ASE 8 - Engine Performance

Module 6
Fuel Injectors
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## Contents

**Module 6 – Fuel Injectors**

Acknowledgements ........................................................................................................ 2

Objectives ....................................................................................................................... 4

- Throttle Body Injection ................................................................................................. 5
- TBI Assembly .................................................................................................................. 6
- Fuel Flow ......................................................................................................................... 8
- Constant Bleed Passage ................................................................................................. 9
- TBI Assemblies with Constant Bleed Passage ............................................................... 9
- TBI Injector ..................................................................................................................... 10
- Multi-port Fuel Injection ............................................................................................... 11
- Multi-port Fuel Injection System Operation ............................................................... 13
- MFI Throttle Body ......................................................................................................... 14
- Exercise 1 ...................................................................................................................... 23
- Exercise 2 ...................................................................................................................... 24
- Exercise 3 (optional) ..................................................................................................... 25
Objectives

Student will become familiar with the various types of fuel injectors as used in applications on General Motors vehicles.

NATEF Area VIII. D.
8. Inspect and test fuel injectors P-2

STC Tasks:

Area A 8 Engine Performance
D. Types of Injectors
   1 Describe the different types of injectors used by GM Powertrain

E. Multi-port Fuel Injector System
   1 Identify the components of the Sequential Multi-port Fuel Injector System
   2 Describe the components of the Sequential Multi-port Fuel Injector System
   3 Identify the components of the Central Sequential Multi-port Fuel Injector System
   4 Describe the components of the Central Sequential Multi-port Fuel Injector System
Throttle Body Injection

GM Throttle Body Injection was introduced in 1980 on the 6.0-liter V8 Cadillac engine and was used extensively throughout the 1980s on many engine applications. Four-cylinder engines used a TBI unit with a single injector mounted in the throttle body. V6 engines and many V8s, including the 1980 Cadillac application, used a single throttle body with dual injectors. Some 5.0-liter and 5.7-liter engines had two TBI units, each with a single injector. It was called Cross Fire Injection, after the design of the cross-over air intake plenum.

In a TBI system, fuel is injected from single or dual injectors into matching throttle bores and delivered to the engine through the intake manifold. Injector pulses occur at regular intervals, usually being timed to ignition reference signals being sent to the PCM. In a dual-injector unit, the injectors are pulsed alternately.

Because fuel atomization does not depend on intake manifold pressure/vacuum, TBI has many advantages over a carburetor system:

- Fuel is atomized better during cold starts and engine warm-up
- The fuel mixture is enriched more accurately during cold starts, depending on engine coolant and ambient temperature
- Mixture enrichment is kept to the minimum necessary during cold starts
- The only mechanical linkage is the throttle
- Air/fuel mixture distribution is more consistent under all operating conditions
- Fuel control is accurately metered for improved fuel economy and reduced emissions
TBI Assembly

The TBI unit consists of two major assemblies, the fuel meter body and the throttle body (Figure 6-1). Depending on the engine, the fuel meter body has a single bore and one injector or dual bores and two injectors. In addition to the injector(s), the fuel meter body contains the pressure regulator. The throttle position sensor, the idle air control valve and the vacuum ports for components such as the MAP sensor, EGR and EVAP canister purge are located in the throttle body.

![TBI Assembly Diagram](image)

*Figure 6-1, TBI Unit (Model 700 shown)*
Several types of TBI units have been used. Some examples are Figure 6-2 and 6-3.

Figure 6-2, TBI Unit

Figure 6-3, TBI Unit
Fuel Flow

Pressurized fuel enters the TBI unit from the supply line and passes through the inlet filter (Figure 6-4). As the injector is pulsed on and off, fuel is atomized and sprayed into the throttle body in a conical pattern. Excess fuel flows past the pressure regulator into the return line and back to the fuel tank.

Figure 6-4, TBI System Components
**Constant Bleed Passage**

Some TBI systems have a constant bleed passage (Figure 6-5) that helps to reduce vapor buildup when a hot engine is shut off. The system consists of a small orifice to allow vapor past the regulator to the return line and back to the fuel tank. In a static system, this creates a circulating fuel flow. The fuel lines are cooled by the flow of fuel, reducing hot start vapor conditions.

![Figure 6-5, Constant Bleed Passages](image)

Because this system has an internal bleed feature, the fuel pressure will drop as soon as the engine and fuel pump turn OFF. This means that the system will NOT have residual pressure, as do all other injection systems. This may lead to misdiagnosis if you are not aware of this feature.

**TBI Assemblies with Constant Bleed Passage**

<table>
<thead>
<tr>
<th>Passenger Car Engines</th>
<th>Light-Duty Truck Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0L VIN P</td>
<td>2.8L VIN R</td>
</tr>
<tr>
<td>2.0L VIN 1</td>
<td>3.1L VIN D</td>
</tr>
<tr>
<td>2.2L VIN G</td>
<td>4.3L VIN Z, B</td>
</tr>
<tr>
<td>3.1L VIN D</td>
<td>5.0L VIN H</td>
</tr>
<tr>
<td>4.3L VIN Z</td>
<td>5.7L VIN K</td>
</tr>
<tr>
<td>5.0L VIN E, 7</td>
<td>7.4L VIN N</td>
</tr>
<tr>
<td>5.7L VIN 7, 8</td>
<td></td>
</tr>
</tbody>
</table>
**TBI Injector**

A TBI injector is an electromagnetic device containing a solenoid, which consists of a coil and a core (equivalent to the winding and the armature in an electric motor). When the PCM energizes the coil through the injector driver, the core is lifted up, moving the spring-loaded ball valve off its seat. Pressurized fuel is directed through the spray tip into the throttle body. The injector on the left in Figure 6-6 is the type used in TBI model 200, 220, 300, 400 and 500 assemblies. The injector on the right is a Multec injector and is used in the TBI model 700.

*Figure 6-6, TBI Injectors*
**Multi-port Fuel Injection**

Multi-port Fuel Injection (MFI)- This term is broadly used to describe all port fuel injection systems. It is more accurately used to describe systems where the injectors are pulsed simultaneously or in groups.

- Sequential Fuel Injection (SFI)- This system pulses the injectors one at a time, in engine firing sequence.
- Central Multi-port Fuel Injection (Central MFI)
- Central Sequential Multi-port Fuel Injection (Central SFI)
- MFI provides better overall performance and fuel economy as compared to TBI. A Multi-port system generally uses one injector per cylinder. One exception is the LT5 V8 engine, which has two injectors per cylinder.

A Multi-port Fuel Injection system uses one injector for each cylinder in the engine. In an MFI system, atomized fuel is injected in a narrow cone into the intake manifold, between 3 and 4 inches from the intake valve (Figure 6-7).

![Figure 6-7, Injector Spray Pattern](image)

As a result of using an individual injector for each cylinder, MFI provides several advantages.

Engine torque output is increased as the result of:

- Ram tuning for a denser air charge to the cylinders
- Lower air/fuel mixture temperatures. This increases cylinder charge density and eliminates Early Fuel Evaporation (EFE) and Thermac air cleaner
Emissions performance is improved as the result of:

- Enhanced air/fuel distribution
- Eliminating problems of fuel condensation on intake manifold walls
- Leaner operation during warm-up
- Improved air flow sensing that takes account of intake air humidity, temperature and pressure

Improved fuel economy results from:

- Lower axle ratios while retaining the same performance level as a higher ratio
- More precise fuel flow management

Figure 6-8, Typical Multi-port Fuel Injection System
Multi-port Fuel Injection System Operation

Of the various Multi-port fuel systems, there are very specific injector operations. They include simultaneous, alternating double-fire, group-timed, and sequential fuel injection.

Simultaneous Fuel Injection

All injectors are energized at the same time, once per crankshaft revolution. Because an engine makes two revolutions per combustion cycle, each port gets two injections of fuel during each cycle. As a result, the sequence is also known as double-fire injection.

Alternating Double-Fire Injection

2.3-liter Quad 4 engines (VIN A and VIN D) use a variation of the simultaneous injection sequence. Two of the four injectors are energized every 1800 of crankshaft rotation, and each pair is triggered twice per combustion cycle. The injectors are paired: #1 with #4 and #2 with #3. The 4-stroke cycle and the double injection of fuel ensures that each cylinder receives the fuel needed for combustion.

Group-Timed Fuel Injection

The 1992-1993 5.7-liter (RPO LT1) engine features group-timed fuel injection. Injector group A (#1, #3, #5, #7) is controlled by one PCM driver circuit and group B (#2, #4, #6, #8) is controlled by another PCM driver circuit. This strategy allows the PCM to manage each cylinder bank separately for performance, fuel economy, and emissions control.

Sequential Multi-port Fuel Injection

The distinguishing feature of Sequential Multi-port Fuel Injection (SFI) is that each injector is energized sequentially (one after the other) in the firing order of the cylinders and timed to the opening of the intake valves. SFI is timed by reference pulses from the crankshaft sensor and sequenced by the camshaft sensor.
MFI Throttle Body

One major difference between MFI and TBI, besides the number of injectors, is the throttle body. Unlike the throttle body of a TBI system, which houses the injector, the MFI throttle body’s primary function is to meter incoming air. The throttle body still houses the TP sensor and IAC valve. In addition, coolant passages have been designed into the throttle body to prevent throttle icing (Figure 6-9).

Figure 6-9, Throttle Body Assembly
Another unique part of the MFI fuel system is the fuel rail. The rail assembly is secured to the intake manifold. It holds the fuel injectors in position and carries pressurized fuel to the injectors. Various fuel rail configurations are shown in Figure 6-10. The injectors are sealed to the fuel rail with an O-ring and retaining clip. The O-ring prevents fuel leaks and helps insulate the injector from vibration and heat. The retaining clip positions the injector and locks it in place on the rail.

A fuel pressure tap is available on most fuel rails. The tap is used to check, or relieve, system pressure for servicing. In addition, the fuel rail may contain an expansion chamber which reduces the pressure pulsations caused by the fuel pump and injector "ON"/"OFF" cycling.

Figure 6-10, Fuel Rail Assembly
**Fuel Injectors**

At the heart of the MFI system is a set of electronically controlled fuel injectors, one per cylinder, operating under the control of the PCM. The PCM uses inputs from numerous sensors and switches to calculate fuel delivery.

Various types of fuel injectors have been used with MFI systems: the Bosch pintle type and the Multec ball-and seat type (Figure 6-11).

The Multec injector has a stainless steel ball and seat valve, which are finished to a near mirror smoothness to obtain a positive seal. A director plate with six holes, which is insensitive to fuel deposits, provides spray pattern control. As a result, the Multec injector is less susceptible to plugging caused by varnish buildup.

The Bosch injector uses a pintle valve and seat. The pintle is ground to provide a leakproof seal. A diffuser below the valve seat provides an atomized fuel spray pattern of approximately 25 degrees.

*Figure 6-11, Bosch and Multec Fuel Injectors*
Later Bosch injector designs have a "chimney" surrounding the pintle to reduce varnish buildup on the pintle and seat (Figure 6-12).

Bottom Feed Port injectors are used on the 2.2-liter (LN2) four-cylinder engine. Fuel enters at the bottom of the injector, as opposed to the top of the injector which is typical (Figure 6-13). The intake manifold features a machined-in longitudinal fuel passage with intersecting injector bores. This eliminates the need for a fuel rail.

The Multec injector design used on the 3.4-liter DOHC V6 has four holes and a "directed" fuel spray pattern (Figure 6-14).
MFI Injector Identification

Different injectors are calibrated for different flow rates. When replacing fuel injectors, be sure to order the correct injector for the application being serviced. Refer to Figures 6-15 and 6-16 for part number location.

Figure 6-15, Bosch Injector Identification

Figure 6-16, MFI Injector Part Number Location
**Multec-II Fuel Injectors**

The 3.1L - (LX5) V6 engine is equipped with new Multec-II fuel injectors. The outside diameter is about half the diameter of the Multec-I injector, which improves fuel targeting. The solenoid coil and bobbin are sealed from the fuel stream to prevent corrosion from materials in the fuel stream. Several other enhancements were also made to the injector to improve performance and durability. Beginning in 1999, several other vehicles began using Multec-II fuel injectors.

Normal resistance of the injector coil is 12.2 ohms. There is an eight digit part number stamped on the fuel injector body for identification. Refer to Figure 6-17.

![Figure 6-17, Multec II Fuel Injector](image)

![Figure 6-18, Multec II Assembly Part Number](image)
Central Multi-port Fuel Injection (CMFI)

Central Multi-port Fuel Injection (CMFI) is a hybrid of Multi-port and throttle body injection. A throttle body-type injector solenoid meters fuel to poppet valves for each cylinder (Figure 6-19).

The CMFI assembly is fully contained within the intake manifold and consists of:

- An injector solenoid located in the center of the lower manifold that meters and distributes fuel simultaneously to six poppet nozzle assemblies. The low-impedance injector solenoid is a single-disc, multiple-hole shutoff design
- A low-gain fuel pressure regulator that is integrally mounted to the CMFI assembly for direct response to manifold pressure and control of fuel pressure within the fuel meter body
- Six poppet nozzles, located at the port entrance of each manifold runner, that simultaneously deliver calibrated fuel flow via nylon tubes from the fuel meter body to the cylinders

Fuel flow in the system is governed by three factors:

1. Fuel pressure at the injector solenoid (regulator)
2. Pulse-width activation of the solenoid controlled by the PCM
3. Constant pressure drop through individual poppet nozzles
**Injector Solenoid**

The single-disc, centrally mounted injector solenoid (Figure 6-20) is controlled by the PCM through injector pulse-width voltage. Fuel pressure at the injector solenoid is controlled by the pressure regulator.

The injector solenoid is a multiple-hole shutoff design that distributes metered fuel. A six-hole distributor gasket seals the pressurized fuel flow to each of the six fuel meter body passages that, in turn, transport the flow to the individual poppet nozzle tubes.

![Figure 6-20, Injector Solenoid](image)

**Poppet Nozzles**

Each poppet nozzle contains a check ball and extension spring that together regulate fuel flow through the valve to its cylinder (Figure 6-21). Fuel flows from the poppet nozzle when pressure exceeds 254 to 296 kPa (37 to 43 psi).

![Figure 6-21, Poppet Nozzles](image)

**Injector Solenoid Energized**

As fuel enters the poppet nozzle, the poppet recognizes an increase in pressure. When this pressure overcomes the force exerted by the extension spring, the ball at the cylinder end of the poppet nozzle unseats. Fuel can then spray to the cylinder.

**Injector Solenoid De-Energized**

When the injector solenoid de-energizes, pressure inside the poppet is reduced. Force applied by the extension spring causes the ball to seat again, thus cutting off fuel flow to the cylinder.
Central SFI, used on light trucks beginning in 1996, is similar to the CMFI system used on the 4.3-liter (RPO L35) V6. Rather than one throttle-body-type injector feeding all the poppet nozzles, there is now one electrical injector for each poppet nozzle (Figure 6-22). Each is fired sequentially for accuracy and precise metering control.

The Central SFI injectors are located in the fuel meter body assembly. Also included in this assembly are the fuel inlet and return, fuel pressure regulator and the electrical connector for the injectors. Each injector and poppet nozzle assembly is a single unit and can be serviced individually.

Within the fuel meter body assembly, the fuel injectors are surrounded by fuel except for the top and bottom. This is similar to bottom feed injectors.

When an injector energizes, the increased fuel pressure pushes the poppet nozzle’s ball off its seat. Fuel is supplied for the cylinder. When the injector de-energizes, spring force overcomes the decreased fuel pressure and the ball seats, cutting off fuel supply at the nozzle.
Exercise 1

Using the assigned vehicle and resources in the classroom, answer the following questions:

1. Vehicle ________________  VIN ______________________________

2. How many fuel injectors does the vehicle have? _______________

3. What type of injectors are they? _____________________________

4. What type of firing sequence does the vehicle use?
___________________________________________________________

5. What is the order of firing for these injectors?
   __ __ __ __ __ __ __ __ __ __
Exercise 2

Fuel injectors are a very specialized type of solenoid. Since a solenoid has to have a power source and a ground to operate, describe below:

1. Injector power source (describe from battery to the injector, circuit number, wire color, fuses, relays, control units, as needed):
   ________________________________________________________
   ________________________________________________________
   ________________________________________________________

2. Source of ground for the injector (describe from injector to battery, circuit number, wire color, fuses, relays control units, as needed):
   ________________________________________________________
   ________________________________________________________
   ________________________________________________________

3. At the vehicle, verify the following:
   a. Power feed wire color injector number:
   b. Control (trigger) wire color:
   c. Does the vehicle wiring match the SI wiring diagram? __________
   d. What is the voltage at the power feed of each injector?
Exercise 3 (optional)
Remove an injector from the engine.

1. Using SI, what precautions are noted for this procedure?
   _______________________________________________________
   _______________________________________________________
   _______________________________________________________

2. What parts must be replaced when changing an injector?
   _______________________________________________________
   _______________________________________________________
   _______________________________________________________

3. What is the part number and/or build date for the injector?
   _______________________________________________________
   _______________________________________________________
   _______________________________________________________