fuel rail assembly to install the injector electrical connector. This may dislodge the retaining clip, and result in improper spray orientation

Connector tabs

- Exercise care that the injector connector tab is not damaged during installation. If the tab becomes damaged, the electrical connector may disconnect in the future causing a customer complaint for engine misfire.

Cushion Seal

Special procedures for cushion seal design injector:

- Verify seals at injector outlet and inlet as well as seal ring at inlet are undamaged and properly located on the injector (see Figure 3-3)
- Use replacement seals as specified in parts listing for the application. Do not substitute with any other seal ring.
- Fuel rail assembly must be installed with proper fasteners to proper torque in order to maintain fuel seal.

TABLE 6.2

LUBRICANT NAME	SUPPLIER	VISCOSITY (cSt) @ 40 deg C	RECOMMENDED / EVALUATED FOR USE WITH...
Spindura 10	Equilon	10	Upper and lower injector seal rings
Spindura 22	Equilon	21	Upper and lower injector seal rings
DTE-24	Mobil	32	Upper and lower injector seal rings
DTE-25	Mobil	46	Upper and lower injector seal rings
DTE-26	Mobil	68	Upper and lower injector seal rings
Norpar 15	Exxon / Mobil	<1	Upper and lower injector seal rings
Drawsol 60	DA Stewart	1 - 2	Upper and lower injector seal rings
NocoLube AW 46	NOCO Energy	46	Upper and lower injector seal rings
NocoLube AW 32	NOCO Energy	32	Upper and lower injector seal rings
Advantage Spindle Oil	Advantage Lubrication Specialties	10	Upper and lower injector seal rings
Penreco Red Petrolatum Grease	Penreco	NA	filler neck to tank installation; not recommended for injector seal ring lubrication

Table 6-2 - Recommended seal ring lubricants

6.6 Component Assembly Best Practices

Component Assembly Best Practice worksheets are included in the appendix (section 10.4.) These worksheets should be completed during a walk through of the current (or proposed) fuel system assembly to engine and vehicle assembly processes. A thorough evaluation of the customer processes at both the engine and vehicle assembly plants where the injector is used should occur as early as possible in the program to provide an opportunity to correct potential deficiencies before pilot and SOP builds.

6.7 Maintenance, Service and Repair

6.7.1 Diagnosing Malfunction Codes

Should a Fuel Trim, Misfire, or Injector Circuit Fault Diagnostic Trouble Code appear during any phase of testing, evaluate all factors that might prove to be the root cause. These Trouble Codes may not indicate an injector or system failure. On the contrary, the fuel trim 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.*

If an injector is suspected of malfunction, perform the following procedures:

- Perform a fuel system pressure test, injector pressure balance, and electrical continuity checks.
- Before a leak check, pulse the injector to make sure the valve is properly seated.

6.7.2 Replacement Techniques

The following procedure outlines standard Multec 3.5 Fuel Injector removal and replacement.

1. Shut off ignition.

Warning *The injector and all associated hardware may be extremely hot.*

2. Disconnect negative battery cable to avoid possible fuel discharge if an accidental attempt is made to start the engine.
3. Disconnect the electrical connector from the injector wiring harness.
4. Relieve fuel pressure (refer to the appropriate service manual procedure).
5. Remove the fuel rail assembly (refer to the appropriate service manual procedure).
6. Remove the retaining clip from the fuel injector.

7. Remove the injector from the fuel rail. Delphi recommends the use of a specific Multec 3.5 removal tool (which is currently in development) to aid in the removal of the injector. (Consult your Delphi representative for current information). If such a tool is not available, the injector can typically be removed by using a twisting motion while pulling downward by hand.

Note *Application of an aerosol lubricant / penetrating oil (WD-40® or equivalent) to the seal ring / socket area will aid in injector removal in a high mileage vehicle. Observe safety precautions when using flammable materials in the engine compartment.*

8. Carefully clean debris from the interface surfaces. Do not damage seal mating surfaces.

9. Install the appropriate injector clip to the replacement injector.

Note *Do not allow contaminants to enter the manifold or fuel rail when removing the seal ring or when cleaning mating surfaces.*

10. Apply a light coating of a lubricant to both the upper and lower injector seal ring of the replacement injector. See Table 6-2 for recommended lubricants.

Caution *Avoid applying lubricant over the director holes in the injector.*

Note *The preferred service technique is to apply the lubricant to the injector seal ring itself. This will help minimize the possibility of injector contamination.*

11. Install the new injector into the fuel rail assembly. Check that the injector is installed in the original orientation to maintain proper spray targeting, and that the retaining clip is properly seated on the injector and fuel rail.

12. Install the fuel rail assembly (refer to the appropriate service manual procedure).

13. Tighten the rail mounting screws to specification.

Note *Hand tighten the bolts before using a torque wrench to tighten them fully.*

Caution *Avoid contacting and damaging the electrical connector's locking tab during installation*

14. Re-install the injector electrical connector and CPA lock (if used)

15. Check for fuel leaks with the key “on” and the engine “off” (refer to the appropriate service manual procedure).
16. Start engine and verify proper operation.

Note

Special procedures for the cushion seal design:

The cushion seal design does not utilize an injector to rail clip, the injector position is trapped between the fuel rail and manifold.

Verify that the cushion seal, manifold face seal and rail o-ring are not damaged and located properly prior to re-installing injector in rail. See Figure 3-3.

The typical assembly procedure is to install the injector in the engine manifold and then place the rail on the injectors and follow steps 13 – 16 above.

6.7.3 Adjustments

There are no service adjustments for the Multec 3.5 Fuel Injector.

6.7.4 Interchangeability

The injector should be replaced in service only with an equivalent injector of the same part number. On occasion, part numbers may be superceded by a new part number. Consult the appropriate vehicle service manual and part number guide for the latest replacement injector part number information. If there is any question as to the correct model required for a given application, please contact a Delphi representative for verification.

6.8 Support of Component After Sale

Fuel Injector Tester, Kent Moore Tool J-39021

The Fuel Injector Tester (J-39021) is capable of performing injector balance and coil tests on many fuel injection systems. The injector balance test measures the drop in fuel pressure caused by energizing an injector for a calibrated amount of time. The pressure drop is compared to those obtained for the other injectors on the engine, or to a published standard.

Note: All Multec 3.5 injectors use a 12 Ohm coil and the 0.5A setting

An Ohmmeter test is intended to detect the deterioration of injector coils causing one or more of the following driveability symptoms:

- Rough idle
- Engine misfire or surge
- Stall after start or hard starting
- Failure of emissions testing
- Poor fuel economy
- Exhaust odor

7.0 Recommendations and Precautions

Note: *Consider design and durability limits when specifying an application to avoid unacceptable injector performance. The following environments must be considered in the application and validation for each new injector vehicle program.*

7.1 Temperature

Temperature is a factor that must be carefully evaluated during vehicle calibration. Temperatures that are either too cold or too hot for prolonged periods of time must be avoided. System designs and software routines that maintain temperatures within the Multec 3.5 Fuel Injector's designed range will prolong injector life and ensure optimum performance. (See Table 3-2)

1. The solenoid is validated for use to temperatures of 125°C (257 °F.) Excursions to 150°C (302°F) for less than 1 hr are possible without failure.
2. Injector coil resistance increases as injector temperature rises, so injector opening/closing response times are therefore affected. To minimize flow shifts due to increased injector resistance, injector operating temperature should be minimized.
3. Operating temperatures as low as -40 °C are possible with the proper seal ring material.
4. Non-operational storage temperatures to -60 °C will not result in permanent injector damage.

Recommendation:

Note: See section 7.3.3-Injector plugging

To minimize the potential for formation of injector tip deposits keep normal usage maximum tip temperatures during hot soak below 95 °C.

Refer to Section 8.4.1-Hot Fuel Handling

Do not exceed the maximum operating tip temperatures shown in Table 8-1for acceptable hot re-start performance.

Temperature Measurement Method:

1. Determine the injector temperature across the full range of vehicle operating conditions — install an injector equipped with thermocouples to monitor temperatures. Instructions for preparing a thermocoupled injector appear in Figure 7-1.

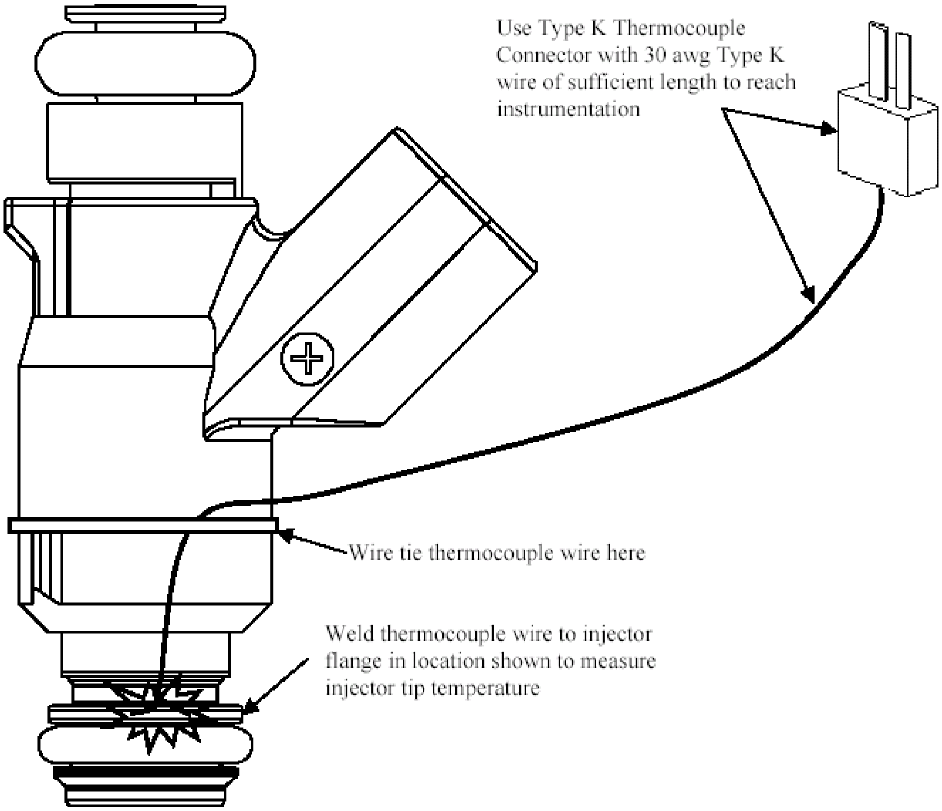


Figure 7-1 - Thermocoupled injector

7.2 Durability

Injector flow performance will vary over its usable life due to mechanical wear and deposit build up. This variation must fall within defined acceptable limits over the application's target life. Injector performance may vary as follows:

- Injector flow rate may shift over the life of the injector due to engine vibration, friction or wear (accelerated by fuel contamination).
- Set point flow shifts are most commonly the result of changes in injector opening and closing response.
- High alcohol fuel or poor quality fuels may accelerate internal injector wear.
- Excessive build-up of deposits on the director may result in a lean shift.

- Injector tip leakage may increase due to excessive wear of the ball seat sealing surfaces.

7.2.1 Injector Characteristics

Multec 3.5 injector field durability flow shift limits are available for each injector model on the Injector Outline Drawing available from Delphi. These limits are based on the application's fuel usage and operating environments.

7.3 Wear and Contamination

7.3.1 Internal Corrosion

Water, salt, oxygen, alcohol, heat and stagnant conditions promote galvanic and pitting corrosion on the surface of injector components. Corrosion can adversely affect injector operation in the following ways

1. Corrosion particles between the ball and seat can damage the seat interface or cause the injector to "stick open" or leak.

2. Corrosion on bearing surfaces will increase friction and cause flow shifts (typically rich).

The Multec 3.5 Fuel Injector is manufactured with stainless steel, which has good corrosion resistance.

7.3.2 External Exposure

Injectors must maintain all functional parameters and remain visually acceptable after intermittent external exposure to:

- Gasoline
- M5 or E15
- Stoddard solvent
- Peroxide test fuel
- 50% high aromatic fuel
- Gas line anti-freeze
- Automatic Transmission Fluid
- Windshield Washer Fluid
- Isopropyl alcohol
- Water or steam
- Salt spray
- Dust
- Ozone
- Brake fluid
- Engine Coolant
- Motor Oil

7.3.3 Plugging

Fuel deposits cause plugging resulting in flow shifts over the life of the injector. Fuel varnish, a type of injector deposit, is created when certain types of fuel are heated by high injector tip temperatures at soak (no fuel flow). Deposit build up in the director holes causes the flow shifts

- Plugging can cause flow restrictions, frictional changes and the collection of other particles attracted by the tacky surface. The flow restrictions can degrade emissions and driveability.
- Other fuel and environmental conditions may cause crystal or corrosion growth in the injector and cause a flow shift.
- Oxidation stability of the gasoline affects the potential for deposit formation and must be controlled by the fuel supplier.
- Increased levels of detergent additives reduce the rate of injector plugging.
- The Multec 3.5 injector features a recessed director design to reduce the exposure of the director surface to deposit forming engine combustion by-products, which contribute to plugging.

Recommendations

A fuel survey should be performed in the markets that the injector is intended to be used to understand the fuel compositions available and their potential impact on injector durability and plugging. Consult your Delphi representative for further information.

Delphi has developed plugging test fuels and procedures to evaluate the susceptibility of injector designs to plugging. These techniques can be applied using the intended engine to evaluate the application's susceptibility to injector plugging.

Maintain maximum injector tip temperatures less than 95°C to minimize injector plugging potential

7.3.4 Contamination Resistance

The chassis fuel line filter is required to protect the fuel system from fuel contamination. A 10-micron inline filter is recommended to prevent injector problems.

Caution

A fuel filter is required in the injector fuel supply line to prevent injector damage from contamination. This applies to vehicle as well as dynamometer and component test equipment fuel supplies.

In addition to a fuel line filter, injector inlet filters also protect the injectors from fuel system initial assembly contamination. The fuel injector inlet filter is not designed to be serviceable and is not intended to be the primary filter in the fuel system.

7.3.5 Fuel System Generated Contamination

The fuel system and injector inlet filters are present to collect particulate contamination. Fuel soluble contaminants may be present in the fuel system that can harm the injector or promote future deposit build-up. Oils, lubricants, and rust inhibitors used during manufacturing are some of the compounds that may be present in the fuel system (fuel lines, fuel rail, fuel pump, fuel tank).

Substances of the types mentioned above should be evaluated by Delphi for potential injector damage or deposit formation. Where the effect of a substance is not known a production process sample may be required for evaluation of the substance's effect on the fuel injector.

Metal fuel lines should be stainless steel to prevent internal corrosion products from aggressive fuel from damaging the injector.

7.3.6 Maximum Fuel Pressure

Caution

The fuel supply system must be designed to prevent failure modes that expose the injector to pressures greater than 1000 kPa (145 psi.) A system FMEA should be performed to verify the fuel injector is protected from excessive pressure. Normally, a valve in the fuel pump protects the fuel system from overpressurization. Injector pressures in excess of 1000 kPa may cause permanent damage to the injector.

7.3.7 Injector Storage

Caution

It is not recommended that the injector be exposed to fuel then stored for a significant period of time (> 3 months). A fuel stabilizer such as Sta-Bil® or equivalent should be added to fuel used for production engine hot testing. Use the treatment rate of concentration of fuel stabilizer recommended by the manufacturer.

Equivalency to Sta-Bil® is defined as:

1. Having similar chemical composition so as to not have an adverse affect on materials of the fuel system.
2. Having similar stabilizing affects on the fuel as demonstrated by the manufacturer.

This will minimize the possibility of residual fuel in the injector from oxidizing and forming gum and varnish. Gum and varnish deposits in the injector may degrade the injector flow performance.

Injectors received from the Delphi production facility should be stored in a clean and dry environment before use (see section 6.2).

7.4 Preventing Engine Hydro-lock

Engine hydro-lock occurs when a fuel quantity is delivered that is greater than the minimum volume of the engine cylinder. The minimum engine cylinder volume occurs when the piston is at Top Dead Center (TDC) and is calculated as follows:

$$Cylinder\ Volume\ at\ TDC = \frac{Engine\ displacement\ /\ \#\ of\ cylinders}{compression\ ratio}$$

Caution

In order for engine hydro-lock to occur, fuel must be present in a cylinder with sufficient volume to restrict the piston's movement when approaching TDC during the compression stroke.

The maximum allowable on-time for the fuel injector can be calculated as follows:

$$Max\ On-Time = \frac{Cylinder\ Volume\ at\ TDC\ (ml)}{Injector\ Static\ Flow\ (g/s)\ /\ Fluid\ Density\ (g/ml)}$$

7.4.1 Engine Prime Pulse at Start

In some cases, the engine control software commands an injector prime pulse during the engine start procedure. The prime pulse is intended to provide the initial fuel to start the engine during cranking. Depending on the engine control software, a prime pulse may be delivered at start of cranking. It is recommended that the sum of 5 sequential prime pulse times be less than the maximum on-time calculation above to prevent hydro-lock.

7.4.2 Vehicle Assembly Fuel System Prime

In some instances, at the vehicle assembly plant an injector prime pulse sequence is initiated to expedite purging a new fuel system of air prior to the initial start of the vehicle. For demand fuel systems, the only purge path for air in the fuel system is through an open injector. The injector must be commanded on long enough to purge the air from the fuel system, but not longer than the max on time calculation above to prevent engine hydrolock if the purge sequence is inadvertently repeated.

7.5 Injector Harness Connector – Corrosion

The USCAR injector connector styles are designed to be submersion – proof to prevent external corrosive materials from attacking the electrical terminals. Yet, fretting corrosion can occur from relative micro-movement between the mating terminals. As a preventative measure against fretting corrosion, a coating of oil or grease is recommended on the mating connector terminals:

Recommendation

Nyosil M25 oil or Nyogel 760G grease terminal lubricants are recommended on the harness connector to guard against terminal fretting corrosion.

8.0 Testing Recommendations and Precautions

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

8.1 Dynamometer Testing

It is critically important that the Multec 3.5 Fuel Injector be tested under conditions that approximate normal operating conditions to ensure that fueling is accurate. A dynamometer is an ideal facility to set steady state engine conditions for evaluation. The following are a few topics that are important to investigate.

Caution

The dynamometer engine fuel supply should be properly filtered to prevent contamination of the injector. (See section 7.3.4.)

Vibration levels generated on a dynamometer engine may significantly exceed those generated in actual vehicle usage. Dynamometer engines used for durability testing should have the vibration levels measured and compared to those in the actual vehicle application. Excessive vibration levels can result in accelerated injector wear.

8.1.1 Cylinder-to-Cylinder Distribution

Cylinder-to-cylinder air/fuel distribution should be tested in a dynamometer environment. Thermocouples should be inserted into each exhaust port so temperature can be monitored, along with air/fuel ratio, and emissions variation. Rail flow distribution, manifold airflow distribution, and EGR distribution should be included in addition to injector flow in any cylinder-to-cylinder air/fuel ratio investigation.

8.2 Durability Testing

Real world durability tests are performed in an application environment and conditions specified by the manufacturer (i.e., on vehicles). These tests should evaluate the range of environmental and fuel conditions expected in customer usage. The application's environmental stress levels can be compared to those previously used for Multec 3.5 testing to determine whether additional durability evaluations are required.

In addition, Delphi conducts generic bench injector durability testing to determine injector useful life. The generic test schedules are intended to comprehend the worst case customer usage.

8.3 Dynamic Vehicle Testing

Dynamic Vehicle Testing is conducted at the vehicle assembly plant as a quality assurance check that all vehicle systems are operating properly. Typically, sensor output and engine performance are measured to verify they are within expected limits as an indication of correct assembly. The measured value acceptable range should be the same or greater than that used during vehicle calibration. Any change in tolerance requirements should be reviewed with the Delphi Application Engineer.

8.4 Standard Vehicle Development Tests

This section contains an overview of a number of recommended development tests that should be conducted during the vehicle development process to determine calibrations and or conformance to requirements. This manual provides rough guidelines only, as procedures vary from manufacturer to manufacturer.

8.4.1 Hot Fuel Handling

The purpose of hot fuel handling testing is to determine the effects of high ambient temperature conditions on vehicle driveability and startability. High temperatures increase the likelihood of fuel vaporization in the injector and a resulting lean flow condition. (See section 2.2.7.2)

Tests typically consist of a prep of the vehicle by stabilizing temperatures at highway speeds followed by soaks or extended idles and soaks. After the soak, the vehicle is started and driven away, and the performance compared to baseline results. Ambient temperatures should be at least 100 ^{o}F (38^{o}C), and the test should be done using high RVP fuel in the 11 to 14 PSI (76 – 97 kPa) range. (These parameters are selected based on the customer's application validation requirements.) Temperatures, pressures, and engine control parameters should be recorded during testing to assure consistency and for a record of results.

As a guideline for 12 psi (83 kPa) RVP non-oxygenated fuel, the recommended maximum Multec 3.5 soak temperatures for acceptable hot fuel handling are as follows. The injector tip temperature is measured as shown in Figure 7-1:

Maximum Injector Soak Temperature	**Recommended Fuel System Set Pressure**
T less than or equal to 95°C	300 kPa
T less than or equal to 105°C	350 kPa
T less than or equal to 115° C	400 kPa
T less than or equal to 120°C	450 kPa
T greater than 120°C	Contact Delphi

Table 8-1 - Injector tip soak temperature vs required fuel pressure

Table 8-1 is intended as a guideline only. Vehicle hot fuel validation testing is required to confirm adequate hot restart performance in the specific application.

8.4.2 Spray Effect on Emissions

There are two primary areas to investigate with injector spray:

- Determine optimum spray targeting and atomization for a given application
- Once optimum spray is determined, evaluate effect of production variation on engine and vehicle performance

Injector spray includes spray targeting, spray pattern and droplet size, which are a function of the director plate design and fuel system pressure. (Reference section 3.8)

Emission effects would be tested on both a dynamometer and the vehicle, while driveability effects would be tested on the vehicle.

Direct observation of injector fuel delivery on a running engine is possible with a boroscope and high speed imaging through the intake manifold. The interaction of the injector spray and the port geometry can be studied to ensure that the fuel is being delivered as expected and not collecting on port surfaces or the injector tip.

8.4.3 Cold Driveability and Startability

The purpose of cold driveability and startability testing is to determine the effects of extreme low ambient conditions on vehicle driveability and startability. Tests typically consist of a prep of the vehicle to stabilize temperatures followed by a 6 to 8 hour soak. After the soak the vehicle is started and driven away, and the performance compared to baseline results. Temperatures for testing are typically less than -20°F (-29°C), and the test should be done using high RVP fuel in the 12 to 15 PSI (83 – 103 kPa) range. Temperatures, pressures and engine control parameters should be recorded during testing to assure consistency and for a record of results.

8.4.4 Crank vs. Leak

The purpose of crank versus leak is to determine the effect of injector leak rate on vehicle start times, and to determine what is an acceptable or optimum value. Injectors characterized for leak rate are required for this testing. The testing is done at elevated temperature conditions to determine maximum effect. After testing, leak rate versus crank time would be plotted to determine maximum allowable leak for a given application.

In addition, as evaporative emission limits become more stringent, injector tip leak in relation to vehicle evaporative losses should be considered in the overall vehicle emissions plan.

Note: *Hard restart can result from commanding the electronic throttle control valve fully closed during engine shutdown. Large amounts of exhaust gas are drawn into the cylinders resulting in a rich fuel condition at restart. It is recommended to delay full throttle valve closure until after engine rotation has stopped.*

8.4.5 Altitude Driveability and Emissions

It is necessary to verify emissions and driveability at altitude as well as sea level during the development process. In addition to emissions, driveability would consist of cold starts, hot starts, gradeability, etc. Temperatures, pressures, and engine control parameters should always be recorded.

8.4.6 Low Pulse-Width Fueling Accuracy

The purpose of this testing is to develop and verify the low pulse-width corrections in the calibration. This would be done at high and low ambient temperatures, as well as altitude. Long and short-term correction factors would be monitored for repeatability and deviation from nominal. Use a well broken-in engine to minimize internal friction effects and minimize injector pulse widths.

8.4.7 Driveability Index Fuel Sensitivity

In addition to the normal cold start testing, it is necessary to verify calibration sensitivity to high driveability index (DI) fuels. (See section

2.2.6.4) Driveability index is a measure of the distillation curve, and is somewhat independent of the RVP of the fuel. High DI fuel typically results in sags and stalls during warm up as a result of leaner operation due to less evaporation of the fuel. Normal cold start procedures would be used for evaluation.

8.4.8 Spark Plug Fouling Tests

Spark plug fouling tests are conducted to verify the calibration's robustness to short start and run cycles at low ambient temperatures. These are conditions that might be experienced on a new car dealer lot, or by someone driving short distances in the winter. In either case, the vehicle is not allowed to fully warm up and stabilize between soaks and starts. Testing consists of soaks, starts, and short drives at a low ambient temperature, typically -20^{o}F.

8.4.9 Voltage Sensitivity

This testing would verify on the vehicle the voltage correction tables previously developed on the flow stand. This should be done with characterized injectors. System voltage would be varied, and long and short-term correction factors monitored.

8.4.10 Manifold Pressure Sensitivity

This testing would verify on the vehicle the vacuum (or MAP) corrections developed on the flow stand.

8.4.11 Standard Durability Tests

These are vehicle manufacturer specific, but would typically include tests such as: rapid mileage accumulation, salt spray, water intrusion, rough roads, high speed, taxi fleets, etc.

8.4.12 Icing Tests

The purpose of the icing tests would be to verify the resistance of the injector and injector placement to water or ice accumulation. This test would be conducted at low ambient conditions. After each test sequence, it is necessary to remove the injectors and verify the presence of ice, or use a Bore-scope to visually check for ice. (See section 2.2.7.4)

8.4.13 Production Limit Verification Tests

In order to test the limits of the engine calibration and diagnostic algorithms it is recommended to evaluate limit fuel systems. Performance limits to be considered include pressure, flow rate, leak, and spray. The entire tolerance stack up of fuel system tolerances (new and durability) should be evaluated.

In some cases, limit flow hardware can be simulated by adjusting the calibration tables to artificially simulate limit flow conditions. In other cases, specific hardware can be built to represent limit flow, leak and spray. This hardware should be selected in a manner to represent the worst case minimum and maximum fuel delivery. This may include the production and durability flow shift limits for the hardware. The hardware evaluated should include the pump, regulator, and injectors. Additional information can be obtained from your Delphi representative.

9.0 Validation Requirements

9.1 General

This section outlines the validation requirements for the Multec 3.5 Fuel Injector.

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 levels – component, system, and vehicle. The injector DFMEA and SFMEA should be used to pinpoint component/system strengths, weaknesses, and possible failure modes, relative to actual vehicle operation. Laboratory tests (arranged in a synergistic manner) can be used in evaluating component and/or system conformance to QRD performance goals and government standards. Delphi schedules and past experience, along with field/road tests, are procedures used to provide validation data for the component/system/vehicle relative to the “overall” package. Evaluation of limit parts is crucial and will enhance comprehension of the scope of injector performance under all conditions.

In some cases the injector is tested as a component of the fuel rail or IAFM assembly.

9.2 Validation Tests

The validation tests to which Delphi-E&C has tested the Multec 3.5 injectors are listed below. A comprehensive validation plan may entail performing the complete array of tests or a smaller selection of them, based on the characteristics of the product and its intended application. Consult Delphi-E&C for the appropriate requirements for each specific application.

***Note**: Except where noted, the part is to be mounted and connected per application design requirements.*

9.2.1 Preliminary Physical Analysis

The Multec 3.5 Fuel Injector should be inspected for build anomalies prior to validation testing. All data sheets from the assembly source should be reviewed to determine if all limits were in specification prior to starting any functional tests. Any Multec 3.5 Fuel Injector, which does not meet these quality requirements, will not be used for validation.

1. Verify that the part number and serial number of the test fuel injector matches the data sheet.
2. At end of test, or as required, perform tear down analysis on all parts and inspect condition.

9.3 Environmental Exposure

Environmental exposure testing consists of monitoring injector performance and physical condition after exposure to temperatures and substances that may be encountered in actual field use. Exposures to these environments will not cause injector flow shift exceeding the limits on the Outline Drawing for the injector model, or result in unacceptable physical alteration or damage.

The requirements in this section relate to testing performed in the course of injector validation for structural integrity, fuels compliance, and injector flow performance over anticipated service life. All testing, unless otherwise noted, should be performed using the operating parameters in Delphi Product Test Instructions.

9.3.1 External Corrosion

Multec 3.5 injectors will not experience any loss of function, as stated, and will pass evaluation criteria as outlined in the Delphi corrosion standards as outlined below: Reference SAE J1832 Section 5.5.

9.3.1.1 Corrosion - Cosmetic

Multec 3.5 injectors will exhibit no red rust when subjected to 32 hours of 5% neutral salt mist per ASTM B117. Injectors will not experience any loss of function, or reduction in service life as a result of this exposure. Additionally, injectors will be validated for cosmetic corrosion using DX900115 (6 cycles of accelerated corrosion schedule) with <5% corrosion.

9.3.1.2 Corrosion-Functional

Multec 3.5 injectors will not experience any loss of the ability to comply with the durability flow tolerance requirements as defined on the Test Specification Sheet after exposure to salt spray per DX900115 (27 cycles of accelerated corrosion schedule). Injectors will not experience any loss of function, or reduction in service life as a result of this exposure.

9.3.2 Temperature

Typical injector temperature environments are defined below. Multec 3.5 injectors will not experience any loss of the ability to comply with the durability flow tolerance requirements as defined on the Test Specification Sheet after exposure to the following temperature environments. Also, Multec 3.5 injectors will not experience unacceptable external leakage, any type of physical degradation, or loss of service life during or after being exposed to these ambient temperatures.

- Normal Operating Temperature Range:
  -30 to 125°C (-22 to 257°F)
- Extreme Operating Temperature Range (some performance degradation):
  -40 to 150°C (-40 to 300°F)
- Storage Temperature Range:
  -60°C to 60°C (-76 to 140°F)

The Multec 3.5 injector has been designed for operation within these temperature limits. Injector design modifications may be required for operation outside of these temperature limits.
Reference SAE J1832 Section 5.3.

9.3.2.1 Temperature Shock

Temperature shock shall consist of cycling the injectors between –40 and 100 C with a 0.5-hour dwell at each of the temperature endpoints for a total of 120 hours exposure. The transition between temperatures should be instantaneous. The injectors will not experience any loss of the ability to comply with the durability flow tolerance requirements stated on the Injector Outline Drawing. The injectors will not experience any loss of function or reduction in service life as a result of this exposure.

9.3.3 Life Cycling

Injector life cycling will consist of actuating a population of injectors in the specified test fuel, at the specified fuel temperature for 1.0 B cycles, which approximates 2 to 3 times (or more) expected service life for most applications. Testing will be performed at the system fuel pressure or greater, at a duty cycle of 2.0 ms pulse width / 4.0 ms period. Periodic flow audits will be performed to track the flow performance of the hardware relative to the initial flow values. At the end of test, injector performance should comply with the flow tolerance requirements as stated on the Injector Outline Drawing (Reference section 5.9 of SAE J1832).

The requirements in this section relate to testing performed in the course of injector validation for structural integrity, fuels compliance, and injector flow performance over anticipated service life. All testing, unless otherwise noted, should be performed using Delphi test procedures.

Multec 3.5 will be validated for durability flow performance on a number of fuels that are arrived at through Customer request or market analysis. While it is difficult to validate for every fuel available in the marketplace, the list of validation fuels, shown in Table 9-1, is intended to be comprehensive, and cover all but the most severe fuels, for which additional design measures may be required.

In some cases engineering and materials analyses will be used in place of physical testing to verify compatibility with certain fuels in Table 9-1.

Fuel	Description	Comments
TF1	E10 Non Corrosive	
TF3	15% MTBE	
Phase II	CARB Spec	with MTBE
Peroxide Fuel Mix	Fuel "C" + Peroxides	
Corrosive NAE10	E10 + Corrosive Pkg	
Brazilian E20	Fuel "C", E20 - 24 + Corrosive pkg.	E22 Commonly used
Delphi Plugging Fuels	Delphi Formulation	For plugging test

Table 9-1 - Potential Injector Test Fuels

9.3.4 Mechanical Integrity

Mechanical integrity testing consists of monitoring injector performance and physical condition after exposure to forces that may be encountered in actual field use. Exposures to these forces will not cause injector flow shift exceeding the limits defined on the Injector Outline Drawing, or result in unacceptable physical alteration or damage.
(Reference section 5.8 of SAE J1832)

9.3.4.1 Structural Tests

Multec 3.5 injectors will meet flow shift requirements per the Injector Outline Drawing after the following structural tests:

9.3.4.2 Axial Force

Apply 800 N compressive and tensile to the injector between the injector tip and the end of the fuel inlet. For the tensile test the load may be applied at the shoulder of manifold seal ring gland and to the upper seal ring retainer.

9.3.4.3 Bending

Apply a bending moment of 6 N*m to the injector. Clamp the injector in a collet or suitable fixture on the outside diameter in the vicinity of the manifold seal ring and apply a load to the vicinity of the upper seal ring to achieve 6 N*m for 30s. The seal rings may be removed for the purpose of this test.

9.3.4.4 Torsion

Apply a torsional moment of 0.6 N*m to the injector. Fixture the outside diameter in the vicinity of the manifold seal ring in a collet or suitable fixture and apply a suitable load to the side of the connector to create a 0.6 N*m torsional load for 5s. Support the fuel inlet of the injector to prevent application of a bending moment.

9.3.4.5 Vibration

Multec 3.5 injectors will withstand accelerated vibration exposure in 3 axis without loss of ability to comply with the durability flow tolerance requirements as shown on the Injector Outline Drawing. The vibration schedule, “Multec 3.5 Enhanced Generic Fuel Rail Schedule”, is based on an average worst case accelerated schedule for 4, 6, and 8 cylinder applications. The injector will be pressurized at normal operating pressure with calibration test fluid during vibration. The injector will be actuated at 2.0 ms pulse width and 10.0 ms period during the vibration test. No component degradation or physical damage is acceptable as a result of this procedure. (See section 4.2.3 for vibration measurement level procedure.)

9.3.4.6 Shock

Multec 3.5 injectors will withstand shock exposure, without loss of the ability to comply with the flow tolerance requirements as defined on the Injector Outline Drawing when exposed to 50 g peak, half sine, 11 ms duration shocks in three axis (6 times per axis) at ambient temperature of 25 ± 2°C (77±3.6°F.)

9.3.5 Overpressurization

Multec 3.5 injectors will withstand an overpressurization of 1000 kPa (145 psi) fluid pressure for a duration of 3 minutes without loss of the ability to comply with the flow tolerance requirements as defined on the Injector Outline Drawing and without sustaining any permanent physical damage.

9.3.6 Over-voltage

Multec 3.5 injectors will withstand high voltage exposure without loss of the ability to comply with the durability flow tolerance requirements on the Injector Outline Drawing. The test consists of exposure to voltage of 26V for 1 minute at a duty cycle of 100 ms pulse width and 200 ms period. The injector will be pressurized with calibration test fluid at normal operating pressure during the test. This test will not result in any permanent physical damage to the injector or coil assembly, or any degradation in electrical performance. Reference SAE J1832 Section 4.1.23.3.

9.3.7 Injector Noise

Injector acoustical noise shall be evaluated in an anechoic chamber. The microphone shall be located a distance of 1 meter above the injector. The injector shall be pressurized with test fluid at the normal operating presssure.

After purging the injector of trapped air by actuating at 3.5 ms pulse width and 5.0 ms period, adjust the actuation to 3.5 ms pw and 20 ms period and perform the noise measurment. The sound pressure level due to injector opening and closing events shall be reported in dBA. (Reference SAE J1832 Section 5.11.2.)

9.3.8 Note on Additional Exposures

Other environmental test schedules, as performed for Fuel Rail Assemblies are not mentioned here. These include (but are not limited to) sand and dust exposure, submersion, and road splash. Information on these tests can be obtained from Delphi separately.

9.4 Verification

A validation matrix (see Table 9-2) has been compiled which contains the Multec 3.5 Fuel Injector Requirements that should be addressed in the Component Technical Specification. The matrix shows these requirements with a corresponding method of evaluation and the respective responsibility level for performing the validation process. The matrix should be used as a guideline when setting up a complete validation analysis for a fuel injector application.

Note that only selected tests are performed for new injector applications or injector design / process changes. These tests consist of application specific tests that have not been comprehended in previous Multec 3.5 testing and have been commercially agreed to by Delphi (i.e. vibration levels, fuel usage, etc). For a design or process change, only tests that are identified as applicable to the change (through the DFMEA) would be repeated.

VERIFICATION (VALIDATION MATRIX)							
ITEM	METHOD				LEVEL OF EVALUATION		
	ANALYSIS	TEST	INSPECTION	DEMONSTRATION	COMPONENT	SUBSYSTEM	VEHICLE
3.0 REQUIREMENTS							
3.1 DEFINITION							
3.1.1 Appearance (new and after durability) 3.1.2 Contents (features functions) 3.1.3 Environment (usage environment) 3.1.4 External Interfaces (Mechanical, electrical) 3.1.5 Usage Definition (Service life, etc)							
3.2 CHARACTERISTICS							
3.2.1 Performance (Product performance) 3.2.2 Physical (Outline) 3.2.3 Reliability & Quality 3.2.4 Maintenance, Service & Repair 3.2.5 User-Component Interface (Safety)							
3.3 DESIGN AND CONSTRUCTION							
3.3.1 Materials, Process & Parts 3.3.2 Design Guidelines 3.3.3 Identification & Markings 3.3.4 Interchangeability							
3.4 DOCUMENTATION							
3.5 SUPPORT AFTER SALE							
3.6 OPERATOR TRAINING							
3.7 MAJOR SUBORDINATE SUBSYSTEM CHARACTERISTICS							
5.0 PROVISIONS FOR SHIPPING							
5.1 DOMESTIC							
5.2 EXPORT							
5.3 INTERMEDIATE DESTINATIONS							

Table 9-2 - Injector Verification Matrix Template

10.0 Appendix

10.1 Introduction.

This section contains three checklists intended to verify that all aspects have been considered for the proper application of the Multec 3.5 injector. The first checklist (section 10.2) covers the system related topics that need to be considered when specifying a fuel injector for a particular engine application. A column is included in the checklist to enter the pertinent section from the customer requirements document (if applicable) as a cross-reference. Values for each item should be provided when known. Delphi can provide technical assistance to determine appropriate values to use in cases where data is not available.

The second checklist (section 10.3) is focused on specific injector component details. These details are best considered and documented during the initial stages of the program. Items requiring additional testing or consideration can then be identified and included in the program test plan.

The third checklist (section 10.4) deals with all aspects of product handling at the customer manufacturing facilities. This checklist should be used as early in the program as possible to verify that acceptable product handling and in-plant diagnostic procedures are employed. Any modifications to the customer manufacturing process highlighted by this checklist are easiest to implement early in manufacturing process development.

10.2 Multec 3.5 Fuel Injector System Customer Component Checklist

	Customer Component Checklist MPFI Injector Fuel System			
	Subsystem Drivers for Component Selection	**Application Manual Reference**	**Requirements Doc. Section**	**Value**
	Emissions Requirements			
1	Engine out HC, CO, NOx goals (g/mile for emissions test) and durability requirement	2.2.1 2.4.1 7.2		
2	Evaporative emissions requirements	2.4.2 3.11		
3	Diagnostic Requirements	5.3		
4	Verify flow limit parts meet emissions, diagnostics and driveability requirements (Delphi to advise test conditions)	8.4.13		
	Air/Fuel Distribution and Injector Targeting			
5	A/F ratio at stabilized idle	2.2.1		
6	Idle misfire A/F ratio	2.2.1		
7	Max. port-to-port inlet air mal-distribution at idle and worst part throttle point – Indicate air rate and throttle position (max. % deviation)	5.2.3.10 8.1.1		
8	Max. external EGR mal-distribution – Indicate EGR flow rate (max % deviation).	2.4.4		
9	Max. PCV air mal-distribution. Indicate PCV flow rate (max % deviation)	2.4.4		
10	Rail induced fuel mal-distribution at idle (max. % dev. richest to leanest port)	4.2.4 5.2.3.10 8.1.1		
11	Number of engine intake valves per cylinder	3.5.1 3.8.2		

12	For 2 intake valves per cylinder applications and dual spray injectors: Injector and or retention clip to have rotational orientation feature to fuel rail – Describe recommended feature	3.3.5		
13	% Fuel on intake valve (by design layout) – Requires interactive process between injector targeting and spray geometry (% of total fuel pulse mass)	3.8.1 3.8.2		
14	Spray atomization requirements (droplet size distribution – SMD, DV90)	3.8.3		

	Engine Fueling Requirements			
15	System fuel pressure	2.3.4,8.4.1		
16	Idle fuel mg/inj. pulse per injector – Include impact of canister purge if active	2.4.3 3.7 5.2.2.3 5.2.2.5		
17	Max. SF rate at RPM, A/F ratio, inlet air temperature (add formula for computing when data not available) (g/sec per injector)	3.7		
18	Min. A/F ratio for converter protection	5.2.3.9		
19	Max. cold crank, cold ambient fuel rate (g/sec per injector)	3.7 5.2.3.13		
20	Verify injector minimum controllable fuel per pulse and tolerance sufficient for transient fuel control (DFCO, DE, fuel trim pulse, etc.) – Emissions and driveability assessment	3.9.1 5.2.2.5 8.4.6		
21	Hot idle RPM Automatic/Neutral/Manual	3.7		
22	Injector fuel pressure biased to MAP, yes or no	2.3.4 3.7 5.2.3.2		
23	MAP at idle and WOT (100 kPa barometric pressure (kPa)	2.3.4 3.7		
24	Pressure drop across injector: idle and max. SF rate (kPa)	3.7 4.2.4		

	Software and Control Interface			
25	Open-loop or closed-loop control system (oxygen sensor feedback)	2.4.1 5.2,5.2.3 5.2.4		
26	Speed density or mass air flow system	5.1		
27	Firing scheme at idle/off idle: Seq., SDF, ASDF, SSF	Figure 5-1		
28	Closed-loop correction authority limit (short term proportional/integral control air/fuel ratio correction term) (+/- % authority)	5.2.4		
29	Adaptive multiplier (BLM) authority partitioned for fuel injectors at nominal rail pressure: software correction tables enabled. Specify system voltage, altitude range, injector tip temp, range (°C) – Includes injector durability shifts (+/- % authority)	5.2.4 8.4.13		
30	Adaptive multiplier (BLM) authority limits at open loop engine crank and run (+/- % authority)	5.2.3.13		
31	Software fuel correction/control: 1-low pulse-width, 2-voltage, 3-MAP, 4-charge temp., 5-baro. press., 6-varying inj. press. drop, 7-fuel pump voltage, 8-individual cylinder fuel trim, 9-fuel trim pulse, 10-engine prime pulse	5.2.3		
32	Max. % injector on time during open intake valve event – Calculate or measure for emissions test closed loop engine fueling, non transient, non trim pulse conditions only (%)	5.2.5 8.4		

	Electrical Interface			
33	Sat. switch amps ☐ peak-and-hold amps ☐ peak current at volts ☐	3.6 4.4.5		
34	Min. voltage at injector required for opening during cold ambient engine crank (system pressure determined from fuel pump output curves) (volts)	2.2.7.5 3.6.1 2.3.1		
35	Injector operating voltage range, engine running – Also specify voltage range for emissions diagnostics operation if applicable (volts at injector)	3.15 5.3 9.3.6		
36	Injector drivers meets Delphi recommendations	4.4.5		
37	Injector wiring and mating connector meet Delphi recommendations	4.4.2,4.4.3,4.4.4		
38	Injector electrical connector style	4.4.4		

	Fuel Supply Interface			
39	Max. pump check valve determined failure mode pressure (< 900 kPa)	2.3.3 7.3.6		
40	Fuel pump operating voltage range, engine running (volts)	2.3.1		
41	Minimum fuel pump operating voltage during cold ambient crank; (volts at temp.)	2.3.1 2.2.7.5		
42	Fuel pump press. vs. supply rate and tolerance – Include flow vs. voltage and temp. curves (g/sec)	2.3 3.7		
43	Vehicle fuel supply line pressure drop from fuel pump to fuel rail inlet at nominal pump flow rate & conditions (kPa)	2.3 3.7 5.2.3.14		

	Engine Start/Restart Requirements			
44	Min. rail inlet pressure vs. vehicle soak time (kPa at specified time)	2.2.7.2		
45	Time to reach fuel pressure or max. cranking pressure at rail inlet. Specify temp. and conditions (secs at °C)	2.3		
46	Engine start time requirements (secs at °C)	2.2.7.2 2.2.7.3 2.2.7.5		
47	Max. allowable injector tip leak (cc per min. at specified time)	3.11		

	Fuels and Environment			
48	Validation fuel exposure: methanol/ethanol blends; RVP/driveability index; fuel contaminants	2.2.6 8.4.7 9.3.3		
49	Max. particle size passing through upstream (of injector) fuel filter (microns)	3.12,7.3.4		
50	Injector tip operating temp. range (°C)	3.16, 7.1,8.4.1		
51	Component surrounding air temperature (°C)	3.16		
52	Minimum liquid fuel sealability temperature at system pressure (°C)	3.16,3.3.6		
53	Peak injector tip temp. after soak (°C)	7.1,8.4.1		
54	Estimate of component vibration severity – Include component 3 axis vibration levels vs. rpm when available	4.2.3		

	Others			
55	Injector mechanical and sealing interfaces to fuel rail and head/manifold meets Delphi recommendations – Include analysis of injector clip interface	3.3.5,3.3.6,4.2		
56	Other significant component drivers (external noise, external corrosion) specify driver and requirement	3.14 3.15 4.4.5.1, 9.3.1		
57	Injector tip to interface with cylinder head	4.2.1		
58	Component assembly best practices evaluated (engine and vehicle plants).	10.4		
59	Max injector prime pulse and vehicle assembly prime analyzed with respect to engine hydrolock	7.4		
60	Use of proper seal ring lubricants at engine assembly verified.	6.5		
61	Reviewed Multec 3.5 Fuel Injector Handling Recommendations	Table 6-1		
62	Injector service procedure set-up according to Delphi guidelines prior to SOP	6.7		

Note: Final injector selection requires verification by customer for emissions and driveability compliance. This should include limit flow distribution and injector tip leakage hardware.

Seq: Sequential fire; SDF: Simultaneous Double Fire; ASDF: Alternating Simultaneous Double Fire; SSF: Simultaneous Single Fire; SFC: Specific Fuel Consumption; MAP: Manifold Absolute Pressure; BLM: Block Learn Multiplier

If the injector lower seal is located in cylinder head, this will expose the injector to higher than normal temperatures.

10.3 Component Application Checklist

CHARACTERISTIC	APPLICATION MANUAL SECTION(S)	CAPABILITY/ RECOMMENDATION VERIFICATION	RESULT
Environment:			
Temperature			
	3.3.6	‘O’-ring compatible	
	3.16 Table 3-2 5.3.6 7.1 8.4.3 9.3.2	Acceptable to application	
Corrosion			
	3.16.2 9.3.1	Acceptable to application	
	4.2.1	Injectors should be shielded from road splash	
Fuels			
	2.2.6 3.3.6	‘O’-ring compatible	
	3.6.2 7.2	Alcohol fuels utilized (Y/N)	
	3.16.2 Table 2-1 9.3.3	Acceptable to application	
	7.3.3	Application robust to plugging	
Contaminants			
	3.12 7.3.4 7.3.5	Acceptable to application	
	3.16.2	Acceptable to application	
	7.3.2	External exposure contaminant list acceptable	
Vibration			
	3.16.2 4.2.3 7.2 9.3.4.5 8.1	Acceptable to application	
Electromagnetic Compatibility			

CHARACTERISTIC	APPLICATION MANUAL SECTION(S)	CAPABILITY/ RECOMMENDATION VERIFICATION	RESULT
	4.4.1	Acceptable to application	
Voltage			
	3.15 3.6 5.3.6 8.4.9 9.3.6	Defined limits acceptable to application	
Dust			
	3.16.2	Acceptable to application	
Humidity			
	3.16.2	Acceptable to application	
Fuel Pressure			
	3.16.2 5.2.3.2	Vacuum biasing utilized	
	5.3.6 7.3.6 Table 8-1 9.3.5	Acceptable to application	
Icing			
	2.2.7.4 8.4.12	Application robust to icing	
Calibration:			
	8.3	DVT tests simulate calibration limits	
	8.4.7	Calibration robust to DI fuels	
	8.4.8	Application pass spark plug fouling tests	
Slope			
	5.2.2.1	Slope acceptable to application	
Offset			
	5.2.2.2	Voltage offsets acceptable to application	
Voltage Flow Curve			
	5.2.2.4 5.3.6 8.4.9	Acceptable to application	
Low Pulse Width Correction			
	5.2.2.3 8.4.6	LPW correction table acceptable to application	
Fuel Pump Correction			

CHARACTERISTIC	APPLICATION MANUAL SECTION(S)	CAPABILITY/ RECOMMENDATION VERIFICATION	RESULT
	5.2.3.14 5.3.6	Utilize fuel pump correction	
Minimum Pulse Width			
	3.9.1 5.2.1.4.1 5.2.2.5	Meet application recommendation	
Interface:			
Stack-up			
	3.2.2 3.3.1 3.8 4.2.1	Ensure no solid contact of injector with any other surface	
	3.2.2 3.3.1 4.2.1	Ensure clearance recommendations are met	
	3.2.2 4.2.1	Ensure injector cup and manifold interfaces are correct	
	3.2.2 3.3.5 4.2.1.1	Ensure injector stays in rail if clip missing	
	3.8 5.2.3.12 8.4.8	Minimize wall wetting from spray	
	3.3.1 4.2.1	Injector meets application packaging requirements	
	3.3.5 3.5.1 4.2.2	Injector oriented properly	
Contamination			
	7.3.4 3.12	10 micron in-line filter utilized	
Wiring			
	3.6.2	Use “high-side” drive circuit for alcohol fuel applications	
	4.4.2	Dedicated wiring for injectors	
	4.4.2	Proper routing	
	4.4.4	Use proper connector	
	4.4.3	Maintain polarity	
	4.4.4	Use non-wicking wire	
Controller			

CHARACTERISTIC	APPLICATION MANUAL SECTION(S)	CAPABILITY/ RECOMMENDATION VERIFICATION	RESULT
	3.6 3.6.3 4.4.5	Saturated switch driver utilized Clamping voltage	
Avalanche Energy			
	3.15.2 4.4.5.1	Acceptable to application	
Performance:			
Appearance			
	3.2.1	Black and Stainless Steel acceptable to application	
Fuel Pressure			
	2.2.7.2 3.16 8.4.1	Fuel System pressure robust to Hot Fuel Handling	
Max Flow Rate			
	3.7 3.16 5.2.3.13	Proper injector sizing	
	3.9.2	Consider tailbiting when sizing injector	
Flow curve			
	3.10.1	LFR acceptable to application	
	3.13	SP acceptable to application (consider idle condition)	
Flow Variation			
	3.10.2	WFR acceptable to application	
	5.3.1 5.3.5	Limit parts tested with diagnostics	
	7.2.1 8.1.1 9.3.3	Durability flow shift acceptable to application	
Minimum Operating Voltage			
	3.6.1	Acceptable to application	
Spray			
	3.8 5.2.5	Cone angle proper for application	

CHARACTERISTIC	APPLICATION MANUAL SECTION(S)	CAPABILITY/ RECOMMENDATION VERIFICATION	RESULT
	8.4.2 8.4.8	Spray variation acceptable for application	
Velocity			
	3.8 5.2.5 8.4.8	Velocity and distance correct for injection timing	
Leakage			
	2.4.2 3.11 7.2 8.4.4	Durability acceptable to application (crank vs leak) (evaporative emissions)	
Noise			
	3.14	Acceptable to application	
Injection Method			
	5.2.1 5.2.1.4.1	Number of durability pulses acceptable to application	

10.4 Component Assembly Best Practices

(See following page)

DELPHI

COMPONENT ASSEMBLY BEST PRACTICES
FUEL SYSTEM DATA SHEET
ENGINE ASSEMBLY PLANT(EAP) PROCESS REVIEW

EAP: ____________
Reviewer: ____________
DATE: ____________

STORAGE - Build Date Code

	Part Number:		Part Number:		Part Number:		Part Number:	
		Date Code		Date Code		Date Code		Date Code
1								
2								
3								
4								
5								

PRODUCT HANDLING

1.	Is plant receiving & using Delphi Fuel Rail Assemblies in FIFO order? (Circle One)	YES	NO
2.	Assembly Plant - "Daily Volumes". ____________		
3.	On average, the number of shifts worked per plant. (i.e. 1, 2 or 3) ________		
4.	Is plant leaving rail assemblies in dunnage until ready to install? (Circle One)	YES	NO
5.	Is plant unloading and installing units one at a time from packing trays? (Circle One)	YES	NO
6.	Does plant return dropped, damaged or suspect material tagged with problem description? (Circle One)	YES	NO

INSTALLATION

1.	Does plant use approved "O"-ring lubrication technique? (Circle One)	YES	NO
2.	Does plant use approved "O" ring lubrication material? (Circle One)	YES	NO
	If no, please identify material used. ______________		
3.	Is injector electrical connection made at the engine plant? (Circle One)	YES	NO
	If yes, is injector electrical connection made carefully? (Circle One)	YES	NO
	If yes, is injector wiring excessively stretched, pinched or chafed? (Circle One)	YES	NO
4.	Does plant use back up wrench on threaded fuel line connections? (Circle One)	YES	NO
5.	If threaded fittings are used, are fittings properly torqued? (Circle One)	YES	NO
6.	Does plant hot test engines on gasoline? (Circle One)	YES	NO
7.	Are engines hot tested on gasoline at an outside vendor? (Circle One)	YES	NO
8.	If engines are hot tested using gasoline, is fuel system purged per Delphi recommendation? (Circle One)	YES	NO
9.	Are shipping caps in place on rail, when engine is shipped? (Circle One)	YES	NO
10.	If injectors or rails are replaced are "O" rings reused? (Circle One)	YES	NO
11.	Record # of replacement rails / Injectors used per day. Rails ________	Injectors ________	
12.	Are latest assembly instruction documents available & being observed by plant? (Cir	YES	NO

(Please e-mail and/or fax assembly instruction documents to Bruce Gardephe @ (585 359-6361)

Comments

Note: Please complete & forward information to Bruce Gardephe @ Delphi E&C. TCR, via e-mail Bruce.Gardephe@delphi.com and/or fax (585) 359-6464
Any questions, concerns and/or comments please call (585) 359-6361. Thanks! again for your participation.

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COMPONENT ASSEMBLY PRACTICES(CAP) MANUAL
FUEL SYSTEM DATA SHEET
VEHICLE ASSEMBLY PLANT(VAP) PROCESS REVIEW

VAP: ____________________
Reviewer: ____________________
DATE: ____________________

STORAGE - Build Date Code

	Part Number:		Part Number:		Part Number:		Part Number:	
		Date Code		Date Code		Date Code		Date Code
1								
2								
3								
4								
5								

FUEL SUPPLY

1. What brand of fuel is factory fill? ________________________
2. Alcohol content __________________ Percent
3. RVP ________________________ PSI
4. DI _________
5. What is factory fill storage tank location? (in ground / above ground) ____________
6. How frequently are storage tanks cleaned? (Monthly/Quarterly/Yearly) ______________
7. What is the approximate distance of storage tanks to assembly line? ________________
8. What type of fuel lines are used to pipe fuel from storage tank to assembly line? ______________
9. What type of fuel filters are used? _______________
10. What is the location of the fuel filters? ____________________
11. What is filter media size? ________________ micron
12. What is PM procedure for fuel filters? _______________
13. What is quantity of factory fill? ___________ Gallons
14. What is vehicle fuel tank capacity? _____________ Gallons
15. What percentage of fuel tank capacity is factory fill? ______ %

INSTALLATION AND FUEL SYSTEM PRIME

1. Is assembly plant receiving & using engines in FIFO order? (Circle One) YES NO
2. Assembly Plant - "Daily Volumes". ____________
3. On average, the number of shifts worked per plant. (i.e. 1, 2 or 3) __________
4. Does assembly plant use lubricants in assembly of fuel system? (Circle One) YES NO
   If yes, please identify in detail. _____________________________________
5. Is injector electrical connection made at the vehicle plant? (Circle One) YES NO
   If yes, is injector electrical connection made carefully? (Circle One) YES NO
   If yes, is injector wiring excessively stretched, pinched or chafed? (Circle One) YES NO
6. At what point is key first turned on following fuel fill? ____________________
7. Is engine controller (PCM/VCM) programmed on line? (Circle One) YES NO
8. If yes, what is program / fuel fill / system prime sequence?
   Program / fuel fill / prime ☐
   Fuel fill / program / prime ☐
8. Does fuel pump run during programming? (Circle One) YES NO
9. What is fuel system prime procedure? ____
10. How long does fuel pump run to prime system? __________________seconds
11. Are the latest assembly instruction documents available & being observed by plant? YES NO

DELPHI

VEHICLE START AND DVT

1. At what point in assembly is engine started? ________________________
2. What is typical crank time before start? _________________seconds
3. Is engine rough running on initial start? (Circle One) YES NO
4. If yes, how long does engine run rough? ________________seconds
5. How long does engine run prior to a dynamic vehicle test? ___________minutes
6. Are misfire codes checked prior to dynamic vehicle test and case learn? (Circle One) YES NO
7. Are misfire history codes cleared prior to dynamic vehicle test and case learn? (Circle One) YES NO

VEHICLE DIAGNOSTICS

1. Where in the process are hydro-locked engines typically detected? _____________________
2. What is the frequency of hydro locked engines? ___________ engines per month
3. Average daily number of vehicles in repair due to fuel system related issues? ___________

	Diagnostic	**Always**	**Sometimes**	**Never**
4.	Use diagnostic tool (Tech 2) to identify misfiring cylinder.	☐	☐	☐
5.	Check for spark on suspect cylinder.	☐	☐	☐
6.	Pull spark plug to check for wetness/fouling.	☐	☐	☐
7.	Perform fuel pressure test.	☐	☐	☐
8.	Perform injector balance test.	☐	☐	☐
9.	Check oil for presence of gasoline.	☐	☐	☐

10. Does plant return suspect material tagged with detailed problem description and any test results? (Circle One) YES NO
(Please e-mail and/or fax assembly instruction documents to Bruce Gardephe @ (585 359-6361)

Comments

Note: Please complete & forward information to Bruce Gardephe @ Delphi E&C. TCR, via e-mail Bruce.Gardephe@delphi.com and/or fax (585) 359-6361
Any questions, concerns and/or comments please call (585) 359-6361. Thanks! again for your participation.

Criteria of 'Assembly Practice Evaluation'

	Inventory Management (FIFO)	
●	Best Practice - totally meets requirements	Inventory weeks < or = to 4
◑	Process in place, but does not meet requirements	Inventory weeks > 4 and < 12
○	No Process in place - does not meet requirements	Inventory weeks > 12
	Injector Lubrication (Engine Plant)	
●	Best Practice - totally meets requirements	Light Mineral oil applied to manifold injector socket
◑	Process in place, but does not meet requirements	Lubricant other than mineral oil applied to manifold injector socket
○	No Process in place - does not meet requirements	Lubricant applied directly to injector
	Injector Electrical Connection	
●	Best Practice - totally meets requirements	Connection made carefully, wires, not stretched pinched or chaffed.
◑	Process in place, but does not meet requirements	Wires stretched during process, but ok at final vehicle assembly
○	No Process in place - does not meet requirements	Wires stretched, pinched or chaffed at vehicle final assembly
	Fuel System Lubrication (Vehicle Plant)	
●	Best Practice - totally meets requirements	Light Mineral oil applied to components or no lubrication used
○	No Process in place - does not meet requirements	Lubricant other than light mineral oil applied to components
	Fuel Line Connection	
●	Best Practice - totally meets requirements	Back up wrench used on threaded fittings
○	No Process in place - does not meet requirements	No ack up wrench used on threaded fittings
	Fuel System Purge After Hot Test (Engine Plant)	
●	Best Practice - totally meets requirements	Run the fuel system dry by turning off fuel supply and continuing to run engine at a part throttle condition until the fuel in the rail is exhausted
◑	Process in place, but does not meet requirements	Pressures in excess of 450 kPa, vacuums in excess of 24" Hg applied to rail or voltages greater than 6 at 100% Duty Cycle
○	No Process in place - does not meet requirements	
	Fuel System Prime (Vehicle Plant)	
●	Best Practice - totally meets requirements	System primed for 15 to 20 seconds
◑	Process in place, but does not meet requirements	System primed for <10 seconds >20 seconds
	Misfires recorded prior to case being learned	
●	Best Practice - totally meets requirements	Misfires not recorded prior to case being learned, or history codes cleared prior to DVT
◑	Process in place, but does not meet requirements	
○	No Process in place - does not meet requirements	Misfires recorded prior to case learn, and history codes not cleared prior to DVT
	Vehicle Repair - Root Cause Analysis	
●	Best Practice - totally meets requirements	Use proper procedures have all essential tools
◑	Process in place, but does not meet requirements	Use proper procedures do not have all essential tools
○	No Process in place - does not meet requirements	Do not use proper procedures
	Injector or Fuel System Replacements	
●	Best Practice - totally meets requirements	Proper lubrication and "O" rings not reused
◑	Process in place, but does not meet requirements	Improper lubrication, or "O" rings reused
○	No Process in place - does not meet requirements	
	Part Return Process	
●	Best Practice - totally meets requirements	Parts returned in a timely manner, tagged and clearly marked with reason for return and diagnostic results as applicable
◑	Process in place, but does not meet requirements	Parts returned in a timely manner, but with little or no information
○	No Process in place - does not meet requirements	Parts not returned in a timely manner, and with little or no information

10.5 Glossary of Terms and Abbreviations

AAMA	American Automobile Manufacturers Association
A/C	Air Conditioner
AE	Acceleration Enrichment
A/F	Air/Fuel Ratio
ASDF	Alternating Simultaneous Double Fire
ASTM	American Society for Testing and Materials
BDC	Bottom Dead Center
BLM	Block Learn Multiplier
BSFC	Brake Specific Fuel Consumption
BPW	Base Pulse Width
CARB	California Air Resource Board
C/L	Closed-Loop
Component Technical Specification	(CTS) Delphi authored document containing the injector performance requirements for a specific application.
COT	Catalyst Over-Temperature Protection
CPA	Connector Position Assurance
CPS	Crankshaft Position Sensor
CR	Closing Response
CTS	Coolant Temperature Sensor
D_{32}	Sauter Mean Diameter
DE	Deceleration Enleanment
DI	Driveability Index (Fuel)
DI	Direct Injection
DLC	Data Link Connector
DFCO	Decel Fuel Cut Off
DFMEA	Design Failure Mode Effects Analysis
DMOV	Dynamic Minimum Operating Voltage
DV_{90}	Droplet size which 90% of spray volume is less than
DVT	Dynamic Vehicle Testing
E-85	85% Ethanol Fuel Blend
ECM	Engine Control Module
ECT	Engine Coolant Temperature
EGR	Exhaust Gas Recirculation
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency (US)
FIFO	First In First Out
FMD	Fuel Mode Device
FMEA	Failure Modes Effect Analysis
FTP	Federal Test Procedure

	(Emissions)
GM	Grams
HP	Horsepower
IAC	Idle Air Control
IAFM	Integrated Air Fuel Module
IAT	Intake Air Temperature
ISO	International Standards Organization
KPH	Kilometers per Hour
LEV	Low Emissions Vehicle
LR	Linear Range
M5	5% Methanol Fuel Blend
MAF	Mass Air Flow
MAP	Manifold Absolute Pressure
MIL	Malfunction Indicator Lamp
MOV	Minimum Operating Voltage
MPFI	Multi Port Fuel Injection
MPH	Miles per Hour
MPW	Minimum Pulse Width
MTBE	Methyl Tertiary Butyl Ether
OBD	On Board Diagnostics
OR	Opening Response
PAD	Production Assembly Document
PCV	Positive Crankcase Ventilation
PCM	Powertrain Control module
PE	Power Enrichment
PS	Power Supply
PSD	Power Spectral Density
PW	Pulse Width
PWM	Pulse-Width Modulation
PZEV	Partial Zero Emissions Vehicle
QA	Quality Assurance
QRD	Quality Reliability Durability
RFG	Reformulated Gasoline
RFI	Radio Frequency Interference
RMS	Root Mean Square
RPM	Revolutions per Minute
RR	Repetition Rate (Period)
RVP	Reid Vapor Pressure
SAE	Society of Automotive Engineers
SCR	Specific Component Requirements
SD	Sequential Driver
SDF	Simultaneous Double Fire
SF	Static Flow
SFI	Sequential Fuel Injection
SFMEA	System Failure Mode Effects Analysis
SMD	Sauter Mean Diameter

SMOV	Static Minimum Operating Voltage
SOP	Start of Production
SP	Set Point Flow Rate
SSF	Simultaneous Single Fire
SULEV	Super Low Emissions Vehicle
TCC	Torque Converter Clutch
T/C	Thermocouple
TDC	Top Dead Center
TLEV	Transitional Low Emissions Vehicle

Test Specification Sheet	Delphi document containing application specific injector performance specifications
TPA	Terminal Position Assurance
TPS	Throttle Position Sensor
ULEV	Ultra Low Emissions Vehicle
USCAR	United States Council For Automotive Research
VCM	Vehicle Control Module
VE	Volumetric Efficiency
VSS	Vehicle Speed Sensor
WFR	Working Flow Range
WOT	Wide Open Throttle
ZEV	Zero Emissions Vehicle

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