WOODWARD

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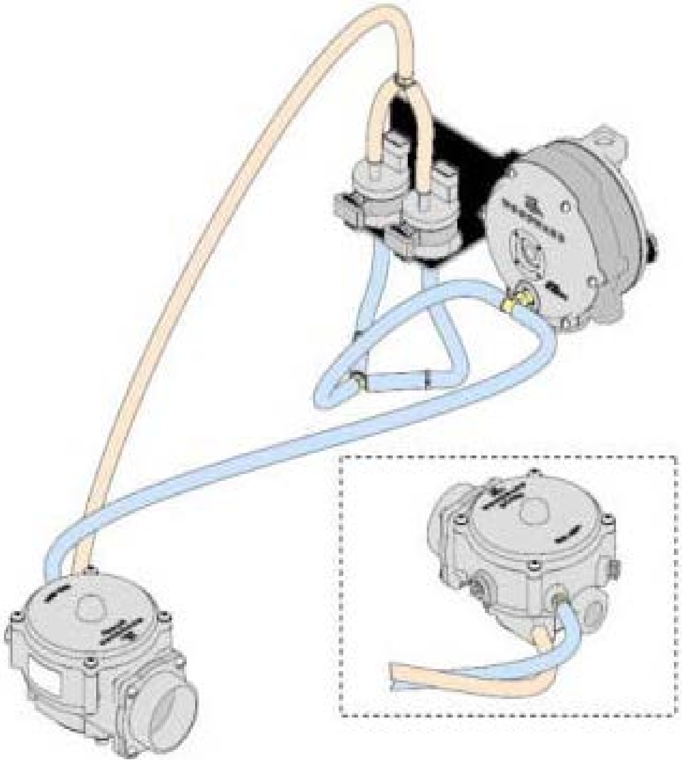

MI-21 Engine Control System for HMC 2.4L

Optional Supplementary Information

Application and Troubleshooting Manual

⚠ **General Precautions**	**Read this entire manual and all other publications pertaining to the work to be performed before installing, operating, or servicing this equipment.** **Practice all plant and safety instructions and precautions.** **Failure to follow instructions can cause personal injury and/or property damage.**

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Revisions— A bold, black line alongside the text identifies changes in this publication since the last revision.

Manual 35187

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Warnings and Notices

Important Definitions

⚠ This is the safety alert symbol used to alert you to potential personal injury hazards. Obey all safety messages that follow this symbol to avoid possible injury or death.

- **DANGER** - Indicates a hazardous situation, which if not avoided, will result in death or serious injury.
- **WARNING** - Indicates a hazardous situation, which if not avoided, could result in death or serious injury.
- **CAUTION** - Indicates a hazardous situation, which if not avoided, could result in minor or moderate injury.
- **NOTICE** - Indicates a hazard that could result in property damage only (including damage to the control).
- **IMPORTANT** - Designates an operating tip or maintenance suggestion.

⚠WARNING

Overspeed / Overtemperature / Overpressure

The engine, turbine, or other type of prime mover should be equipped with an overspeed shutdown device to protect against runaway or damage to the prime mover with possible personal injury, loss of life, or property damage.

The overspeed shutdown device must be totally independent of the prime mover control system. An overtemperature or overpressure shutdown device may also be needed for safety, as appropriate.

⚠WARNING

Personal Protective Equipment

The products described in this publication may present risks that could lead to personal injury, loss of life, or property damage. Always wear the appropriate personal protective equipment (PPE) for the job at hand. Equipment that should be considered includes but is not limited to:

- **Eye Protection**
- **Hearing Protection**
- **Hard Hat**
- **Gloves**
- **Safety Boots**
- **Respirator**

Always read the proper Material Safety Data Sheet (MSDS) for any working fluid(s) and comply with recommended safety equipment.

⚠WARNING

Start-up

Be prepared to make an emergency shutdown when starting the engine, turbine, or other type of prime mover, to protect against runaway or overspeed with possible personal injury, loss of life, or property damage.

⚠WARNING

Automotive Applications

On- and off-highway Mobile Applications: Unless Woodward's control functions as the supervisory control, customer should install a system totally independent of the prime mover control system that monitors for supervisory control of engine (and takes appropriate action if supervisory control is lost) to protect against loss of engine control with possible personal injury, loss of life, or property damage.

NOTICE

Battery Charging Device

To prevent damage to a control system that uses an alternator or battery-charging device, make sure the charging device is turned off before disconnecting the battery from the system.

Electrostatic Discharge Awareness

NOTICE

Electrostatic Precautions

Electronic controls contain static-sensitive parts. Observe the following precautions to prevent damage to these parts:

- **Discharge body static before handling the control (with power to the control turned off, contact a grounded surface and maintain contact while handling the control).**
- **Avoid all plastic, vinyl, and Styrofoam (except antistatic versions) around printed circuit boards.**
- **Do not touch the components or conductors on a printed circuit board with your hands or with conductive devices.**

To prevent damage to electronic components caused by improper handling, read and observe the precautions in Woodward manual *82715*, *Guide for Handling and Protection of Electronic Controls, Printed Circuit Boards, and Modules*.

Follow these precautions when working with or near the control.

1. Avoid the build-up of static electricity on your body by not wearing clothing made of synthetic materials. Wear cotton or cotton-blend materials as much as possible because these do not store static electric charges as much as synthetics.
2. Do not remove the printed circuit board (PCB) from the control cabinet unless absolutely necessary. If you must remove the PCB from the control cabinet, follow these precautions:
    - Do not touch any part of the PCB except the edges.
    - Do not touch the electrical conductors, the connectors, or the components with conductive devices or with your hands.
    - When replacing a PCB, keep the new PCB in the plastic antistatic protective bag it comes in until you are ready to install it. Immediately after removing the old PCB from the control cabinet, place it in the antistatic protective bag.

NOTICE

Exposing the boot to battery acid may damage the boot or limit its life and it is recommended that the boot be replaced if exposure occurs.

Warranty will be void if boot is exposed to battery acid.

All MI-21 active electronic components manufactured by the Woodward Inc. have been developed and individually tested for electromagnetic compatibility using standardized industry methods under laboratory test conditions. Actual Electromagnetic Compatibility (EMC) performance may be adversely affected by the wiring harness design, wire routing, the surrounding structure, other EMC generating components, and other factors that are beyond the control of the Woodward Inc. It is the responsibility of the vehicle and/or application manufacturer to confirm that the overall system's EMC performance is in compliance with all standards that they wish to apply for their particular use.

Regulatory Compliance

EPA / EU Emissions Certification: When properly applied, calibrated, and using an approved three-way catalyst, Woodward's Mobile Industrial (MI-21) control system is capable of meeting EPA 2007 Large Spark Ignited (LSI) emission standards (40 CFR Part 1048.101) and European Union (EU) regulation 2016/1628 of the European Parliament and of the Council of September 14, 2016 on requirements relating to gaseous pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery.

Evaporative emissions comply with 40 CFR Part 1048.105. These standards apply only to volatile liquid fuels such as gasoline.
Note: that the engine crankcase must be closed.

As defined in applicable regulations, the engine control system is designed to maintain emissions compliance for seven (7) years or 5000 hours, whichever occurs first, provided appropriate maintenance is performed as defined in the service manual for the system. Maintenance intervals shall be defined and approved by the regulating body. Component warranty shall comply with regulatory requirements (40 CFR Part 1048.120) for all emission related components. Warranty for non-critical emissions components will be as defined in the individual purchase agreement.

Maintenance Providers: Maintenance and repair services may be performed by you or any qualified engine service provider that you choose. However, your engine warranty does not cover damage or failure caused by improper maintenance or repairs.

North American Compliance: The N-2007 regulator is UL listed per Category ITPV LP-Gas Accessories for Engine Fuel Systems.

The N-2007 regulator and CA100 mixer have tamper-resistant features.

Chapter 1.
LPG System Overview

MI-21 General Description

Certified Engine Systems

Woodward's emission-certified MI-21 control system provides a complete, fully integrated engine management system for LSI engines as defined by the Environmental Protection Agency (EPA) or internal combustion engines for non-road mobile machinery as defined by the European Union (EU).

The control system is applicable to naturally aspirated engines ranging in size from 1.5L to 8.1L (25 HP to 170 HP) with up to 6 cylinders running on Liquified Petroleum Gas (LPG) and/or gasoline in mobile industrial applications.

It provides accurate, reliable, and durable control of fuel, spark, and air over the service life of the engine in the extreme operating environment found in heavy-duty, under hood, on-engine electronic controls.

MI-21 is a closed loop system utilizing a catalytic muffler to reduce the emission level in the exhaust gas. To obtain maximum efficiency from the catalyst, an accurate control of the air fuel ratio is required. A SECM uses two heated exhaust gas oxygen sensors (HEGO) in the exhaust system to monitor exhaust gas content. One HEGO is installed in front of the catalytic muffler and one is installed after the catalytic muffler. See Figure 1-1 for a system level diagram.

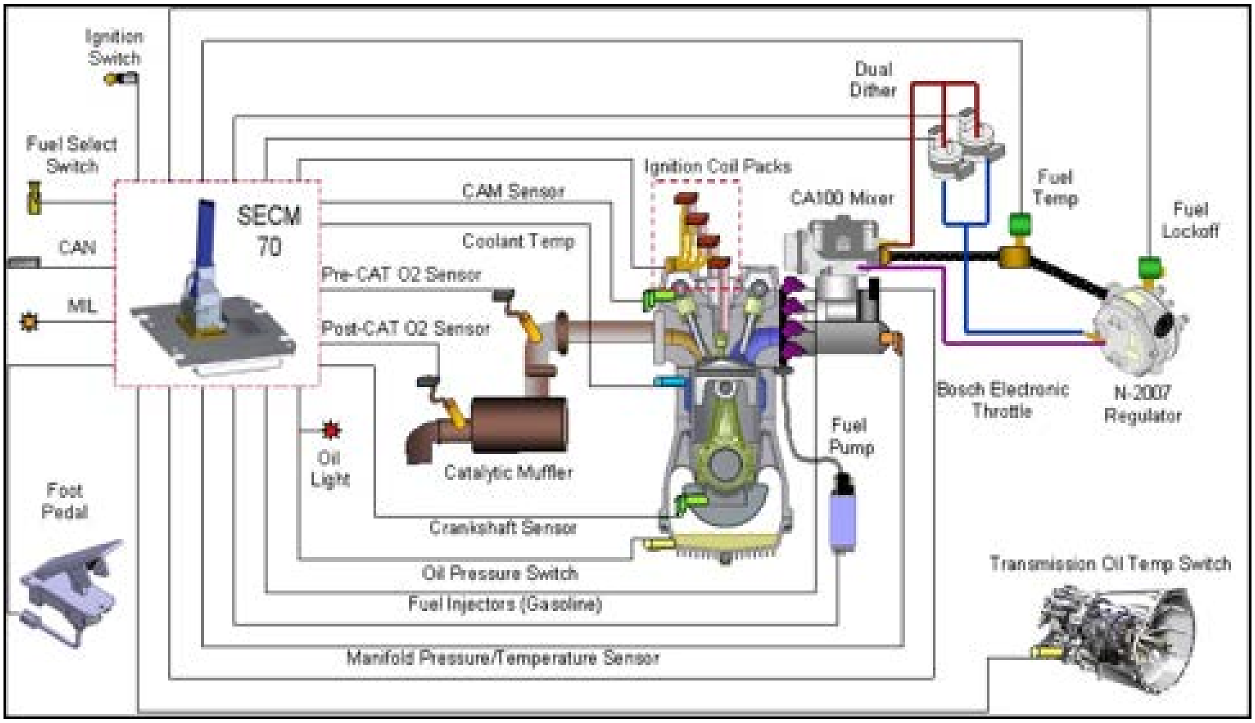


Figure 1-1. MI-21 Bi-Fuel System for 2.4L Hyundai Engine on Certified Systems

In LPG operation, the SECM makes any necessary corrections to the air fuel ratio by controlling the inlet fuel pressure to the air/fuel mixer by modulating the dual fuel trim valves (FTV) connected to the regulator. Reducing the fuel pressure leans the air/fuel mixture and increasing the fuel pressure enriches the air/fuel mixture. In gasoline operation, the SECM makes any necessary corrections to the air fuel ratio by controlling the fuel injectors. To calculate any necessary corrections to the air fuel ratio, the SECM uses several different sensors to gain information about the engine’s performance. Engine speed is monitored by the SECM through a variable reluctance (VR) or Hall Effect sensor. Intake manifold air temperature and absolute pressure are monitored with a Temperature and Manifold Absolute Pressure (TMAP) sensor. MI-21 is a drive-by-wire (DBW) system connecting the accelerator pedal to the electronic throttle through the electrical harness; mechanical cables are not used. A throttle position sensor (TPS) monitors throttle position in relation to the accelerator pedal position sensor (APP) command. Engine coolant temperature and adequate oil pressure are monitored by the SECM. The SECM controller has full adaptive learning capabilities, allowing it to adapt control function as operating conditions change. Factors such as ambient temperature, fuel variations, ignition component wear, clogged air filter, and other operating variables are compensated.

Non-Certified Engine Systems

In non-certified systems the LPG regulator and the mixer are operated in open loop as no mixture adjustments are made by the SECM. The LPG fuel temperature sensor and FTV’s have been removed with a balance line connecting the regulator secondary with the air valve vacuum (AVV) of the mixer. Both idle mixture adjustment and a power valve adjustment are used on the non-certified mixer. Manifold pressure from the TMAP, Revolutions Per Minute (RPM) from the crank position sensor and throttle position is used by the SECM to calculate load. Feedback from the electronic throttle is still provided to the SECM by the TPS as in the certified system. See Figure 1-2 for a system level diagram.

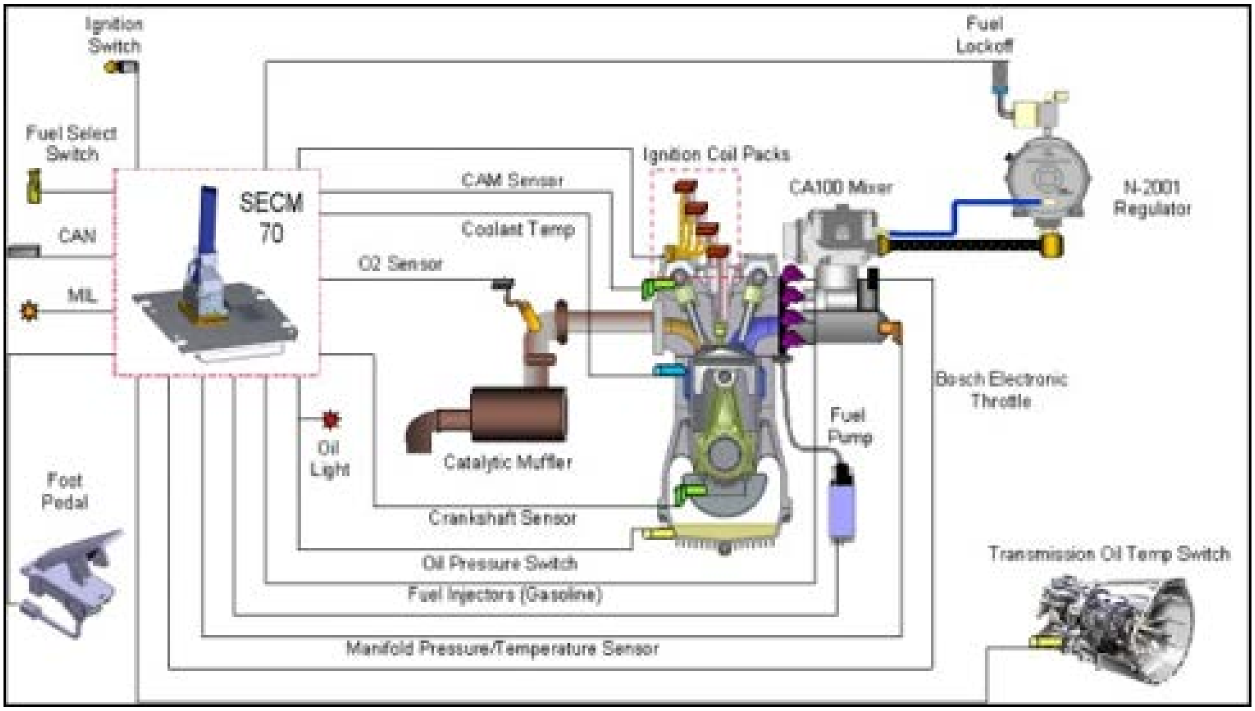


Figure 1-2. MI-21 Bi-Fuel System for 2.4L Hyundai Engine on Non-Certified Systems

Key Component Differences between Certified and Non-Certified Systems

See block diagrams in Figure 1-1-3 and Figure 1-1-4 for key differences between certified and non-certified systems.

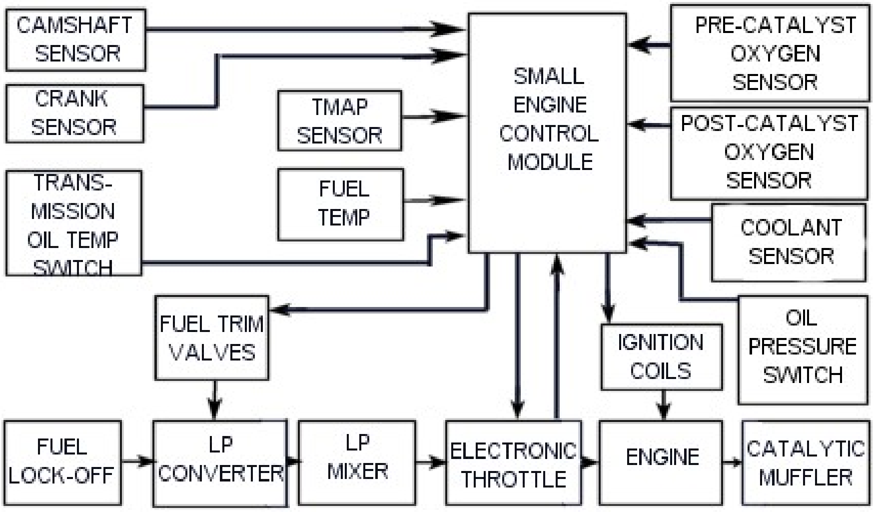


Figure 1-3. MI-21 Closed Loop LPG Fuel System (certified engine systems)

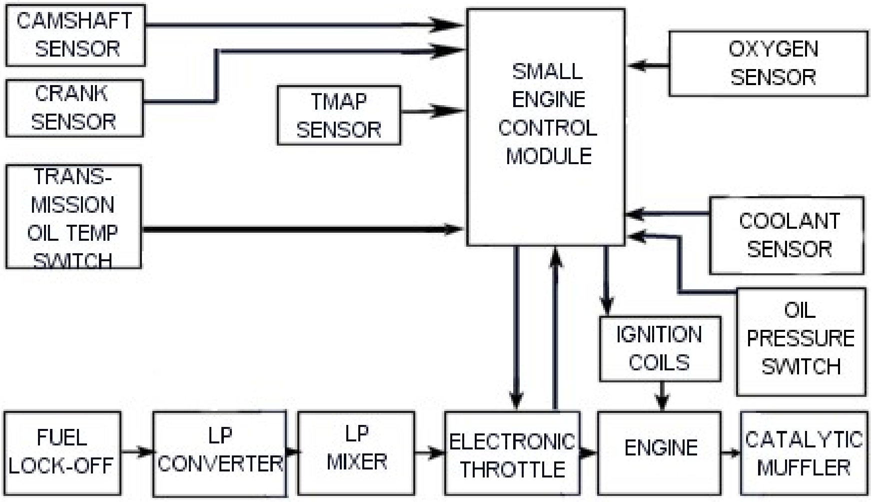


Figure 1-4. MI-21 Open Loop LP Fuel System (non-certified engine systems)

In non-certified systems using gasoline or dual fuel, a camshaft position sensor and pre-catalyst oxygen sensor are added. The camshaft sensor along with the crankshaft sensor is used to control the gasoline fuel injectors. Feedback from the pre-catalyst oxygen sensor is used by the SECM to adjust the gasoline delivery.

MI-21 System Components

The MI-21 control system provides electronic control to the following subsystems on mobile industrial engines:

- Fuel delivery system
- Spark-ignition control system
- Air throttle
- Sensors/Switches/Speed inputs

Key Components

The MI-21 system functions primarily on engine components that affect engine emissions and performance. These key components include but are not limited to the following:

- Engine/Combustion chamber design
- Intake/Exhaust valve configuration, timing and lift
- Intake/Exhaust manifold design
- Catalytic converter and exhaust system
- Throttle body
- Air intake and air filter
- Gaseous fuel mixer[†]
- Gaseous fuel pressure regulator[†]
- Fuel trim valves
- Fuel trim orifices
- SECM, firmware and calibration[†]
- Fuel system sensors and actuators
- Ignition system including spark plugs, cables, coils and drivers
- Gasoline injectors and fuel pressure regulator (bi-fuel systems only)

(†) Components of MI-21 system manufactured by Woodward

MI-21 System Features

The MI-21 system uses an advanced speed-density control strategy for fuel, spark, and air throttle control. Key features include the following.

- Closed-loop fuel control with fuel specific controls for LPG, and gasoline (MPI) fuels
- Speed-load spark control with tables for dwell, timing, and fuel type
- Speed-load throttle control with table for maximum TPS limiting
- Closed-loop fuel control with two oxygen sensors (one installed pre catalyst and one installed post catalyst). The pre-catalyst oxygen sensor includes adaptive learn to compensate for fuel or component drift. The post-catalyst oxygen sensor includes air fuel ratio compensation to achieve maximum catalyst efficiency.
- LPG fuel temperature compensation
- Min/max RPM governing
- All-speed isochronous governing
- Fixed-speed isochronous governing with three switch-selectable speeds

⚠WARNING

Ground Speed

Ground speed switch input does not have diagnostics for open wire. This can cause engine speed to run higher than expected and subsequently ground speed.

- Fuel enrichment and spark timing modifiers for temperature and fuel type
- Transient fuel enrichment based on rate of change of TPS
- Transient wall wetting compensation for gasoline
- Input sensor selection and calibration
- Auxiliary device control for fuel pump, fuel lock-off solenoid, tachometer, MIL, interlocks, vehicle speed limiting, etc.
- CANBus data transfer for speed, torque, etc.

Other system features include:

Tamper-Resistance

Special tools, equipment, knowledge, and authorization are required to effect any changes to the MI-21 system, thereby preventing unauthorized personnel from making adjustments that will affect performance or emissions.

Diagnostics

MI-21 is capable of monitoring and diagnosing problems and faults within the system. These include all sensor input hardware, control output hardware, and control functions such as closed-loop fuel control limits and adaptive learn limits. The list of faults can be seen in Table . Upon detecting a fault condition, the system notifies the operator by illuminating the Malfunction Indicator Lamp (MIL) and activating the appropriate fault action. The action required by each fault shall be programmable by the Original Equipment Manufacturer (OEM) customer at the time the engine is calibrated.

Diagnostic information can be communicated through both the service tool interface and the MIL lamp. With the MIL lamp, it is possible to generate a string of flashing codes that correspond to the fault type. These diagnostics are generated only when the engine is not running, and the operator initiates a diagnostic request sequence such as repeated actuations of the pedal within a short period of time following reset.

Limp Home Mode

The system is capable of "limp-home" mode in the event of particular faults or failures in the system. In limp-home mode the engine speed is approximately 1000 rpm at no load. A variety of fault conditions can initiate limp-home mode. These fault conditions and resulting actions are determined during calibration and are OEM customer specific.

Service Tool

A scan tool/monitoring device is available to monitor system operation and assist in diagnosis of system faults This device monitors all sensor inputs, control outputs, and diagnostic functions in sufficient detail through a single access point to the SECM to allow a qualified service technician to maintain the system. This software requires specific files and passwords to allow access to information.

Bi-Fuel System

A bi-fuel system operates on either LPG or gasoline. The engine will run on only one fuel at a time. The fuel type can be switched while the engine is stopped or running at low speeds and low loads. The fuel selection switch is a three-position type where the center position is fuel off.

Customer-Supplied Components

MI-21 requires additional components to operate that are not included with the system. These include the wire harness, mixer-to-throttle adapter, air horn adapter, mounting brackets, non-critical fittings, and hoses. These items are application specific and are the responsibility of the packager, manufacturer of record (MOR), or OEM. Woodward will aid as needed to ensure proper fitting to the MI-21 system components.

NOTICE

It is the responsibility of the customer to consult with Woodward regarding the selection or specification of any components that impact emissions, performance, or durability.

LPG Fuel System Operation

The principles outlined below describe the operation of MI-21 on an LPG fuel system.
- An LPG fuel system consists of the following components:
- Fuel filter (supplied by customer)
- Electric fuel lock-off solenoid valve
- Fuel pressure regulator/vaporizer
- Two fuel trim valves and fixed orifice fitting
- Gas/Air mixer with fixed orifice for trim system and fuel temperature sensor
- Miscellaneous customer-supplied hoses and fittings

Fuel is stored in the customer-supplied LPG tank in saturated liquid phase and enters the fuel system from the tank as a liquid and at tank pressure. Fuel passes through a high-pressure fuel filter and lock-off solenoid and is then vaporized and regulated down to the appropriate pressure to supply the mixer. The regulator controls the fuel pressure to the gas/air mixer.

Fuel Trim Valves (Dither Valve)

The key to meeting emissions requirements when operating in LPG is the dual fuel trim valves (dither valves) in the fuel system. The dual dither system modulates the fuel pressure regulator outlet pressure by providing an offset to the regulator secondary stage reference pressure. By adding a second dither valve, or FTV, smoother, more accurate control of supply pressure is achieved, resulting in better control of air fuel ratio and emissions. This smooth control also minimizes wear on fuel system components such as the regulator diaphragm and lever by significantly reducing the pressure pulsations observed with a single FTV.

Regulator Pressure Offset

Regulator pressure offset is achieved using a fixed orifice and a variable orifice in series. The inlet to the fixed orifice is connected to the mixer inlet pressure (roughly equal to ambient pressure). The outlet of the fixed orifice is connected to both the pressure regulator reference port and the inlet to the two FTVs (the variable orifice) that act in parallel. The outlets of the FTVs are connected to the mixer outlet, AVV. Thus, by modulating the FTVs, the pressure regulator reference pressure can be varied between mixer inlet pressure and AVV. For a given change in the pressure regulator reference pressure, the pressure regulator outlet pressure changes by the same amount and in the same direction. The result is that a change in FTV modulation changes the outlet pressure of the regulator/fuel inlet pressure of the mixer, and thus the air fuel ratio (AFR). A major benefit of this trim system results from the use of mixer inlet pressure and AVV as the reference pressure extremes. The pressure differential across the mixer fuel valve is related to these same two pressures, and thus so is fuel flow. Given this arrangement, the bias-pressure delta scales with the fuel-cone delta pressure. The result is that the trim system control authority and resolution on AFR stays relatively constant for the entire speed and load range of the engine.

SECM

The SECM controls the LPG lock-off solenoid valve and the FTVs. The lock-off solenoid is energized when LFP is selected as the fuel source and the engine is turning. FTV modulation frequency will be varied as a function of rpm by the SECM in order to avoid resonance phenomena in the fuel system. FTV commands will be altered by the SECM in order to maintain a stoichiometric air-fuel ratio. Commands are based primarily on feedback from the exhaust gas oxygen sensor, with an offset for fuel temperature.

MI-21 LP Fuel Filter

After exiting the fuel tank, liquid propane passes through a serviceable inline fuel filter to the electric fuel lock off. Figure 1-1-5 shows a typical inline type Liquified Petroleum (LP) fuel filter manufactured by Century. The primary function of the fuel filter is to remove particles and sediments that have found their way into the tank. The LP fuel filter will not remove heavy end solids and paraffins that build up in LPG fuel systems because of vaporization.

Figure 1-5. Inline LP Fuel Filter

MI-21 Fuel Lock-Off (Electric)

The fuel lock-off (Figure 1-1-6) is a safety shutoff valve, normally held closed by spring pressure, which is operated by an electric solenoid and prevents fuel flow to the regulator/ converter when the engine is not in operation. This is the first of three safety locks in the MI-21 system.

In the MI-21 design, power is supplied to the fuel lock-off via the main power relay with the SECM controlling the lock-off ground (earth) connection. The lock-off remains in a normally closed (NC) position until the key switch is activated. This supplies power to the lock-off and the SECM but will not open the lock-off via the main power relay until the SECM provides the lock-off ground connection. This design gives the SECM full control of the lock-off while providing additional safety by closing the fuel lock-off in the unlikely event of a power failure, wiring failure or module failure.

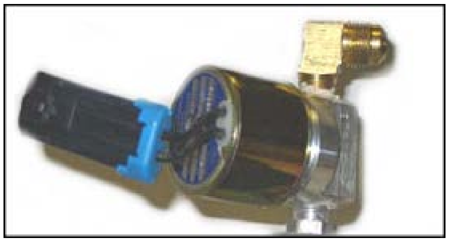


Figure 1-6. Electric Fuel Lock Assembly

When the liquid service valve in the fuel container is opened, liquid propane flows through the LP filter and through the service line to the fuel lock-off. Liquid propane enters the lock-off through the 1/4" NPT liquid inlet port and stops with the lock-off in the normally closed position. When the engine is cranked over the main power relay applies power to the lock-off and the SECM provides the lock-off ground causing current to flow through the windings of the solenoid creating a magnetic field. The strength of this magnetic field is sufficient to lift the lock-off valve off of its seat against spring pressure. When the valve is open liquid propane, at tank pressure, flows through the lock-off outlet to the pressure regulator/converter. A stall safety shutoff feature is built into the SECM to close the lock-off in case of a stall condition. The SECM monitors three engine states: Crank, when the crankshaft position sensor detects engine revolutions above a threshold; Stall, when the key is in the ON position but the crankshaft position sensor detects engine revolutions below a threshold; and the Run state, when the engine reaches pre-idle rpm. When an operator turns on the key switch the lock-off is opened, but if the operator fails to crank the engine the SECM will close the lock-off after 5 seconds.

N-2007 Pressure Regulator/Vaporizer

The pressure regulator/vaporizer (Figure 1-1-7) receives liquid LPG from the fuel storage tank, drops the pressure, changes the LPG phase from liquid to vapor, and provides vapor phase LPG at a regulated outlet pressure to the mixer. To offset the refrigeration effect of the vaporization process, the regulator will be supplied with engine coolant flow sufficient to offset the latent heat of vaporization of the LPG. An inline thermostat is recommended in the coolant supply line to maintain regulator outlet coolant temperature at or below 140 ^{o}F (60 °C). This will minimize the deposit of fuel contaminants and heavy ends in the regulator and assure a more controlled vaporization process with reduced pressure pulsations.

Figure 1-7. N-2007 Pressure Regulator/Vaporizer

A higher flow pressure regulator is required on larger engines.

The regulator is normally closed, requiring a vacuum signal (negative pressure) to allow fuel to flow. This is the second of three safety locks in the MI-21 system. If the engine stops, vacuum signal stops and fuel flow will automatically stop when both the secondary (2nd stage) valve and the primary (1st stage) valve closes. Unlike most other regulator/converters, the N-2007 primary valve closes *with* fuel pressure rather than against pressure, extending primary seat life and adding additional safety.

Liquid propane must be converted into a gaseous form in order to be used as a fuel for the engine. When the regulator receives the desired vacuum signal, it allows propane to flow to the mixer. As the propane flows through the regulator the pressure is reduced in two stages from tank pressure to slightly less than atmospheric pressure. As the pressure of the propane is reduced, the liquid propane vaporizes, and refrigeration occurs inside the regulator due to the vaporization of liquid propane. To replace heat lost to vaporization, engine coolant is supplied by the engine driven water pump and pumped through the regulator. Heat provided by this coolant is transferred through to the fuel vaporization chamber.

N-2007 Operation

(Refer to Figure 1-8)
Liquid propane, at tank pressure, enters the N-2007 through the fuel inlet port (**1**). Propane liquid then flows through the primary valve (**2**). The primary valve located at the inlet of the expansion chamber (**3**), is controlled by the primary diaphragm (**4**), which reacts to vapor pressure inside the expansion chamber. Two springs are used to apply force on the primary diaphragm in the primary diaphragm chamber (**5**), keeping the primary valve open when no fuel pressure is present.

A small port connects the expansion chamber to the primary diaphragm chamber. At the outlet of the expansion chamber is the secondary valve (**6**). The secondary valve is held closed by the secondary spring on the secondary valve lever (**7**). The secondary diaphragm controls the secondary lever. When the pressure in the expansion chamber reaches 1.5 psig (10.342 kPa) it causes a pressure/force imbalance across the primary diaphragm (**8**). This force is greater than the primary diaphragm spring pressure and will cause the diaphragm to close the primary valve.

Since the fuel pressure has been reduced from tank pressure to 1.5 psig (10.342 kPa) the liquid propane vaporizes. As the propane vaporizes it takes on heat from the expansion chamber. This heat is replaced by engine coolant, which is pumped through the coolant passage of the regulator. At this point vapor propane will not flow past the expansion chamber of the regulator until the secondary valve is opened. To open the secondary valve, a negative pressure signal must be received from the air/fuel mixer. When the engine is cranking or running a negative pressure signal (vacuum) travels through the vapor fuel outlet connection of the regulator, which is the regulator secondary chamber, and the vapor fuel inlet of the mixer. The negative pressure in the secondary chamber causes a pressure/force imbalance on the secondary diaphragm, which overcomes the secondary spring force, opening the secondary valve and allowing vapor propane to flow out of the expansion chamber, through the secondary chamber to the mixer.

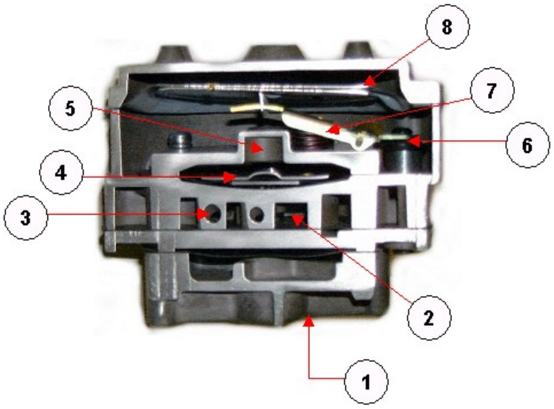


Figure 1-8. Part View of N-2007 Regulator

Because vapor propane has now left the expansion chamber, the pressure in the chamber will drop, causing the primary diaphragm spring force to re-open the primary valve allowing liquid propane to enter the regulator, and the entire process starts again. This creates a balanced condition between the primary and secondary chambers allowing for a constant flow of fuel to the mixer as long as the demand from the engine is present. The fuel flow is maintained at a constant output pressure, due to the calibrated secondary spring. The amount of fuel flowing will vary depending on how far the secondary valve opens in response to the negative pressure signal generated by the air/fuel mixer. The strength of that negative pressure signal developed by the mixer is directly related to the amount of air flowing through the mixer into the engine. With this process, the larger the quantity of air flowing into the engine, the larger the amount of fuel flowing to the mixer.

CA100 Mixer

The mixer (Figure 1-1-9) is installed above the throttle body and meters gaseous fuel into the airstream at a rate that is proportional to the volumetric flow rate of air. The ratio between volumetric airflow and volumetric fuel flow is controlled by the shaping of the mixer fuel cone and biased by the controllable fuel supply pressure delivered by the pressure regulator. Fuel flow must be metered accurately over the full range of airflows. Pressure drop across the mixer air valve must be minimized to assure maximum power output from the engine

Figure 1-9. CA100 Mixer

The mixer fuel inlet is fitted with a thermistor-type temperature sensor. This permits the SECM to correct fuel pressure to compensate for variations in fuel temperature. Left uncorrected, fuel temperature variations can cause significant variations in air fuel ratio.

A higher flow mixer is required on larger engines. A lower flow mixer is required on smaller engines.

CA100 Mixer Operation

Vapor propane fuel is supplied to the CA100 mixer by the N-2007 pressure regulator/converter. The mixer uses a diaphragm type air valve assembly to operate a gas-metering valve inside the mixer. The gas-metering valve is normally closed, requiring a negative pressure (vacuum) signal from a cranking, or running engine to open. This is the third of the three safety locks in the MI-21 system. If the engine stops or is turned off, the air valve assembly closes the gas-metering valve, stopping fuel flow past the mixer. The gas-metering valve controls the amount of fuel to be mixed with the incoming air at the proper ratio. The air/fuel mixture then travels past the throttle, through the intake manifold and into the engine cylinders where it is compressed, ignited, and burned. Mixer attached to throttle is shown in Figure 1-10

Figure 1-10. CA100 Mixer Attached to Throttle Body

(Refer to Figure 1-11)
The air/fuel mixer is mounted in the intake air stream between the air cleaner and the throttle. The design of the main body incorporates a cylindrical bore or mixer bore, fuel inlet (**1**) and a gas discharge jet (**2**). In the center of the main body is the air valve assembly, which is made up of the air valve (**3**), the gas-metering valve (**4**), air valve diaphragm (**5**), and air valve spring (**6**). The gas-metering valve (Figure 1-1-12) is permanently mounted to the air valve diaphragm assembly with a face seal mounted between the two parts.

When the engine is not running this face seal creates a barrier against the gas discharge jet, preventing fuel flow with the aid (downward force) of the air valve spring. When the engine is cranked over it begins to draw in air, creating a negative pressure signal. This negative pressure signal is transmitted through four vacuum ports in the air valve (Figure 1-1-12).

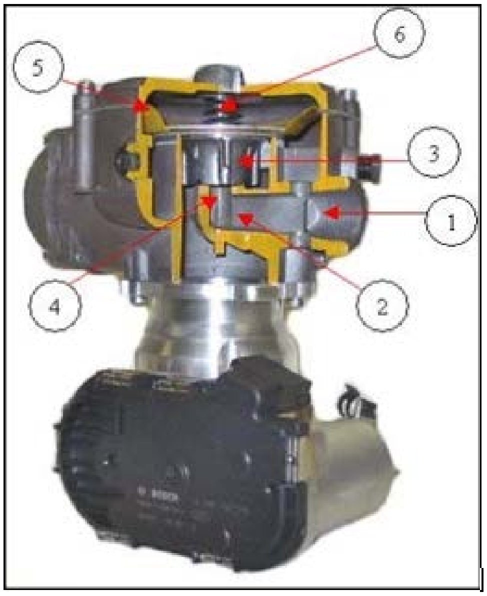


Figure 1-11. Part View of CA100 Mixer

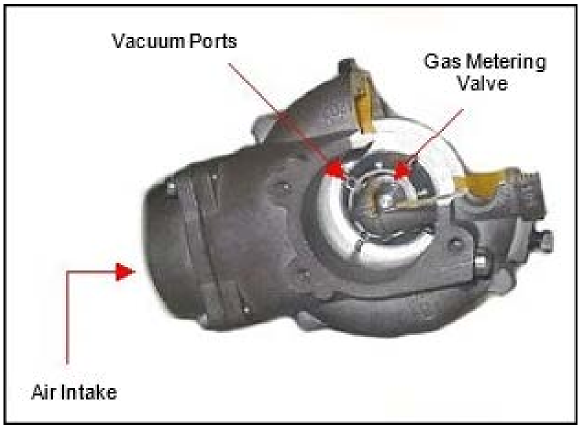


Figure 1-12. Bottom View of Air Valve Assembly

A pressure/force imbalance begins to build across the air valve diaphragm between the AVV chamber (above the diaphragm) and atmospheric pressure below the diaphragm. Approximately 6 inH2O (14.945 mbar) of negative pressure is required to overcome the air valve spring force and push the air valve assembly upward off the valve seat. Approximately 24 inH2O (59.781 mbar) pulls the valve assembly to the top of its travel in the fully open position.

The amount of negative pressure generated is a direct result of throttle position and the amount of air flowing through the mixer to the engine. At low engine speeds, low AVV causes the air valve diaphragm assembly to move upward a small amount, creating a small venturi. At high engine speeds, high AVV causes the air valve diaphragm assembly to move much farther creating a large venturi. The variable venturi air/fuel mixer constantly matches venturi size to engine demand. Mixer and throttle assembly in application is shown in Figure 1-1-13.

Figure 1-13. CA100 Mixer Installed with Electronic Throttle

A main mixture adjustment valve on the fuel inlet of the CA100 is not used in the MI07 system. However, an idle mixture adjustment is incorporated into the mixer (Figure 1-1-14). The idle mixture adjustment is an air bypass port, adjusting the screw all the way in, blocks off the port and enriches the idle mixture. Backing out the idle adjustment screw opens the port and leans the idle mixture. The idle mixture screw is a screw with locking threads that is factory set with a tamper proof cap installed after adjustment. Accurate adjustment of the idle mixture can be accomplished by adjusting for a specific FTV duty cycle with the Service Tool software or with a voltmeter.

NOTICE

Adjustments should only be performed by trained technicians at the factory.

Figure 1-14. Idle Mixture Adjustment Screw (with tamper proof cap removed)

Fuel Trim Valve (FTV)

FTV (Figure 1-1-15) is a two-way electric solenoid valve and is controlled by a pulse-width modulated (PWM) signal provided by the SECM. Two FTVs are used to bias the output fuel pressure on the LPG regulator/converter (N-2007), by metering AVV into the atmospheric side of the N-2007 secondary regulator diaphragm. An orifice balance line connected to the air inlet side of the mixer provides atmospheric reference to the N-2007 when the FTV is closed. The SECM uses feedback voltage from the O2 sensor to determine the amount of bias needed to the regulator/converter.

Figure 1-15. Fuel trim valve

The FTVs should be mounted using a 3 mm +/- 0.1 mm thick tab following the dimensions in Figure 1-1-16.

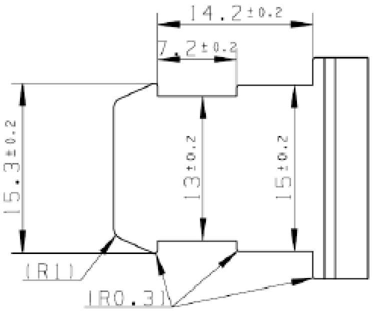


Figure 1-16. Recommended FTV Mounting Tab Dimensions (3 mm +/- 0.1 mm thick)

In normal operation the N-2007 maintains fuel flow at a constant output pressure, due to the calibrated secondary spring. The amount of fuel flowing from the N-2007 will vary depending on how far the secondary diaphragm opens the secondary valve in response to the negative pressure signal generated by the air/fuel mixer. One side of the N-2007 secondary diaphragm is referenced to FTV control pressure while the other side of the diaphragm reacts to the negative pressure signal from the mixer. If the pressure on the reference side of the N-2007 secondary diaphragm is reduced, the diaphragm will close the secondary valve until a balance condition exists across the diaphragm, reducing fuel flow and leaning the air/fuel mixture.

Branch-Tee Fitting

A branch-tee fitting is installed in the atmospheric vent port of the N-2007 with one side of the branch-tee connected to the intake side of the mixer forming the balance line and referencing atmospheric pressure. The other side of the branch-tee fitting connects to the FTV inlet (small housing side). The FTV outlet (large housing connector side) connects to the AVV port. When the FTVs are open AVV is sent to the atmospheric side of the N-2007 secondary diaphragm, which lowers the reference pressure, closing the N-2007 secondary valve and leaning the air/fuel mixture. The MI-21 system is calibrated to run rich without the FTV. By modulating (pulsing) the FTVs the SECM can control the amount of AVV applied to the N-2007 secondary diaphragm. Increasing the amount of time, the FTVs remain open (modulation or duty cycle) causes the air/fuel mixture to become leaner; decreasing the modulation (duty cycle) enriches the mixture. See Figure 1-1-17 and Figure 1-1-18 for the configuration.

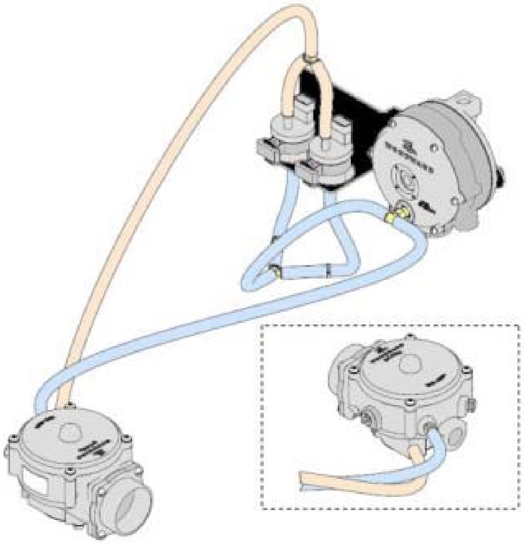


Figure 1-17. Fuel Trim Valve Branch-Tee Configuration

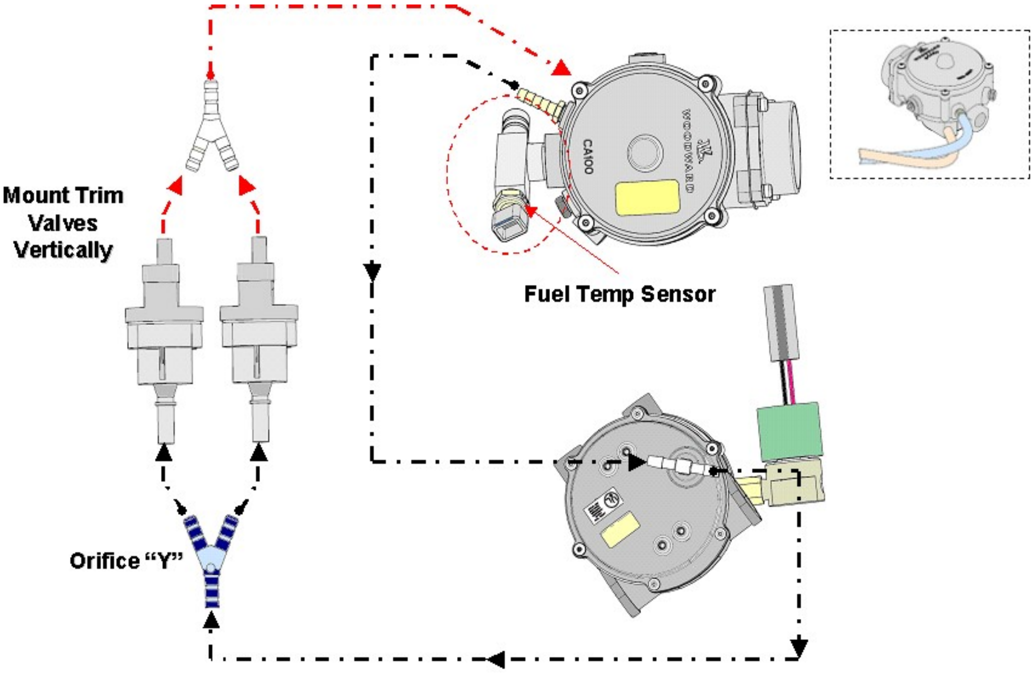


Figure 1-18. Fuel Trim Valves Connected to MI-21 System

Electronic Throttle System

The electronic throttle system controls engine output (speed and torque) through electronic control of mass airflow to the engine. Any DC motor-actuated or Limited Angle Torquemotor (LAT)-actuated throttle that meets the specifications in the SECM70 manual can be controlled. The TPS must be directly coupled to the throttle shaft for direct shaft position measurement.

A commonly used throttle is the Bosch DV-E5. This throttle is available in a variety of bore sizes to meet specific engine needs: 32mm, 40mm, and 54mm are readily available throttle bore sizes; other sizes are possible. The Bosch throttle is a fully validated automotive component incorporating a brushed DC motor with gear reduction, dual throttle position sensors, throttle plate, and cast aluminum housing. In the event of an electrical disconnection or other related failure, the throttle plate returns to a limp-home idle position at a no-load engine speed above curb idle speed. This provides sufficient airflow for the engine to move the vehicle on level ground. Any throttle bodies used for MI-21 must meet or exceed the specification of the Bosch throttle body.

In terms of response, the throttle is capable of fully opening and closing in less than 50 msec. Position resolution and steady state control should be 0.25% of full travel or better.

MI-21 Electronic Throttle

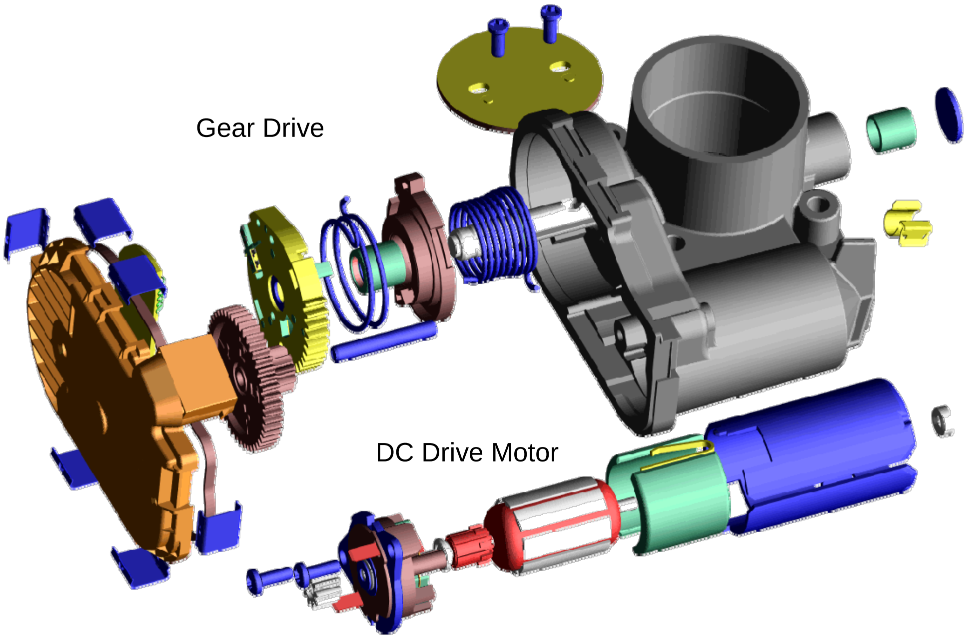
The MI-21 system uses electronic throttle control (ETC). The SECM controls the throttle valve based on engine RPM, engine load, and information received from the foot pedal. Two potentiometers on the foot pedal assembly monitor accelerator pedal travel. The electronic throttle used in the MI-21 system is a Bosch 32mm or 40mm electronic throttle body DV-E5 (Figure 1-1-19). The DV-E5 is a single unit assembly, which includes the throttle valve, throttle-valve actuator (DC motor) and two throttle position sensors (TPS). See Figure 1-1-20 for an exploded view of the throttle. The SECM calculates the correct throttle valve opening that corresponds to the driver's demand, makes any adjustments needed for adaptation to the engine's current operating conditions and then generates a corresponding electrical (driver) signal to the throttle-valve actuator.

Figure 1-19. Bosch Electronic Throttle Body

The MI-21 uses a dual TPS design (TPS1 and TPS2). The SECM continuously checks and monitors all sensors and calculations that effect throttle valve position whenever the engine is running. If any malfunctions are encountered, the SECM's initial response is to revert to redundant sensors and calculated data. If no redundant signal is available or calculated data cannot solve the malfunction, the SECM will drive the system into one of its limp-home modes or shut the engine down, storing the appropriate fault information in the SECM.

There are multiple limp-home modes available with electronic throttle control:

1. If the throttle itself is suspected of being inoperable, the SECM will remove the power to the throttle motor. When the power is removed, the throttle blade returns to its "default" position, approximately 7% open.
2. If the SECM can still control the throttle but some other part of the system is suspected of failure, the SECM will enter a "Reduced Power" mode. In this mode, the power output of the engine is limited by reducing the maximum throttle position allowed.
3. In some cases, the SECM will shut the engine down. This is accomplished by stopping ignition, turning off the fuel, and disabling the throttle.



Picture courtesy of Robert Bosch GmbH

Figure 1-20. Throttle Body Assembly Exploded View

Ignition System

Spark-ignited engines require accurate control of spark timing and spark energy for efficient combustion. The MI-21 ignition system provides this control. The system consists of the following components:

- SECM
- Ignition coil drivers *
- Ignition coil(s) *
- Crankshaft position sensor *
- Crankshaft timing wheel *
- Cam position sensor *
- (for sequential ignition or fuel injection only)
- Cam timing wheel *
- (for sequential ignition or fuel injection only)
- Spark plugs *

(*) Customer-supplied components

The SECM, through use of embedded control algorithms and calibration variables, determines the proper time to start energizing the coil and fire the spark plug. This requires accurate crank/camshaft position information, an engine speed calculation, coil energy information, and target spark timing. The SECM provides a Transistor-Transistor Logic (TTL) compatible signal for spark control. The coil must contain the driver circuitry necessary to energize the primary spark coil otherwise an intermediary coil driver device must be provided. The SECM controls spark energy (dwell time) and spark discharge timing.

Coil-On-Plug (Coil Pack) Ignition System

Coil-on-plug (COP) is a type of distributor-less ignition system where individual ignition coils are mounted directly over each spark plug. No spark plug wires are used. See Figure 1-1-21 for a typical configuration. On most engines, the plugs and coils are located on top of the cylinder head for easy mounting of the coils. A topside location is best because it keeps the coils away from the heat of the exhaust.

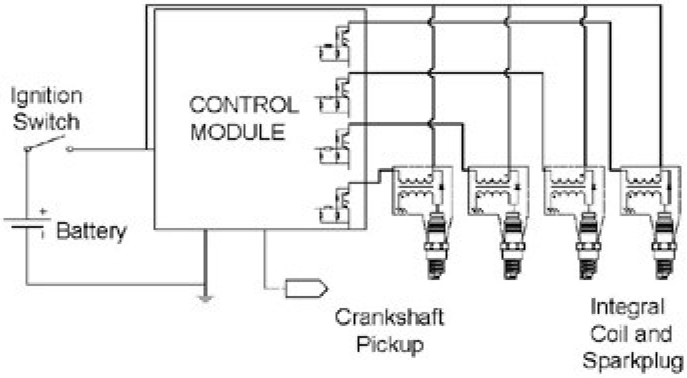


Figure 1-21. Coil-On-Plug ignition system

COP Components

In a typical COP ignition system, a crankshaft position sensor generates a basic timing signal by reading notches on the crankshaft, flywheel, or harmonic balancer. The crank sensor signal goes to the SECM, where it is used to determine firing order and turn the individual ignition coils on and off.

The operation of the ignition system is essentially the same as any other ignition system. Each coil has a low primary resistance (0.4 to 0.6 ohms) and steps up the primary system voltage from 12 volts to as much as 40,000 volts to produce a spark for the spark plug.

The primary difference between COP and other ignition systems is that each COP coil is mounted directly atop the spark plug, so the voltage goes directly to the plug electrodes without having to pass through a distributor or wires. It is a direct connection that delivers the hottest spark possible. Resistor plugs are generally used to suppress electromagnetic interference (EMI).

Misfires

COP problems can include many of the same ailments as other ignition systems such as misfiring, hard starting, or a no start. Spark plugs can still be fouled by oil or fuel deposits, as well as pre-ignition and detonation.

If the crankshaft position sensor fails, the loss of the basic timing signal will prevent the system from generating a spark and the engine will not start or run. A failed driver circuit within the SECM can kill an individual coil and prevent that cylinder from firing. But with COP, an individual coil failure will only cause misfiring in one cylinder.

It is important to remember that ignition misfire can also be caused by other factors such as worn or fouled spark plugs, loose or damaged coil connector or terminals, dirty fuel injectors, low fuel pressure, intake vacuum leaks, loss of compression in a cylinder, even contaminated fuel. These other possibilities should all be ruled out before a COP unit is replaced.

A COP engine that cranks but fails to start, in many cases, will often have a problem in the crankshaft or camshaft position sensor circuits. Loss of sensor signals may prevent the SECM from properly synchronizing, thereby preventing the engine from starting and running.

COP Checks

Individual ignition coils can be tested with an ohmmeter the same as those on a conventional distributor or DIS ignition system. Measure primary and secondary resistance and compare to specifications. If resistance is out of specification, the coil is bad and needs to be replaced.

Also, pay close attention to the tube that wraps around the spark plug. Cracks can allow voltage to jump to ground causing a misfire. The spark plug terminal should also fit tightly. If a COP coil tests bad and is replaced, cleaning the COP connector, and wiring harness terminals can often avoid future problems. Corrosion at either place can cause intermittent operation and loss of continuity, which may contribute to component failure. Applying dielectric grease to these connections can help prevent corrosion and assure a good electrical connection. See Figure 1-1-22 for an example of coils used on the MI-21 system.

Figure 1-22. MI-21 Ignition Coil and Extension Wire Assembly

Position Sensor Checks

Magnetic crankshaft position sensors can be tested with an ohmmeter, and the sensor output voltage and waveform can be read with an oscilloscope. The output voltage of a Hall Effect crankshaft position sensor can be checked with a voltmeter. On most vehicles, a defective crank position sensor will usually set a fault code that can be read with the Service Tool.

Exhaust System

Heated Exhaust Gas Oxygen Sensors (HEGO)

The MI-21 system utilizes two HEGO (O2) sensors (Figure 1-1-23). One sensor is a pre-catalyst sensor that detects the amount of oxygen in the exhaust stream and is considered the primary control point. Based upon the O2 sensor feedback, the MI-21 system supplies a stoichiometric air-fuel ratio to the catalytic converter. The catalytic converter then reduces emissions to the required levels. The second sensor is a post-catalyst sensor that detects the amount of oxygen after the catalyst. This sensor is used as a secondary control point to adjust the pre-catalyst setpoint to ensure proper catalyst conversion efficiency.

Once a HEGO sensor reaches approximately 600 °F (316 °C), it becomes electrically active. The concentration of oxygen in the exhaust stream determines the voltage produced. If the engine is running rich, little oxygen will be present in the exhaust and voltage output will be relatively high. Conversely, in a lean situation, more oxygen will be present, and a smaller electrical potential will be noticed.

Figure 1-23. HEGO (O2) Sensor

For the sensor to become active and create an electrical signal below exhaust temperatures of 600 °F (316 ºC), a heated element is added to the sensor housing. Two wires provide the necessary 12 Vdc and ground signal for the heater element. A fourth wire provides an independent ground for the sensor. The HEGO sensor heaters are powered from a relay that is controlled by the SECM. Continuous 12 Vdc should never be applied to the HEGO heater as this will damage the sensor. The heater requires a PWM signal from the ECU to maintain the correct element temperature. This relay is only energized when the SECM calculates that water condensation in the exhaust system and catalytic muffler prior to the sensor should be evaporated. This is to avoid thermal shock of the sensor that could prematurely fail the sensor.

⚠ **CAUTION**

The HEGO sensors are calibrated to work with the MI-21 control system. Use of alternate sensors (including MI-07 sensors) will impact performance and the ability of the system to diagnose rich and lean conditions correctly.

Catalytic Muffler

To meet applicable emission standards, a 3-way catalyst is necessary.

The MI-21 control system monitors the exhaust stream pre and post catalyst and uses this information to control the air-fuel mixture. By using the signals from the HEGOs, the SECM can increase or decrease the amount of oxygen in the exhaust by modulating the FTVs and adjusting the air-fuel ratio. This control scheme allows the SECM to make sure that the engine is running at the correct air to fuel ratio so that the catalyst can perform as required to meet the emissions standards.

SECM Controller

The Woodward SECM controller (Figure 1-1-24) has full authority over spark, fuel and air. Utilizing a Freescale micro controller, the SECM has 70 pins of I/O and is fully waterproof and shock hardened. To optimize engine performance and drivability, the SECM uses several sensors for closed loop feedback information. These sensors are used by the SECM for closed loop control in three main categories:

- Fuel Management
- Load/Speed Management
- Ignition Management

The SECM monitors system parameters and stores any out of range conditions or malfunctions as faults in SECM memory. Engine run hours are also stored in memory. Stored fault codes can be displayed on the MIL as flash codes or read by the MI-21 Service Tool software through a CAN (Controller Area Network) communication link.

Figure 1-24. MI-21 SECM 70 Controller

Constant battery power (12 Vdc) is supplied through the fuse block to the SECM and the main power relays. Upon detecting a key-switch ON input, the SECM will fully power up and energize the main power relays. The energized power relays supply 12 Vdc power to the heated element of the oxygen sensors, fuel lock-off, fuel trim valves (FTVs), gasoline injectors, gasoline fuel pump, crank sensor, cam sensor, and the ignition coils. The SECM supplies voltage to the electronic throttle actuator, oil pressure switch, fuel temperature sensor, and the coolant temperature sensor. Transducer or sensor power (+ 5 Vdc) is regulated by the SECM and supplied to the TMAP sensor, TPS, and the accelerator pedal position sensors (APP1 & APP2). The SECM provides a transducer ground for all the sensors, and a low side driver signal controlling the HEGO heaters, fuel lock-off, MIL, gasoline injectors, gasoline fuel pump, and FTVs.

Fuel Management

During engine cranking at startup, the SECM provides a low side driver signal to the fuel lock-off, which opens the lock-off allowing liquid propane to flow to the N-2007 regulator. A stall safety shutoff feature is built into the SECM to close the lock-off in case of a stall condition. The SECM monitors three engine states:

- Crank: when the crankshaft position sensor detects any engine revolutions
- Stall: when the key is in the ON position, but the crankshaft position sensor detects no engine revolutions
- Run: state when the engine reaches pre-idle RPM.

When an operator turns on the key switch the lock-off is opened but if the operator fails to crank the engine, the SECM will close the lock-off after 5 seconds.

To maintain proper exhaust emission levels, the SECM uses a HEGO mounted before the catalyst to measure exhaust gas content and a ramp and jump-back algorithm to maintain the proper AFR. The ramp and jump-back calibration is based on optimizing AFR for catalyst efficiency for a given load and speed. As shown in Figure 1-1-25, when the HEGO sensor indicates a lean equivalence ratio, the fuel trim is ramped up at a fixed rate until the sensor switches rich. When the HEGO sensor indicates a rich equivalence ratio, the fuel trim is ramped down at a fixed rate until the sensor switches lean. Jump up and jump down offsets may be used to speed up the switching and minimize equivalence ratio excursions.

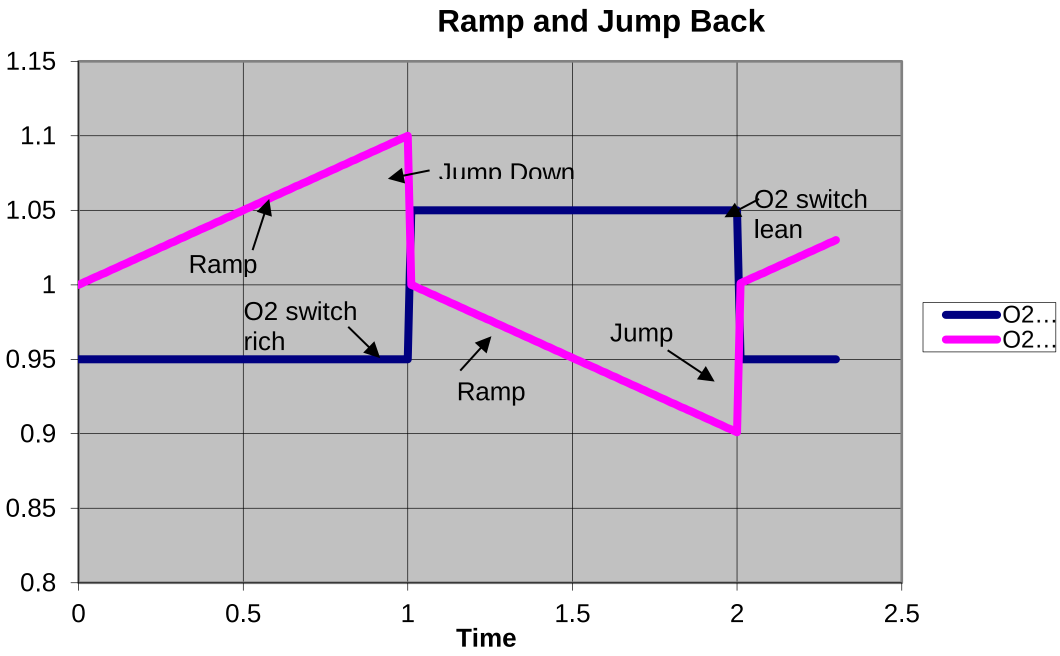


Figure 1-25. Ramp and Jump-Back Algorithm Details

The ramp and jump-back algorithm switches at a fixed HEGO sensor voltage that does not vary with rpm, load, rich-to-lean transition, or lean-to-rich transition. Equivalence ratio biasing is achieved by biasing the ramp-up rate and jump up relative to the ramp down rate and jump down. Increasing the ramp up rate and jump up relative to the ramp down rate and jump down will bias the exhaust rich by decreasing the time spent lean and increasing overshoot following the lean-to-rich transition. Similarly, decreasing the ramp up rate and jump up relative to the ramp down rate and jump down will bias the exhaust lean be increasing the time spent lean and decreasing overshoot following the lean-to-rich transition.

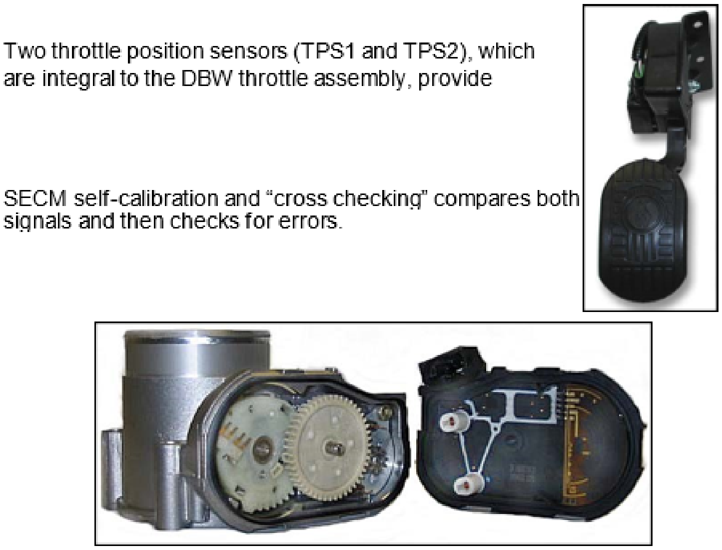
The system operates in open loop fuel control until the engine has done a certain amount of work. This ensures that the engine and HEGO are sufficiently warmed up to stay in control. In open loop control, the FTV duty cycle is based on engine speed and load. Once the HEGO reaches operating temperature the fuel management is in closed loop control. In closed loop mode, the FTV duty cycle is based on feedback from the HEGO sensor and output from the ramp and jump-back algorithm.

The SECM makes corrections to the air-fuel ratio by controlling the inlet fuel pressure to the air-fuel mixer by means of the FTVs. Reducing the fuel pressure (increasing FTV duty cycle) leans the AFR and increasing the fuel pressure (decreasing FTV duty cycle) enriches the air-fuel mixture. Control is achieved by modulating the fuel trim valves duty cycle. Closed loop fueling can additionally be modified based on feedback from the post-catalyst HEGO sensor. Fueling can be periodically offset to maintain optimal post-cat AFR for catalyst efficiency.

Speed Management

Engine speed is monitored by the SECM through a VR sensor or Hall-Effect type sensor. The SECM controls the speed of the engine using the DBW throttle and ignition timing. DBW refers to the fact that the MI-21 control system has no throttle cable from the foot pedal to the throttle body. Instead, the SECM is electronically connected both to the foot pedal assembly and the throttle body. The SECM monitors the foot pedal position and controls the throttle plate by driving a DC motor connected to the throttle. The DC motor actuates the throttle plate to correspond to the foot pedal position when the operator depresses the pedal. The SECM will override the pedal command above a maximum engine speed and below a minimum idle speed.

The use of ETC ensures that the engine receives only the correct amount of throttle opening for any given situation, greatly improving idle quality and drivability. feedback for position control by monitoring the exact position of the throttle valve. See Figure 1-26.



Two throttle position sensors (TPS1 and TPS2), which are integral to the DBW throttle assembly, provide

SECM self-calibration and "cross checking" compares both signals and then checks for errors.

Figure 1-26. Throttle Position Sensor (TPS) on DV-E5 Throttle

NOTICE

The DV-E5 throttle is not a serviceable assembly. If a TPS sensor fails, the assembly should be replaced.

The MI-21 system also performs minimum (min) and maximum (max) speed governing through the SECM and DBW throttle. For min governing, or idle speed control, the idle speed is fixed by the SECM. Unlike a mechanical system, the idle speed is not adjustable by the end user. The idle speed is adjusted by the SECM based on engine coolant temperature. At these low engine speeds, the SECM uses spark and throttle to maintain a constant speed regardless of load.

When the engine speed reaches the max governing point the speed is controlled by closing the DBW throttle. Using the DBW throttle as the primary engine speed control allows for a smooth transition into and out of the governor. If excessive over speed is detected, the engine is shut down.

Figure 1-1-27 describes the signal flow process of the MI-21 DBW. The foot pedal assembly uses two potentiometers to detect pedal position. These two signals, APP1 and APP2 are sent directly to the SECM. The SECM uses a series of algorithms to self-calibrate and cross check the signals from the pedal assembly. A demand position for the throttle will then be derived and sent to the throttle as a throttle position sensor demand (TPSd). This signal will be processed through a PID (Proportional, Integral, Derivative) controller in the SECM to achieve the appropriate motor-current response then passed to the throttle. The throttle moves to the commanded position and provides a feedback signal from the throttle position sensors (TPS1 and TPS2) to the SECM.

Drive-By-Wire Signal Flow Process

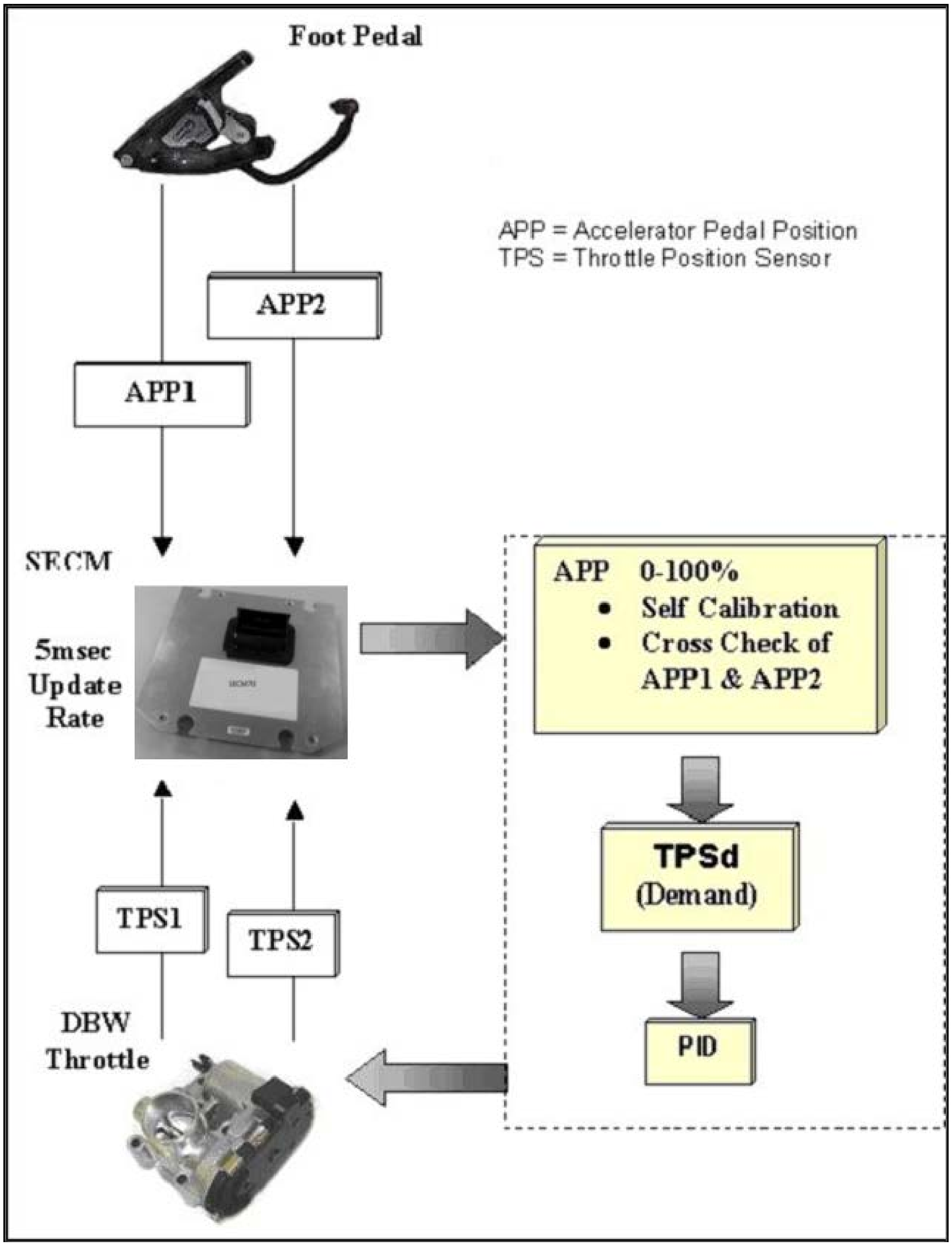


Figure 1-27. Drive-By-Wire Signal Flow Process

Ignition Management

In the normal course of events, with the engine operating at the correct temperature in defined conditions, the SECM will use load and engine speed to derive the correct ignition timing. In addition to load and speed there are other circumstances under which the SECM may need to vary the ignition timing, including low engine coolant temperature, air temperature, start-up, and idle speed control.

SECM Mounting Recommendations

To prevent the possibility of any SECM malfunctions due to installation, engine packagers and OEMs should follow the SECM mounting and harness recommendations listed in the SECM 70 installation manual (Product Manual 26784)

SECM / Sensors

The 70-pin SECM (Figure 1-1-24) and sensors provide the computational power, algorithm logic, sensor inputs and control outputs to control the system. The SECM receives signals from the sensors, digitizes these signals, and then, through algorithms and calibration maps, computes the desired output response to effect control of fuel, spark and air to the engine. The SECM also provides a variety of other functions and features. These include system monitoring and diagnostics to aid in maintaining efficient system operation and auxiliary control.

SECM/sensor inputs and control output specifications are specific to the application. Specifics on the inputs and outputs can be found in the SECM 70 hardware manual (Product Manual 35088)

Lamp Outputs

The MI-21 application uses 1 lamp output to drive the MIL. The SECM 70 does not support LED lamps. MIL lamps need to be resistive style lamps.

SECM70 Wiring Diagrams

The MI-21 system and SECM70 can be configured in many ways to meet customer requirements. Please refer to Woodard Inc. approved application specific wiring diagrams.

⚠CAUTION	**PROPER WIRING: To prevent system faults, be sure to follow good wiring practices. Poor wiring may cause unexpected or intermittent failures not related to MI-21 components.**

NOTICE	**Always refer to MOR-furnished wiring diagrams for your specific application.**

Chapter 2.
Gasoline Engines.

Gasoline Fuel System

A bi-fuel system operates on either LPG or gasoline. The engine will run on only one fuel at a time. The fuel type can be switched while the engine is stopped or running at low speeds and low loads. The fuel selection switch is a three-position type where the center position is fuel off.

The gasoline system utilizes all the same sensors and components described in chapter 1 except for fuel system components. The gasoline fuel system includes the components listed below and are required to be supplied by the customer.

- Fuel Pump Module (Figure 2-)
  - Gasoline fuel pump
  - Fuel filter
  - Pressure regulator
- Fuel rail
- Fuel injectors
- Fuel lines and connections
- Fuel tank and cap

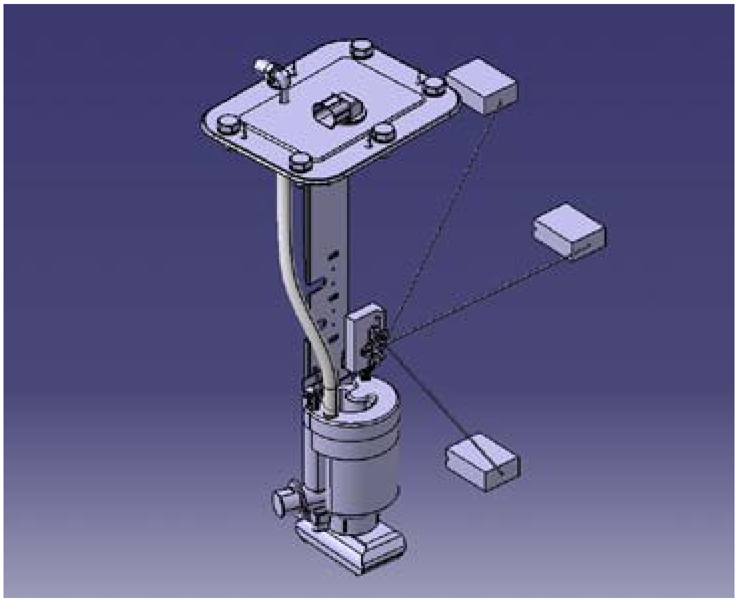


Figure 2-1. Fuel pump module with pump, filter, and regulator.

The fuel pump module should be in the tank and all electrical parts and wires are waterproof and sealed.

MI-21 uses multi-point injection (MPI) method and the fuel rail should be setup in a non-return configuration. The gasoline fuel pressure regulator should provide fuel to the rail at 3.5 kg/cm^2 (50 psig). All gasoline specific components are automotive production parts and validated to strict automotive standards. Four sequential injection channels are supported.

To comply with 40 CFR Part 1048.105 (evaporative emissions requirements), the following considerations for lines, tank, and cap should be followed.

- For nonmetallic fuel lines, you must specify and use products that meet the Category 1 specifications for permeation in SAE J2260.
- Use a tethered or self-closing gas cap on a fuel tank that stays sealed up to a positive pressure of 24.5 kPa (3.5 psig); however, they may contain air inlets that open when there is a vacuum pressure inside the tank.
- Use a metal or low permeation plastic (2 ROG/m2/day) fuel tank.
- Use metal or low-permeability gaskets and fuel caps.
- The fuel tank and fuel lines should be a minimum of 15 cm away from the exhaust pipe and catalyst and/or should be shielded from these heat sources.

In addition to these requirements the equipment manufacturer must verify that liquid fuel in the fuel tank does not reach the boiling point during continuous engine operation in the final installation at an ambient temperature of 30°C. Do this using fuel temperature data measured during normal operation. Note that gasoline with a Reid vapor pressure of 62 kPa (9psi) begins to boil at about 53°C at atmospheric pressure and at about 60o C for fuel tanks that hold pressure to 24.5 kPa (3.5 psig).

Use of unleaded gasoline of 87 AKI octane or higher is recommended for optimal performance of the MI-21 system.

Fuel Management

During engine cranking at startup, the SECM provides a low side driver signal to the fuel pump, which supplies pressure to fuel rail and subsequently to the fuel injectors. A stall safety shutoff feature is built into the SECM to turn off the fuel pump in case of a stall condition. The SECM monitors three engine states:

- Crank: when the crankshaft position sensor detects any engine revolutions
- Stall: when the key is in the ON position, but the crankshaft position sensor detects no engine revolutions
- Run: state when the engine reaches pre-idle RPM.

When an operator turns on the key switch the fuel pump is operated but if the operator fails to crank the engine, the SECM will turn off the pump after three seconds. A periodic safety check should verify the fuel pump turns off after 3 seconds. This will check the system for short to ground conditions that could cause the pump to run continuously.

The system utilizes the same HEGO sensors and ramp and jump-back algorithm as detailed in Fuel Management section of **Error! Reference source not found.** The system operates in open loop fuel control until the engine has done a certain amount of work. This ensures that the engine and HEGO are sufficiently warmed up to stay in control. In open loop control, the injectors are driven base on a speed density algorithm. Once the HEGO reaches operating temperature the fuel management is in closed loop control. In closed loop mode, the injectors are driven based the speed density algorithm and feedback from the HEGO sensor and output from the ramp and jump-back algorithm. Closed loop fueling can additionally be modified based on feedback from the post-catalyst HEGO sensor. Fueling can be periodically offset to maintain optimal post-cat AFR for catalyst efficiency.

Chapter 3.
Specifications

Specifications for the MI-21 system can be seen in Table 3-1 - Table 3-7.

Fuel System Requirements

Table 3-1. Fuel System Requirements

Operating Temperature:	-20 °F to 221°F [-29 °C to 105 °C]
Long-term Storage Temperature:	-40 °F to 140 °F [-40 °C to 60 °C]
Short-term Storage Temperature (Heat Soak):	≤257 °F [125 °C]
LPG Composition Requirements:	EPA Regulation Regions - HD5 / HD10 EU Regulation Regions – Fuel A / Fuel B Failure to use correct fuel will void the user warranty. More details on fuels in **Error! Reference source not found.**
Gasoline Requirements:	Unleaded gasoline of 87 AKI octane or higher
LPG Fuel Filter Requirement:	10 micron or better at 99% efficiency
Gasoline Fuel Filter Requirement:	Follow requirements of customer supplied fuel module

Environmental / Electrical Specifications

Table 3-2. Environmental/Electrical Specifications

Ambient Operating Temperature:	-20 °F to 221°F [-29 °C to 105 °C]
Cold Start Temperature:	-4 °F [-20 °C] Appropriate cold start fuels must be used
LPG Fuel Temperature:	-4 °F to 120 °F [-20 °C to 49 °C] (Due to the low vapor pressure of LPG at cold temperatures repeated cranking to start the engine may be required
Operating Voltage:	8-16 Vdc
Over Voltage Operation:	18 Vdc for less than 5 minutes 24 Vdc for less than 1 minute

Electronic Throttle System Specifications

Table 3-3. Electronic Throttle System Specifications

Minimum Electrical Resistance of Throttle Actuator:	1.5 ohms

Fuel Trim Valve (FTV) Specifications

Table 3-4. FTV Specifications

Actuator Type:	On/off two-position valve compatible with LPG
Operating Voltage:	9-16 Vdc
Resistance (20 °C):	17 ohms

SECM 70 Specifications

Refer to SECM 70 installation manual (Product Manual 26784) for specifications.

N-2007 Pressure Regulator Specifications

Table 3-5. N-2007 Pressure Regulator Specifications

Fuel Supply Pressure:	10 psi to 250 psi (68.95 kPa to 1723.69 kPa)
Fuel Inlet Fitting:	1/4” NPT
Fuel Outlet Fitting:	Two 3/4” NPT fittings with one plugged and one 1/8” NPT fitting with plug
Fuel Supply Temperature at Tank Outlet:	-20 °F to 120 °F [-29 °C to 49 °C]
Primary Pressure Tap:	1/8” NPT with plug
Coolant Flow to Vaporizer:	> 1.0 gpm/100bhp, equipped with 140 °F (60 °C) thermostat for continuous use applications
Max Flow:	50 lbm/hr LPG)
Fuel Outlet Pressure Setpoints:	-0.7 ± 0.2 inH_2O @ 1.7 lbm/hr LPG (-1.744 ± 0.498 mbar) @ 1.7 lbm/hr LPG) -2.0 ± 0.2 inH_2O @ 50 lbm/hr LPG (-4.982 ± 0.498 mbar) @ 50 lbm/hr LPG)
Mounting:	Regulator should be installed with centerline of outlet at least 15° below horizontal to permit drainage of any liquid precipitates from LPG fuel. Diaphragm should be vertically oriented.

CA100 Mixer Specifications

Table 3-6. CA100 Mixer Specifications

Fuel:	LPG
Fuel Inlet Fitting:	1/2” NPT. Fuel inlet fitted with Delphi temperature sensor
Air Intake Flange:	2.25” (57.15mm) ID inlet, four #10-24 screws in 1.94” (49.28mm) square pattern
Mixer Mounting Flange:	1.87” (47.49mm ID outlet, four #12-24 screws arranged in a rectangular pattern
Reference Pressure Ports:	Two 1/8-NPT ports. Pressure readings must be identical within 0.25 inH_2O (0.623 mbar) at all airflows.
Air Valve Vacuum (AVV) Port Size:	1/4-28 UNF
Fuel Inlet Adjustments:	None
Idle Air Adjustment:	None
Mounting:	Suitable for on-engine mounting in vertical orientation

Ignition System Specifications

Table 3-7. Ignition system specifications

Coil Type:	Inductive
Coil Supply Voltage:	8-16 Vdc
Minimum Open Circuit Voltage:	> 30 kV
Minimum Coil Energy:	35 mJ
Maximum Dwell Time:	4 msec
Operating Temperature:	-20 °F to 221°F [-29 °C to 105 °C]
Long-term Storage Temperature:	-40 °F to 140 ° [-40 °C to 60 °C]
Short-term Storage Temperature (Heat Soak):	≤257 °F [125 °C]

System Control Performance Specifications

Power /Torque

The MI-21 system maximizes engine power and torque while meeting customer specific needs for emissions, fuel consumption, durability, and drivability. Bear in mind that engine power is dependent on many variables other than the fuel control system, i.e., compression ratio, friction, valve timing, etc.

Exhaust Emissions

MI-21 is capable of meeting EPA 2007 LSI engine emission standards and EU Stage V regulations for engines less than 56 kW for non-road mobile machinery when operating properly with an approved three-way catalyst. Emission standards must be met on both the LSI engine off-highway transient emissions test cycle and the ISO 8178 type C2 steady-state emissions test cycle.

The fuel control logic, for both LPG and gasoline, employs a closed-loop exhaust gas oxygen control algorithm to compensate for fuel system tolerances, aging, altitude, and fuel composition. The algorithm utilizes dual HEGO sensors with an output that switches high and low at stoichiometry. When operated with LPG, the control logic compensates for variations in fuel temperature as measured at the mixer inlet.

Drivability / Transient Response

The engine will meet requirements of the EPA LSI engine transient emissions test cycle and EU Stage V regulations for engines less than 56 kW for non-road mobile machinery NRTC-LSI transient test cycle. It should start, run, accelerate, decelerate, and stop without hesitation or misfire.

Low Idle Speed

The low idle speed setpoint ranges between 500 rpm and 800 rpm, as defined by the OEM during calibration.

Maximum Speed / High Idle

The maximum governed speed setpoint ranges between 1800 rpm and 3000 rpm, as defined by the OEM during calibration.

Chapter 4.
Recommended Maintenance.

Suggested maintenance requirements for an engine equipped with an MI-21 fuel system are contained in this section. The operator should, however, develop a customized maintenance schedule using the requirements listed in this section and any other requirements listed by the engine manufacturer.

Maintenance Tests & Inspections

Test Fuel System for Leaks

1. Obtain a leak check squirt bottle or pump spray bottle.
2. Fill the bottle with an approved leak check solution.
3. Spray a generous amount of the solution on the fuel system fuel lines and connections, starting at the storage container. Figure 4-1**.** shows examples of leak check points on LPG tank.

Figure 4-1. Examples of leak check points on LPG tank

4. Wait approximately 15-60 seconds, then perform a visual inspection of the fuel system. Leaks will cause the solution to bubble.
5. Listen for leaks
6. Smell for LPG odor which may indicate a leak
7. Repair any leaks before continuing.
8. Crank the engine through several revolutions. This will energize the fuel lockoff and allow fuel to flow to the pressure regulator/converter. Apply additional leak check solution to the regulator/ converter fuel connections and housing. Repeat leak inspection as listed above.
9. Repair any fuel leaks before continuing.

Inspect Engine for Fluid Leaks

1. Start the engine and allow it to reach operating temperatures.
2. Turn the engine off.
3. Inspect the entire engine for oil and/or coolant leaks.
4. Repair as necessary before continuing.

Inspect Vacuum Lines and Fittings

1. Visually inspect vacuum lines and fittings for physical damage such as brittleness, cracks and kinks. Repair/replace as required.
2. Solvent or oil damage may cause vacuum lines to become soft, resulting in a collapsed line while the engine is running.
3. If abnormally soft lines are detected, replace as necessary.

Inspect Electrical System

1. Check for loose, dirty or damaged connectors and wires on the harness including fuel lock-off, TMAP sensor, O2 sensors, electronic throttle, control relays, fuel trim valves, crank position sensor, and cam position sensor.
2. Repair and/or replace as necessary.

Inspect Foot Pedal Operation

1. Verify foot pedal travel is smooth without sticking.

Check Coolant Level

1. The items below are a general guideline for system checks. Refer to the engine manufacturer's specific recommendations for proper procedures.
2. Engine must be off and cold.

⚠WARNING **Never remove the pressure cap on a hot engine**

3. The coolant level should be equal to the "COLD" mark on the coolant recovery tank.
4. Add approve coolant to the specified level if the system is low.

Inspect Coolant Hoses

1. Visually inspect coolant hoses and clamps. Remember to check the two coolant lines that connect to the pressure regulator/converter.
2. Replace any hose that shows signs of leakage, swelling, cracking, abrasion or deterioration.

Inspect Battery System

1. Clean battery outer surfaces with a mixture of baking soda and water.
2. Inspect battery outer surfaces for damage and replace as necessary.
3. Remove battery cables and clean, repair and/or replace as necessary.

Inspect Ignition System

1. Remove and inspect the spark plugs. Replace as required.
2. Inspect the ignition coil for cracks and heat deterioration. Visually inspect the coil heat sink fins. If any fins are broken replace as required.

Replace Spark Plugs

1. Using a gentle twisting motion, remove the high voltage leads from the spark plugs. Replace any damaged leads.
2. Remove the spark plugs.
3. Gap the new spark plugs to the proper specifications.
4. Install and torque to manufacturer specifications.
5. Re-install the high voltage leads.

⚠CAUTION **Do not over tighten the spark plugs.**

Replace LP Fuel Filter Element

Park the lift truck in an authorized refueling area with the forks lowered, parking brake applied and the transmission in Neutral.

1. Close the fuel shutoff valve on the LP-fuel tank. Run the engine until the fuel in the system runs out and the engine stops.
2. Turn off the ignition switch.

3. Scribe a line across the filter housing covers (Figure 4-2), which will be used for alignment purposes when re-installing the filter cover.

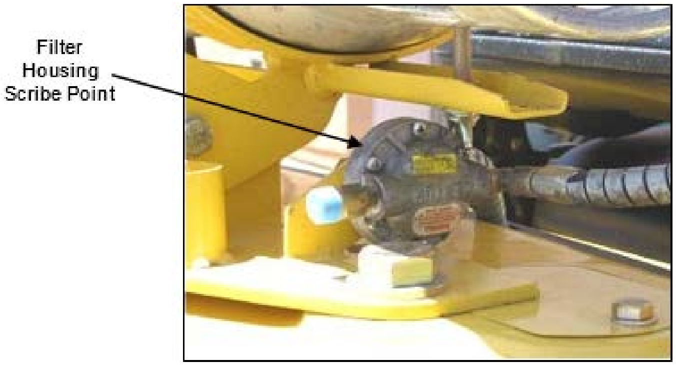


Figure 4-2. Scribe Point for Inline LP Fuel Filter

Refer to Figure 4-3 for Steps 4-7.

4. Remove the cover retaining screws (A).

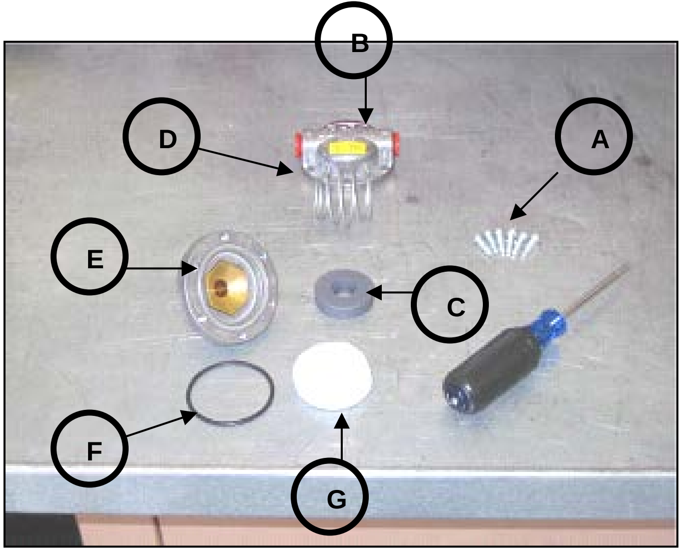


Figure 4-3. Fuel Filter Disassembly and part identification (Steps 4-7)

5. Remove top cover (B), magnet (C), spring (D), and filter element (G) from bottom cover (E).
6. Replace the filter element (G).
7. Check bottom cover O-ring seal (F) for damage. Replace if necessary.
8. Re-assemble the filter assembly aligning the scribe lines on the top and bottom covers.
9. Install the cover retaining screws, tightening the screws in an opposite sequence across the cover.
10. Open the fuel valve by slowly turning the valve counterclockwise.
11. Check the filter housing, fuel lines and fittings for leaks. Repair as necessary.
12. Crank the engine several revolutions to open the fuel lock-off. DO NOT START THE ENGINE. Turn the ignition key switch to the off position.

Testing Fuel Lock-off Operation

Refer to Figure 4-4.

1. Start engine.
2. Locate the electrical connector for the fuel lock (A).
3. Disconnect the electrical connector.
4. The engine should run out of fuel and stop within a short period of time.

NOTICE **The length of time the engine runs on trapped fuel vapor increases with any increase in distance between the fuel lock-off and the pressure regulator/converter.**

5. Turn the ignition key switch off and re-connect the fuel lock-off connector.

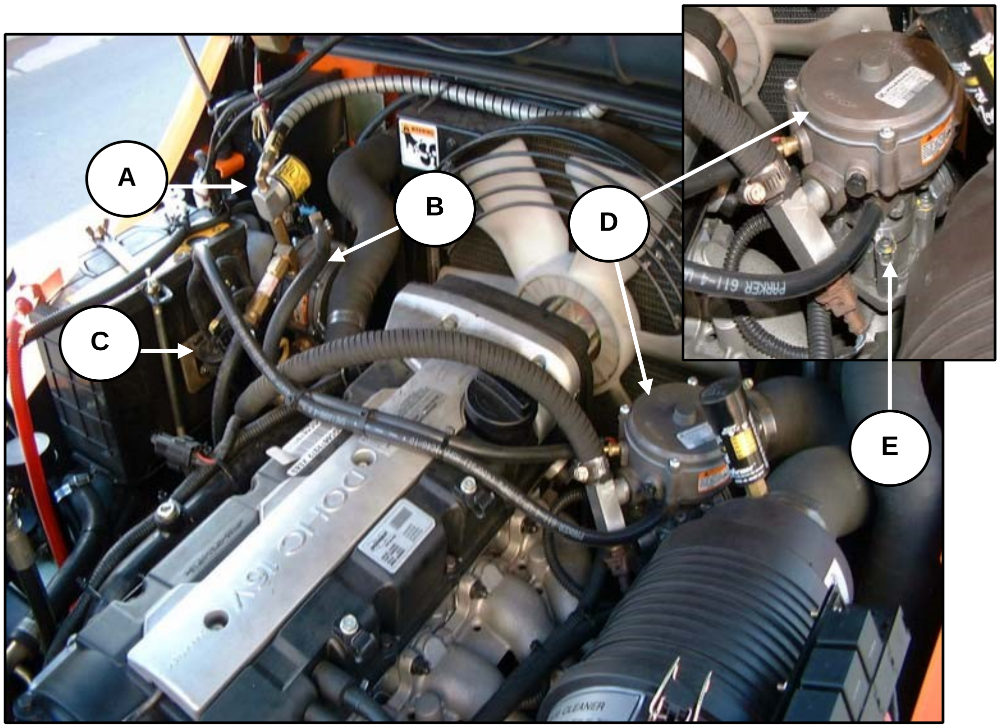


Figure 4-4. MI-21 System Installed on Hyundai 2.4L Engine

Pressure Regulator/Converter Inspection

1. Visually inspect the pressure regulator/converter (B) housing for coolant leaks.
2. Refer to Chapter 5 if the pressure regulator/converter requires replacement.

Fuel Trim Valve Inspection (FTV)

1. Visually inspect the fuel trim valves (C) for abrasions or cracking. Replace as necessary.
2. To ensure a valve is not leaking a blow-by test can be performed.
   a. With the engine off, disconnect the electrical connector to the FTVs.
   b. Disconnect the vacuum line from the FTVs to the pressure regulator/converter at the converter’s tee connection.
   c. Lightly blow through the vacuum line connected to the FTVs. Air should not pass through the FTVs when de-energized. If air leaks past the FTVs when de-energized, replace the FTVs.

Inspect Air/Fuel Valve Mixer Assembly

1. Refer to Chapter 5 for procedures regarding the LP mixer (D).

Inspect for Intake Leaks

1. Visually inspect the intake throttle assembly (E), and intake manifold for looseness and leaks. Repair as necessary.

Inspect Throttle Assembly

1. Visually inspect the throttle assembly motor housing for coking, cracks, and missing cover-retaining clips. Repair and/or replace as necessary.

NOTICE

Refer to Chapter 5 for procedures on removing the mixer and inspecting the throttle plate.

Checking the TMAP Sensor

1. Verify that the TMAP sensor (F) is mounted tightly into the manifold or manifold adapter (E), with no leakage.
2. If the TMAP is found to be loose, remove the TMAP retaining screw and the TMAP sensor from the manifold adapter.
3. Visually inspect the TMAP O-ring seal for damage. Replace as necessary.
4. Apply a thin coat of an approved silicon lubricant to the TMAP O-ring seal.
5. Re-install the TMAP sensor into the manifold or manifold adapter and securely tighten the retaining screw.

Inspect Engine for Exhaust Leaks

1. Start the engine and allow it to reach operating temperatures.
2. Perform visual inspection of exhaust system from the engine all the way to the tailpipe. Any leaks, even after the post-catalyst oxygen sensor, can cause the sensor output to be affected (due to exhaust pulsation entraining air upstream). Repair any/all leaks found. Ensure the length from the post catalyst sensor to tailpipe is the same as original factory.
3. Ensure that wire routing for the oxygen sensors is keeping wires away from the exhaust system. Visually inspect the oxygen sensors to detect any damage.

Maintenance Schedule

NOTICE

The MI-21 fuel system was designed for use with LPG fuel that complies with fuels listed in Chapter 10 - Appendix. Use of non-compliant LPG fuel may require more frequent service intervals and will disqualify the user from warranty claims.

Table 4-1 defines the appropriate maintenance schedule for the MI-21 system. The emission and engine warranty does not cover damage or failure caused by improper maintenance or repairs.

Table 4-1. MI-21 Maintenance Schedule

CHECK POINT	INTERVAL HOURS					
	Daily	**Every 250 Hours or 1 month**	**Every 500 Hours or 3 months**	**Every 1000 Hours or 6 months**	**Every 1500 Hours or 9 months**	**Every 2500 Hours or 1 year**
General Maintenance						
Test fuel system for leaks.	Prior to any service or maintenance activity					
Inspect engine for fluid leaks.	**X**					
Inspect all vacuum lines and fittings.			**X**			

CHECK POINT	INTERVAL HOURS					
	Daily	Every 250 Hours or 1 month	Every 500 Hours or 3 months	Every 1000 Hours or 6 months	Every 1500 Hours or 9 months	Every 2500 Hours or 1 year
Inspect electrical system. Check for loose, dirty, or damaged wires and connections.			X			
Inspect isolation mounts on engine control module for cracks and wear; replace as necessary.			X			
Inspect all fuel fittings and hoses.				X		
Inspect foot pedal travel and operation.	X					
Check for MIL lamp test at key-on. If MIL lamp remains illuminated (indicating a fault), use pedal to recover fault code(s). Repair faults.	X					
Engine Coolant						
Check coolant level.	X					
Inspect coolant hoses and fittings for leaks, cracks, swelling, or deterioration.				X		
Engine Ignition						
Inspect battery for damage and corroded cables.						X
Inspect ignition system.					X	
Replace spark plugs.					X	
Fuel Lock-Off/Filter						
Replace LP fuel filter element.				X		
Inspect lock-off and fuel filter for leaks.				X		
Ensure lock-off stops fuel flow when engine is off.				X		
Pressure Regulator/Converter						
Test regulator pressures.				X		
Inspect pressure regulator vapor hose for deposit buildup. Clean or replace as necessary.				X		

CHECK POINT	**INTERVAL HOURS**					
	Daily	**Every 250 Hours or 1 month**	**Every 500 Hours or 3 months**	**Every 1000 Hours or 6 months**	**Every 1500 Hours or 9 months**	**Every 2500 Hours or 1 year**
Inspect regulator assembly for fuel/coolant leaks.				**X**		
Fuel Trim Valve						
Inspect valve housing for wear, cracks or deterioration.				**X**		
Ensure valve seals in the closed position when the engine is off.				**X**		
Replace FTV.	When indicated by MIL					
Carburetor						
Check air filter indicator.	**X**					
Check for air leaks in the filter system.				**X**		
Inspect air/fuel valve mixer assembly for cracks, loose hoses, and fittings. Repair or replace as necessary.			**X**			
Check for vacuum leaks in the intake system including manifold adapter and mixer to throttle adapter.						**X**
Repair or replace throttle assembly.	When indicated by MIL					
Inspect air filter.			**X**			
Replace air filter element.				**X**		
Check TMAP sensor for tightness and leaks.						**X**
Exhaust & Emission						
Inspect engine for exhaust leaks.	**X**					
Replacement of Positive Crankcase Ventilation (PCV) valve and breather element recommended if applicable.						**X**
Replace HEGO sensors.	When indicated by MIL					
Gasoline Engines						
Replace gasoline fuel filter element.				**X**		
Inspect gasoline fuel system for leaks.				**X**		

CHECK POINT	**INTERVAL HOURS**					
	Daily	**Every 250 Hours or 1 month**	**Every 500 Hours or 3 months**	**Every 1000 Hours or 6 months**	**Every 1500 Hours or 9 months**	**Every 2500 Hours or 1 year**
Confirm gasoline supply pressure is correct.	Pressure should be 45-55 psig (310.26-379.21 kPa)					

Chapter 5.
Installation Procedures.

⚠WARNING

- **LP gas is highly flammable. To prevent personal injury, keep fire and flammable materials away from the lift truck when work is done on the fuel system.**
- **Gas vapor may reduce oxygen available for breathing, cause headache, nausea, dizziness and unconsciousness and lead to injury or death. Always operate the forklift in a well-ventilated area**
- **Liquid propane may cause freezing of tissue or frostbite. Avoid direct contact with skin or tissue; always wear appropriate safety protection including gloves and safety glasses when working with liquid propane.**

⚠CAUTION

The regulator/converter and mixer are part of a certified system complying with EPA and EU emission regulations. Only trained, certified technicians should perform disassembly, service or replacement of the regulator/converter or mixer.

Hose Connections

Proper operation of the closed loop control greatly depends on the correct vacuum hose routing and fuel line lengths. Refer to the connection diagrams below for proper routing and maximum hose lengths when reinstalling system components.

Certified System Connections

Refer to

Figure 5-1 and Table 5-1 for details on component mounting and connections of MI-21 certified system.

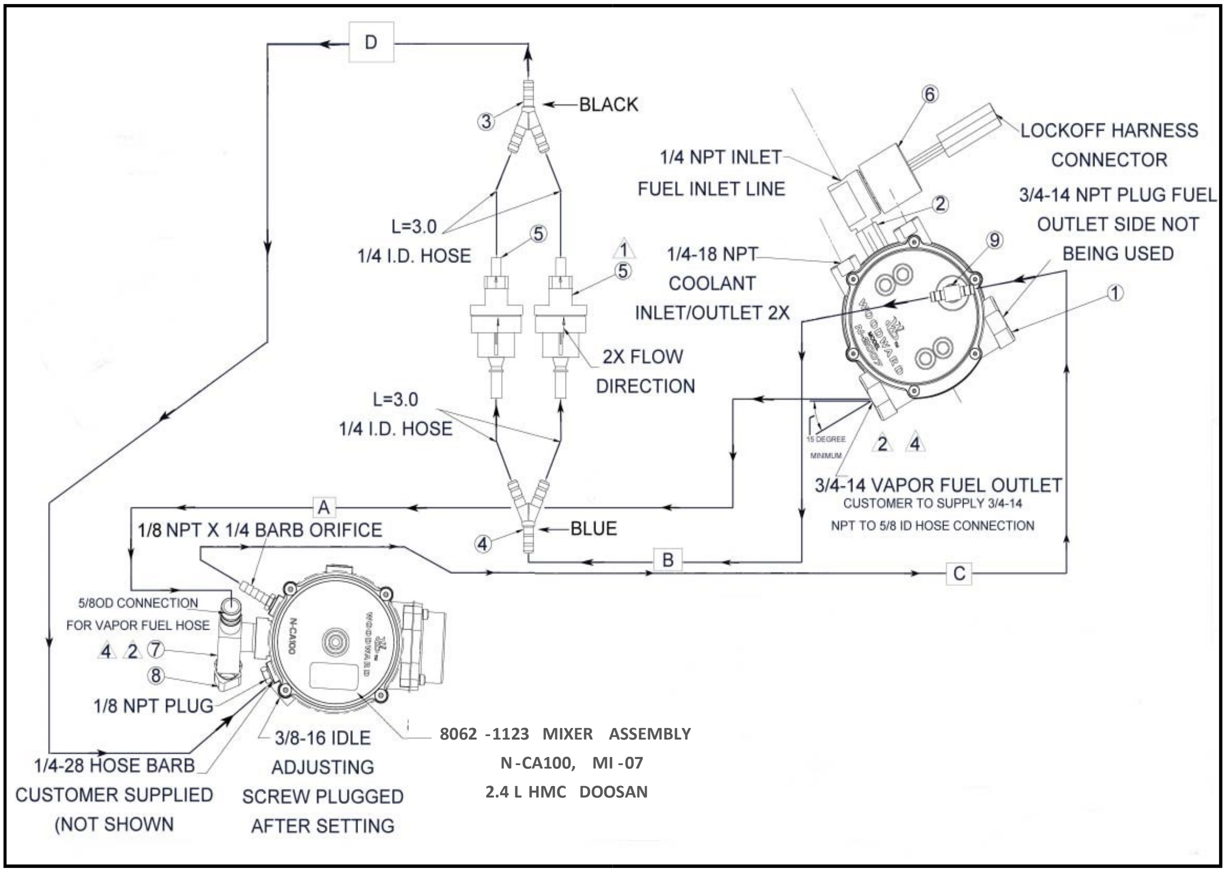


Figure 5-1. Hose Connections for Certified Systems

Table 5-1. Diagram notes for hose connections for certified systems

△1	Trim valves must be positioned vertically	C	1/4" (6.35mm) I.D. Hose. L= 21-32" (533 -813mm) Maximum length specified by engine manufacturer	⑤	Valve (TEV Bosch Canister)
△2	Only one 90° fitting permissible on vapor fuel line between mixer and regulator	D	1/4" (6.35mm) I.D. Vacuum Hose. L= 24-35.5" (610-902mm) Maximum length specified by engine manufacturer	⑥	Solenoid (AFS Lock Off Valve)
△3	Preferred mounting of regulator is off engine	①	N-2007 Regulator	⑦	Temperature Sensor Adapter

△4	Vapor fuel fittings (regulator and mixer) must have minimum ID of 0.46” (11.68mm)	②	5/8” (15.9mm) Hex Nipple, 1/4 x 18 NPT, 2-1/2” (63.5mm) L	⑧	Fuel Temperature Sensor
A	5/8” (15.9 mm) I.D. Vapor hose. L= 18-30” (457-762mm) Maximum length 30” (762mm)	③	Plastic WYE Fitting (black color) for 1/4” (6.35mm) I.D. Tube Hose	⑨	Brass Tee Fitting. 1/4 x 1/8 NPTF x 1/4” [6.35mm] Tube
B	1/4” (6.35mm) I.D. Hose. L= 13-20” (330-508mm) Maximum length specified by engine manufacturer	④	Plastic WYE Fitting (blue color) for 1/4” (6.35mm) I.D. Tube Hose		

Non-Certified System Connections

Refer to Figure and Figure 5-2 and Table 5-2 for details on component mounting and connections of MI-21 non-certified system.

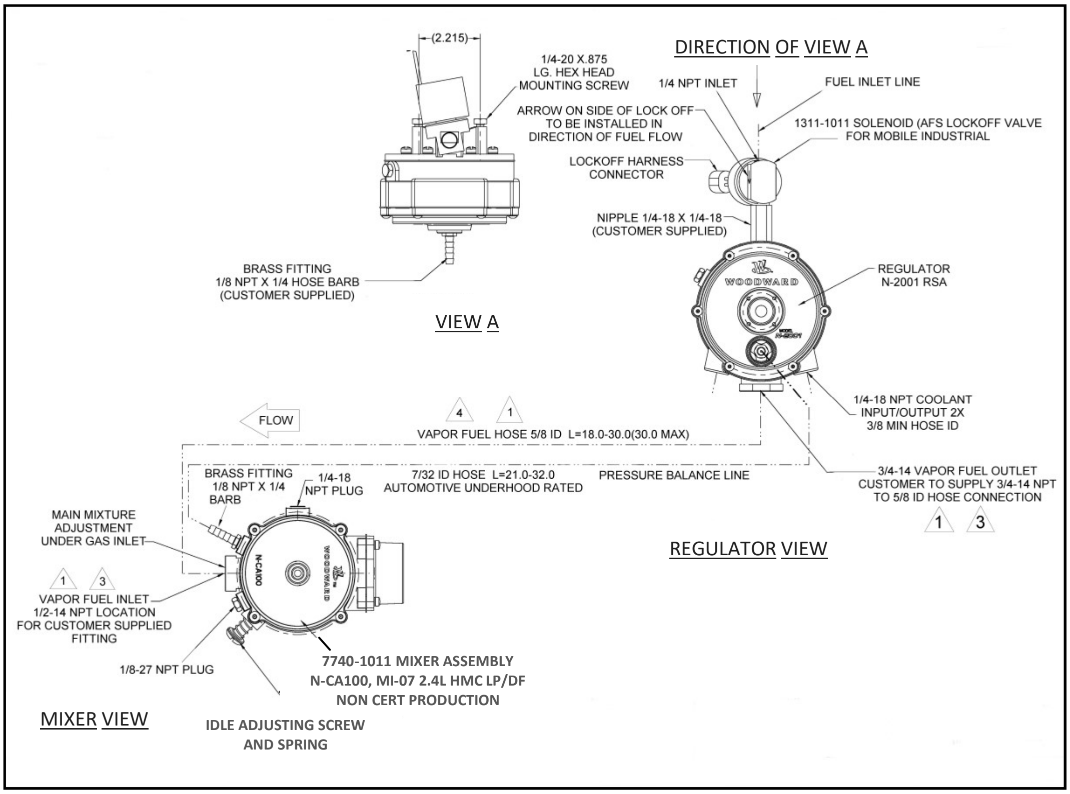


Figure 5-2. Hose Connections for Non-Certified Systems

Table 5-2. Diagram Notes for Hose Connections for Non-Certified Systems

1	Only one 90º fitting permissible on vapor fuel line between mixer and regulator.
3	Vapor fuel fittings (regulator and mixer) must have minimum ID of 0.46” (11.68mm)
4	Vapor hose length to be as short as possible and have no restrictions for best regulator performance
5	Fuel outlet must be positioned vertically in the down position

NOTICE **Preferred mounting of regulator is off engine.**

Removal and Installation of N-2007Certified LP Regulator/Converter

Follow the procedures below for removal and reinstallation of the N-2007 regulator in certified systems.

N-2007 Removal Steps

Refer to Figure 5-3**.**

1. Close the liquid outlet valve in the forklift cylinder or fuel storage container.
2. Purge the system of fuel by starting the engine and running until all trapped fuel in the system is exhausted and the engine shuts down.
3. Key switch in “OFF” position.
4. Remove the fuel inlet line (**1**) from the lock-off, the two vacuum lines (**2**) from the branch-tee fitting in the regulator vent and disconnect the lockoff connector (**3**).
5. Remove the four rear-mounting bolts that hold the regulator to the support bracket. This will allow easier access to the remaining hose clamps.
6. Remove the two cooling lines (**4**) from the regulator. *NOTE: Either drain the coolant system or clamp off the coolant lines as close to the regulator as possible to avoid a coolant spill when these lines are disconnected.*
7. Remove the fuel vapor outlet hose (**5**) from the regulator.
8. Remove the nipple extension (**6**) with the lock-off from the regulator.

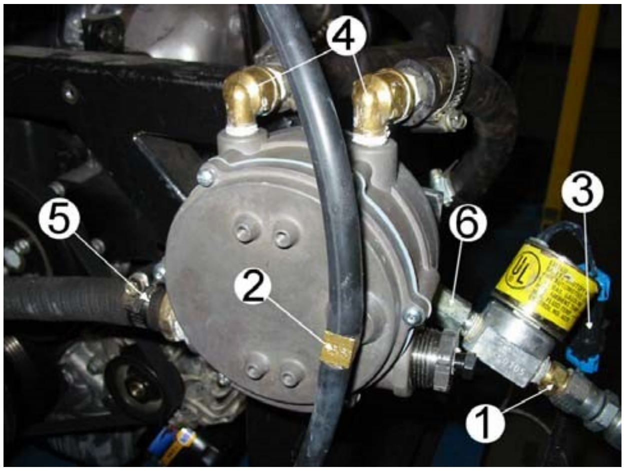


Figure 5-3. N-2007 Regulator in Certified System

N-2007 Installation Steps

Refer to Figure 5-4

1. Install the nipple extension (**6**) with the lock-off to the regulator.
2. Install the fuel vapor outlet hose (**5**) to the regulator.
3. Install the two cooling lines (**4**) to the regulator.
4. Install the four rear-mounting bolts that hold the regulator to the support bracket. Use a torque wrench and tighten each bolt to 60-70 lbf-in (6.78-7.91 N-m).
5. Install the fuel inlet line (**1**) to the lock-off, the two vacuum lines (**2**) to the branch-tee fitting in the regulator vent and re-connect the lock-off connector (**3**).
6. Open the liquid outlet valve in the forklift cylinder or fuel storage container.

Removal and Installation of N-2001 Non-Certified LP Regulator/Converter

Follow the procedures below for removal and reinstallation of the N-2001 regulator.

N-2001 Removal Steps

Refer to Figure 5-4.

1. Close the liquid outlet valve in the forklift cylinder or fuel storage container.
2. Purge the system of fuel by starting the engine and running until all trapped fuel in the system is exhausted and the engine shuts down.
3. Remove the fuel inlet line (**1**) from the lock-off, the two vacuum lines (**2**) from the branch-tee fitting in the regulator vent and disconnect the lock-off connector (**3**).
4. Remove the two rear-mounting bolts that hold the regulator to the support bracket. This will permit easier access to the remaining hose clamps.
5. Remove the two cooling lines (**4**) from the regulator. *NOTE: It will be necessary to either drain the coolant system or clamp off the coolant lines as close to the regulator as possible to avoid a coolant spill when these lines are disconnected.*
6. Remove the fuel vapor outlet hose (**5**) from the regulator.

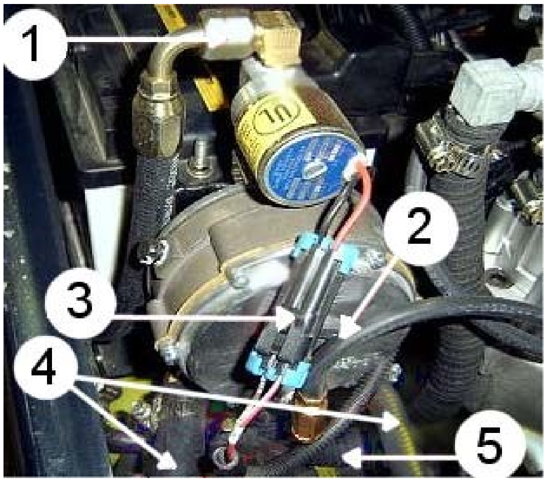


Figure 5-4. N-2001 Regulator in Non-Certified System

N-2001 Installation Steps

Refer to Figure 5-5

1. Install the fuel vapor outlet hose (**5**) from the regulator.
2. Install the two cooling lines (**4**) from the regulator.
3. Install the two rear-mounting bolts that hold the regulator to the support bracket. Use a torque wrench and tighten each bolt to 50-60 lbf-in (5.65-6.78 N-m)
4. Install the fuel inlet line (**1**) from the lock-off, the two vacuum lines (**2**) from the branch-tee fitting in the regulator vent and disconnect the lockoff connector (**3**).
5. Open the liquid outlet valve in the forklift cylinder or fuel storage container.

Removal and Installation of CA100 Certified Mixer

P/N 8062-1123

CA100 Certified Mixer Removal Steps

Refer to Figure 5-5.

1. Close the liquid outlet valve in the forklift cylinder or fuel storage container.
2. Purge the system of fuel by starting the engine and running until all trapped fuel in the system is exhausted and the engine shuts down.
3. Key switch in “OFF” position.
4. Remove the air cleaner hose (**1**).
5. Mark the two vacuum lines to the mixer for identification, as they must be installed correctly for proper operation. Remove the two vacuum lines (**2**).
6. Remove vapor fuel inlet line from the fuel temperature sensor adapter (**3**).
7. Disconnect the fuel temperature sensor connector (**4**).
8. Remove the four bolts that mount the throttle adapter to the electronic throttle body (**5**).
9. Remove the mixer/adapter assembly from the throttle by gently pulling upwards.
10. Take note of the adapter orientation on the mixer, as it must be installed correctly for proper fit on the throttle. Remove the four mount screws that attach the throttle adaptor to the mixer.
11. Remove the fuel temperature sensor from the adapter (**6**).
12. Remove the fuel temperature sensor adapter from the mixer.
13. Remove the vacuum port barb below the idle set screw from the mixer (**7**).

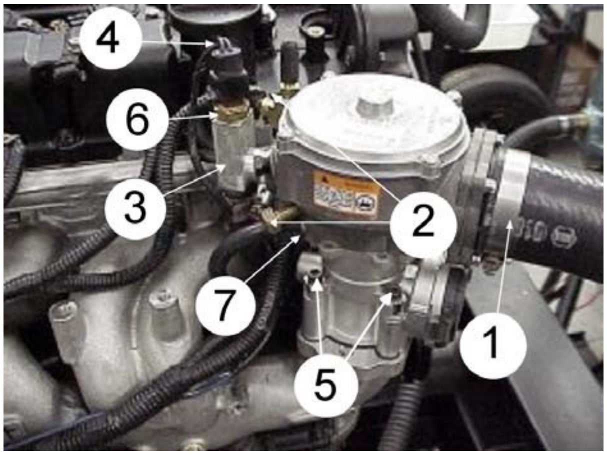


Figure 5-5. CA100 Mixer in Certified System

⚠CAUTION	**The 1/8" NPT x 1/4" hose barb fitting that is installed in the mixer housing uses a specific machined orifice size through the fitting. This orifice fitting is part of the mixer assembly and is an integral part of the MI-21 control. If this fitting is damaged the mixer will need to be replaced. DO NOT replace this fitting with a standard hose barb fitting or use a drill bit to clean out the fitting passageway.**

NOTICE	**A plastic O-ring spacer and an O-ring are inside the mixer/adapter assembly. Be careful not to lose these items when removing the assembly from the throttle (Figure 5-6).**

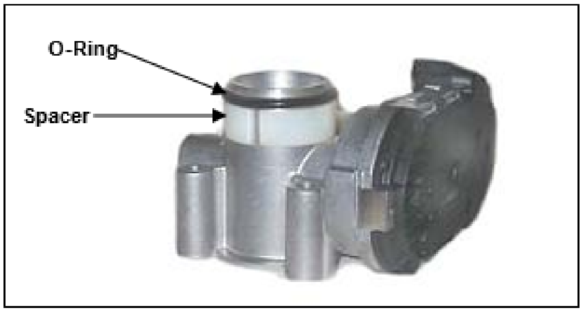


Figure 5-6. O-Ring and Spacer Within Mixer Adapter Assembly

CA100 Certified Mixer Installation Steps

Refer to Figure 5-7.

1. Install the vacuum port barb below the idle set screw on the mixer (**7**).
2. Install the fuel temperature sensor adapter to the mixer.
3. Install the fuel temperature sensor to the adapter (**6**).
4. Install the four mount screws that attach the throttle adaptor to the mixer.
5. Torque bolts to 30-40 lbf-in (3.39-4.52 N-m).
6. Install the mixer/adapter assembly to the throttle by gently pushing downwards.
7. Install the four bolts that mount the throttle adapter to the electronic throttle body (**5**).
8. Re-connect the fuel temperature sensor connector (**4**).
9. Install the vapor fuel inlet line to the fuel temperature sensor adapter (**3**).
10. Install the two vacuum lines to the mixer using the previous marks for identification. Vacuum lines must be installed correctly for proper operation.
11. Install the air cleaner hose (1).

Figure 5-7. Throttle Adapter Mount Screws

Removal and Installation of CA100 Non-Certified Mixer

P/N 7740-1011

Follow the procedures below for removal and reinstallation of the CA100 mixer in non-certified systems. Refer to Figure 5-8

CA100 Non-Certified Mixer Removal Steps

1. Close the liquid outlet valve in the forklift cylinder or fuel storage container.
2. Purge the system of fuel by starting the engine and running until all trapped fuel in the system is exhausted and the engine shuts down.
3. Key switch in “OFF” position.
4. Remove the air cleaner hose (**1**).
5. Remove the vacuum line (**2**).
6. Remove the vapor fuel inlet line from the mixer (**3**).
7. Remove the four bolts that mount the throttle adapter to the electronic throttle body (**4**).
8. Remove the mixer/adapter assembly from the throttle by gently pulling upwards.
9. Take note of the adapter orientation on the mixer, as it must be installed correctly for proper fit on the throttle. Remove the four mount screws that attach the throttle adapter to the mixer. (See Figure .)

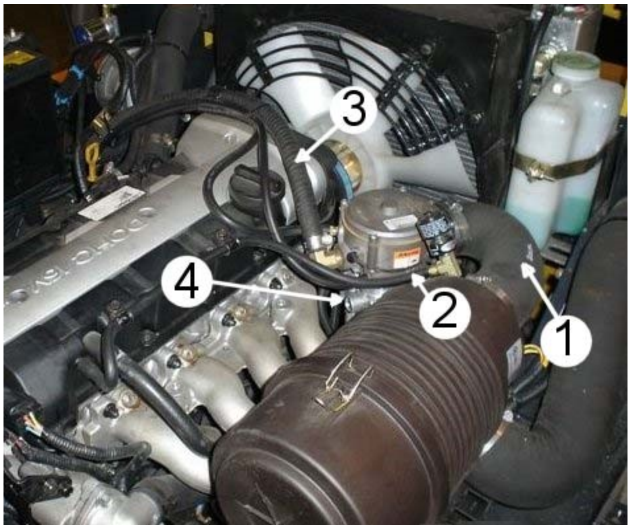


Figure 5-8. CA100 Mixer in Non-Certified System

CA100 Non-Certified Mixer Installation Steps

1. Install the four mount screws that attach the throttle adapter to the mixer.
2. (See Figure 5-8)
3. Torque bolts to 30-40 lbf-in (3.39-4.52 N-m).
4. Install the mixer/adapter assembly to the throttle by gently pushing downwards.
5. Install the four bolts that mount the throttle adapter to the electronic throttle body (**4**).
6. Install the vapor fuel inlet line to the mixer (**3**).
7. Install the vacuum line to the mixer (**2**).
8. Install the air cleaner hose (**1**).

Chapter 6.
Tests and Adjustments

⚠WARNING

- **LP gas is highly flammable. To prevent personal injury, keep fire and flammable materials away from the lift truck when work is done on the fuel system.**
- **Gas vapor may reduce oxygen available for breathing, cause headache, nausea, dizziness and unconsciousness and lead to injury or death. Always operate the forklift in a well-ventilated area**
- **Liquid propane may cause freezing of tissue or frostbite. Avoid direct contact with skin or tissue; always wear appropriate safety protection including gloves and safety glasses when working with liquid propane.**

⚠CAUTION

The regulator/converter and mixer are part of a certified system complying with EPA and EU emission regulations. Only trained, certified technicians should perform disassembly, service or replacement of the regulator/converter or mixer.

N-2007 Regulator Service Testing

For checking the N-2007 regulator/converter operation, the following tests can be performed (See Chapter 5 for removal/installation of the N-2007 regulator). To check the secondary regulation (output) a simple vacuum hand pump can be used to simulate the vacuum signal transmitted from the air/fuel mixer when the engine is running. See listing below for required hardware.

Break-Off Test
Secondary Stage Test Hardware

1. Hand vacuum pump
2. Regulator vapor outlet test fitting 3/4” NPT x 1/4” hose barb
3. Union Tee 1/4” NPT with three 1/4” NPT x 1/4” hose barb
4. Vacuum hose
5. 0-3” WC Magnehelic gauge (inches of water column)

Secondary Stage (Break-Off) Test

1. Connect the vacuum pump, the Magnehelic gauge and the regulator vapor outlet to the Union Tee fitting Figure 6-1). Make sure there is no leakage at any of the fittings.
2. Using the vacuum pump slowly apply enough vacuum to measure above -2” WC on the gauge. This vacuum signal opens the secondary valve in the N-2007 regulator/converter.
3. Release the vacuum pump lever and you will see the gauge needle start falling back toward zero. When the pressure drops just below the specified break-off pressure (-0.5 +/- 0.35 “ WC) of the secondary spring, the needle should stop moving.
4. At this point the secondary valve should close. If the secondary valve seat or the secondary diaphragm is leaking the gauge needle will continue to fall toward zero (proportional to the leak size). An excessively rich air/fuel mixture can be caused by a secondary valve seat leak and the regulator should be replaced.

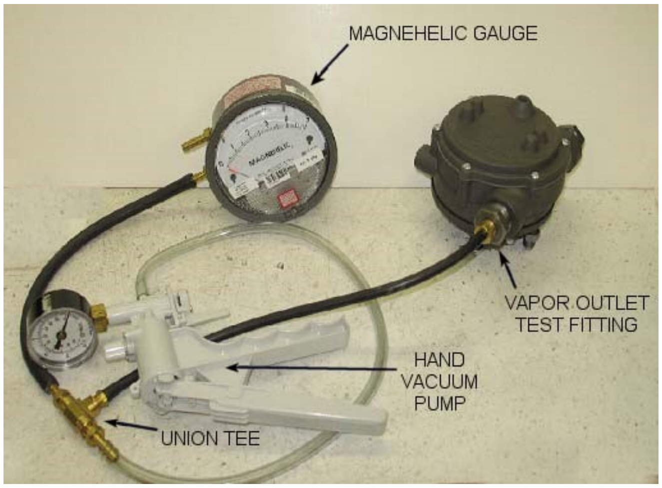


Figure 6-1. Secondary Stage Test Connection

Pressure Test

Primary Stage Test Hardware

1. Shop air pressure regulator adjusted to 100 psi
2. Shop air hose fitting (1/4” NPT to air hose)
3. Air hose
4. Test gauge fitting (1/8” NPT x 1/4” hose barb)
5. Vacuum hose or vinyl tubing
6. 0-60” WC Magnehelic gauge (inches of water column)

Primary Stage Pressure Test

1. Remove the primary test port plug from the side of the regulator and install the 1/8” NPT hose barb fitting (Figure 6-2**)**.
   Note: Earlier versions are equipped with 1/16” NPT fitting.
2. Connect a compressed air line (shop air ~100psi) to the liquid propane fuel inlet of the N-2007 regulator (Figure 6-2**)**.

Figure 6-2. Primary Stage Test Connection

3. Apply compressed air, wait for air to exit the hose barb in the test port, and then connect the Magnehelic gauge (Figure 6-3) to the hose barb using the vacuum hose or vinyl tubing. This prevents the gauge from reading maximum pressure due to the large velocity of compressed air entering the primary chamber.
4. Make sure there is no leakage at any of the fittings. The static pressure should read between 40-60” of water column on the Magnehelic gauge and maintain a constant pressure for 60 seconds.

Figure 6-3. Magnehelic Gauge Connection to Hose Barb

1. If the pressure reading begins to **increase**, a leak is most likely present at the primary valve, either the primary valve O-ring or the valve itself. If a leak is present the regulator should be replaced.
2. If the pressure begins to **decrease**, the secondary seat is probably not making an adequate seal and is leaking. The regulator should be replaced.
3. If the test is successful, re-install the primary test port plug and check the fittings for leaks. See Chapter 5 for installation of the N-2007 regulator.

NOTICE

The N-2007 primary stage pressure can also be tested at idle on a running engine. The N-2007 primary pressure should be between 40 inH20 (99.635 mbar) and 55 inH20 (136.999 mbar) at 750 rpm, idle.

⚠WARNING

- **LP gas is highly flammable. To prevent personal injury, keep fire and flammable materials away from the lift truck when work is done on the fuel system.**

- **Gas vapor may reduce oxygen available for breathing, cause headache, nausea, dizziness and unconsciousness and lead to injury or death. Always operate the forklift in a well-ventilated area**

- **Liquid propane may cause freezing of tissue or frostbite. Avoid direct contact with skin or tissue; always wear appropriate safety protection including gloves and safety glasses when working with liquid propane.**

AVV (Air Valve Vacuum) Testing

Purpose of Test

Check for excessive or inadequate pressure drop across CA100 mixer.

AVV Test Hardware

1. Union Tee fitting, 1/4” (6.35mm) NPT with three 1/4” (6.35mm) NPT x 1/4” (6.35mm) hose barbs
2. Vacuum hose
3. 0-20” H2O differential pressure Magnehelic gauge

AVV Test

1. Install Union Tee fitting in the hose between the FTVs and the AVV fitting. Connect this fitting to the low pressure port of the Magnehelic gauge (Figure 6-4**)**.
2. Leave high pressure port of the Magnehelic gauge exposed to ambient pressure (
3. Figure).
4. With the engine fully warmed up and running at idle (750 rpm) place the transmission in Neutral. The AVV should be between 5” and 8” H2O of pressure vacuum.
5. If the measured pressure drop is excessively high, check for sticking or binding of the diaphragm air valve assembly inside the mixer. Replace mixer if necessary.
6. If the measured pressure drop is low, check for vacuum leaks in the manifold, throttle, mixer, TMAP sensor and attached hoses.

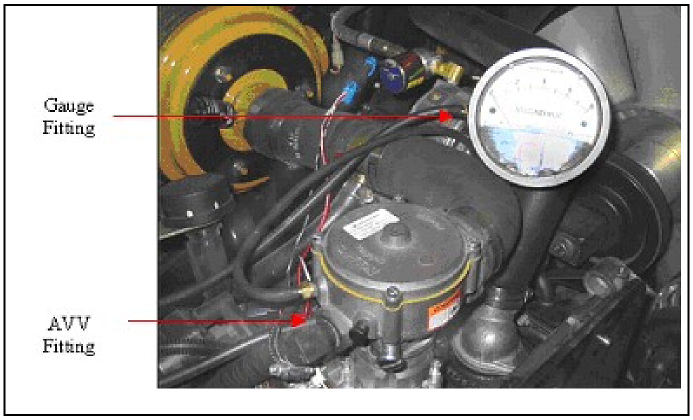


Figure 6-4. Magnehelic Gauge Connection

Ignition Timing Adjustment

With the MI-21 system, ignition-timing advance is controlled by the SECM.

The initial ignition timing needs to be set by the MOR. This setup requires a specific technique for each engine installation.

The timing can be checked by finding the desired ignition timing in the MI-21 service tool and checking against a timing light.

Connection of the MI-21 Service Tool

To use the Service Tool, a USB (Universal Serial Bus) to CAN (Controller Area Network) communication adapter is required. The MI-21 service tool (Toolkit) works with a variety of IXXAT, Kvaser, and RP1210 CAN interfaces. Commonly used adapters include ‘Kvaser Leaf Light HS USB to CAN’ and ‘Kvaser Leaf Light V2 HS USB.

1. With the ignition key in the OFF position, connect the communication cable from a USB port on the computer to the CAN communications cable on the engine. **(**Figure 6-5**)**
2. Turn the ignition key to the ON position ***(Do Not Start the Engine)***.
3. Launch the Woodward Toolkit program on your computer and open the Service Tool display (Figure 6-6).
4. Press the Connect button on Woodward Toolkit and input the connection information as below (Figure 6-7).
   - Check the Extended box for both of Command and Response
   - Command ID: 188C0CF9
   - Response ID: 188BF90C
5. Press the Add button and Connect button to start communication with SECM70

6. Input your access level and password and press Log In to unlock access to the SECM70

Communication Adapter

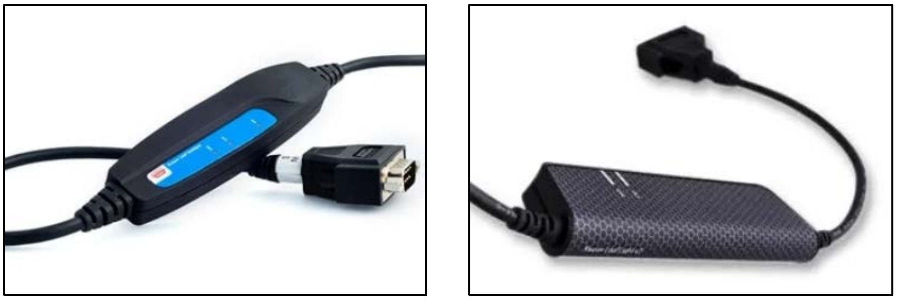
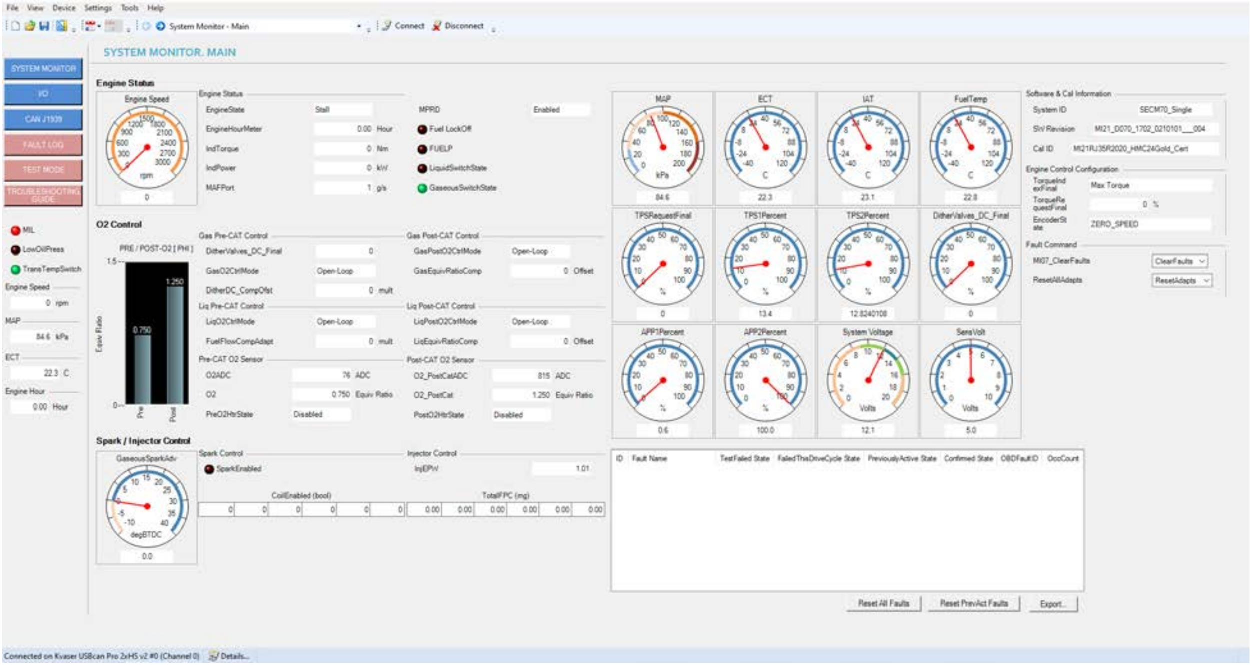


Figure 6-5. Kvaser Leaf Light HS USB to CAN(Left) and Leaf Light V2 HS USB to CAN(Right)



Engine Speed 0 rpm
MAP 84.6 kPa
ECT 22.3 C
Engine Hour 0.00 Hour

Engine Status

Engine Speed 0

Engine Status
EngineState Stall
EngineHourMeter 0.00 Hour
IndTorque 0 Nm
IndPower 0 kW
MAFPort 1 g/s
MPRD Enabled
Fuel LockOff
FUELP
LiquidSwitchState
GaseousSwitchState

O2 Control

Pre 0.750
Post 1.250

Gas Pre-CAT Control
DitherValves_DC_Final 0
GasO2CtrlMode Open-Loop
DitherDC_CompOfst 0 mult

Gas Post-CAT Control
GasPostO2CtrlMode Open-Loop
GasEquivRatioComp 0 Offset

Liq Pre-CAT Control
LiqO2CtrlMode Open-Loop
FuelFlowCompAdapt 0 mult

Liq Post-CAT Control
LiqPostO2CtrlMode Open-Loop
LiqEquivRatioComp 0 Offset

Pre-CAT O2 Sensor
O2ADC 76 ADC
O2 0.750 Equiv Ratio
PreO2HtrState Disabled

Post-CAT O2 Sensor
O2_PostCatADC 815 ADC
O2_PostCat 1.250 Equiv Ratio
PostO2HtrState Disabled

Spark / Injector Control

GaseousSparkAdv 0.0

Spark Control
SparkEnabled

Injector Control
InjEPW 1.01

CoilEnabled (bool)						TotalFPC (mg)					
0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00

MAP 84.6
ECT 22.3
IAT 23.1
FuelTemp 22.8
TPSRequestFinal 0
TPS1Percent 13.4
TPS2Percent 12.8240108
DitherValves_DC_Final 0
APP1Percent 0.6
APP2Percent 100.0
System Voltage 12.1
SensVolt 5.0

Software & Cal Information
System ID SECM70_Single
SW Revision MI21_D070_1702_0210101___004
Cal ID MI21RJ35R2020_HMC24Gold_Cert

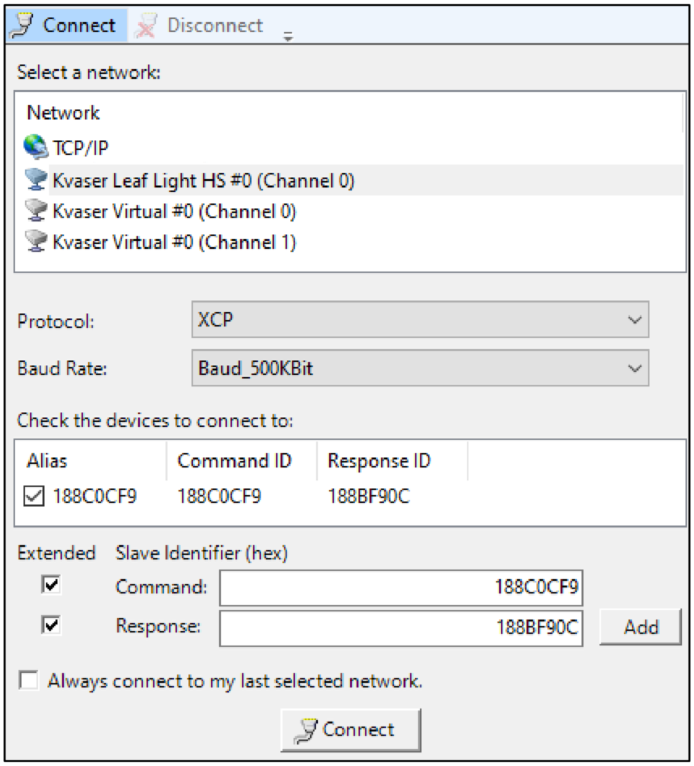
Engine Control Configuration
TorqueIndexFinal Max Torque
TorqueRequestFinal 0 %
EncoderState ZERO_SPEED

Fault Command
MI07_ClearFaults ClearFaults
ResetAllAdapts ResetAdapts

ID	Fault Name	TestFailed State	FailedThisDriveCycle State	PreviouslyActive State	Confirmed State	OBDFaultID	OccCount

Connected on Kvaser USBcan Pro 2xHS v2 #0 (Channel 0)

Figure 6-6. Opening the Service Tool Display



Select a network:

Network
TCP/IP
Kvaser Leaf Light HS #0 (Channel 0)
Kvaser Virtual #0 (Channel 0)
Kvaser Virtual #0 (Channel 1)

Protocol: XCP

Baud Rate: Baud_500KBit

Check the devices to connect to:

Alias	Command ID	Response ID
☑ 188C0CF9	188C0CF9	188BF90C

Extended Slave Identifier (hex)

☑ Command: 188C0CF9

☑ Response: 188BF90C

☐ Always connect to my last selected network.

Figure 6-7. Woodward Toolkit Connection

Idle Mixture Adjustment

The CA100 mixer requires adjustment of the idle mixture screw to assure optimal emissions and performance. This adjustment accounts for minor part-to-part variations in the fuel system/engine and assures stable performance of the engine at idle. Once adjusted, the idle mixture screw is sealed with a tamper proof cap, after which it need not be adjusted for the life of the vehicle. Idle mixture adjustment should only be completed at the factory.

Factory Test Preparation

1.
2. Install the MI-21 fuel system, wiring harness and SECM-70 control module on the engine.
3. All coolant hoses should be attached, filled with coolant and bled to remove any air.
4. Install a representative air filter assembly
5. Attach LPG fuel lines.
6. Attach wiring harness to battery power.
7. Attach exhaust system.
8. If present, set fuel select switch to LPG fuel.

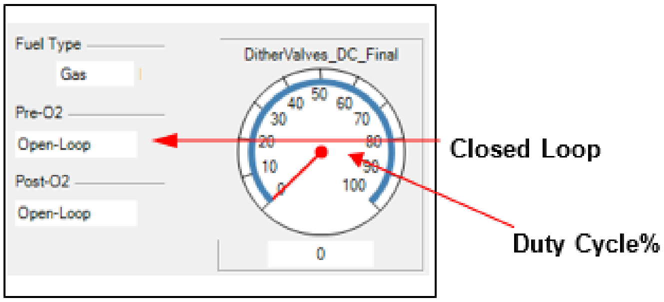
When operated at the factory, it is critical to simulate the airflow found on a forklift at idle as nearly as possible to achieve the proper air valve lift in the mixer. It may be necessary to place a load on the engine to achieve the required airflow without over-speeding the engine. To achieve this load, attach the engine to a dynamometer.

Following procedure requires using Toolkit service tool to display specific engine parameters.

Factory Adjustment Procedure

NOTICE **Be sure engine is fully warm (ECT>167°F [75°C]) before performing the idle mixture adjustment.**

1. Operating the engine on LPG fuel, start the engine and permit it to warm up until the coolant temperature (ECT on Toolkit display) is approximately 167 °F (75 ºC).
2. Adjust load to a representative value for an engine at idle in the specific application. If this value is not known, collect data of MAP or MAFPort on enough applications to obtain a good average.
    a. For the HMC 2.4L MAFPort is approximately 3.6 to 4.2 g/sec with a light load (10 Nm) at 750 RPM.
3. Navigate Toolkit service tool to page “Actuator – Dither Valve”
4. Check Toolkit display parameter Pre-O2 is “Closed Loop”.
5. Monitor Toolkit display parameter “DitherValves_DC_Final”.
6. To adjust the idle mixture screw, use a hex or Allen-type wrench. Turning the screw in (clockwise) should increase the duty cycle; turning the screw out (counterclockwise) should decrease the duty cycle.
7. Adjust the idle mixture screw on the mixer until a reading of **50-60%** is reached for the FTV Duty Cycle in Closed Loop Idle (Figure 6-8). If engine idle performance is unstable, screw the idle screw in slightly to see if stability is obtained, however duty cycles above 60% should be avoided.


Fuel Type: Gas

Pre-O2: Open-Loop

Post-O2: Open-Loop

DitherValves_DC_Final: 0

Closed Loop

Duty Cycle%

Figure 6-8. FTV Duty Cycle Percentage Displayed on Service Tool

8. Use the accelerator pedal to increase rpm above idle momentarily (*rev the engine*) then release the pedal to return to idle rpm. The duty cycle setting should remain within the adjustment range (**50-60%**). Place your thumb over the adjustment port for a more accurate reading by preventing air from leaking past the mixture adjustment screw, which may cause the duty cycle to decrease.
9. If the FTV duty cycle reading is above **60%** adjust the idle adjustment screw outward and re-check the duty cycle reading. Continue to do this until the FTV duty cycle reading is within the optimum range (**50-60%**) and engine rpm is stable. **DO NOT** adjust the screw so far outward that the tamper proof cap cannot be installed. If the FTV duty cycle cannot be adjusted below **60%**, the mixer is faulty and should be replaced.

NOTICE **If the FTV duty cycle reading is NOT between 45-60%, check for possible vacuum leaks, manifold leaks, or a faulty mixer.**

10. Turn the ignition key to the OFF position to shut down the engine.
11. Install the tamper proof cap on the idle mixture screw adjustment port using a large pin punch, so that no further adjustments can be made (Figure 6-9).

Figure 6-9. Installing Tamper Proof Cap

Non-Certified Systems with O2 Sensor

Idle Adjustment

1. Install mixer and a UEGO or HEGO sensor. (A UEGO sensor should be used when desired phi settings are not at stoichiometric.)
2. After the mixer is installed, start and warm up the engine to normal operating temperature (ECT>167°F [75°C]). Also ensure that the vehicle drive train and hydraulic systems are at normal operating temperatures per vehicle manufacturer recommendations.
3. Allow the engine to reach steady state at idle.
4. While monitoring the output of the UEGO or HEGO sensor adjust the idle screw (Figure) using a standard screwdriver until the desired phi reading is achieved (phi = 1.05 to 1.06 is optimal). To make the mixture richer, turn the screw clockwise; to make the mixture leaner, turn the screw counterclockwise.
5. Rev the engine to take it off idle and let it return to idle.
6. Once the engine has reached steady state at idle, verify the phi reading. Adjust further as needed.

Power Valve Adjustment

1. The power valve should only be adjusted after the idle screw has been adjusted properly. The engine and vehicle drive train and hydraulics should also be at normal operating temperatures.
2. Apply a load to the engine while the engine is operating above idle speed. Torque converter stall is the preferred operating mode for this test. If a torque converter speed test cannot be performed, the engine can be run at another speed (max governor), but a load must be applied by using hydraulics.

NOTICE

While adjusting the power valve, do not hold engine at load point for longer than 5-10 seconds. Holding for a longer period of time will cause the fuel temperature to drop, which could adversely affect the power valve setting.

3. Monitor the output of the UEGO or HEGO sensor while the engine is at the higher speed with the load applied (phi = 1.05 to 1.06 is optimal).
4. If the phi reading is not at the desired level, bring the engine back to idle and adjust the power valve (Figure 6-10).
5. Bring the engine back to the higher speed with a load applied and verify the power valve setting. Adjust further as needed.
6. Once the power valve is set, bring the engine back to idle and verify the idle screw setting.

Non-Certified Systems Without O2 Sensor

Idle Adjustment

1. After the mixer is installed, start and warm up the engine to normal operating temperature (ECT>167°F [75°C]). Also ensure that the vehicle drive train and hydraulic systems are at normal operating temperatures per vehicle manufacturer recommendations.
2. Allow the engine to reach steady state at idle.
3. With the idle screw completely tightened clockwise, use a standard screwdriver to adjust the idle screw (Figure 6-10) counterclockwise until a minimum average MAP value has been reached. The MAP value is displayed on the Service Tool screen.

Power Valve Adjustment

1. The power valve should only be adjusted after the idle screw has been adjusted properly. The engine and vehicle drive train and hydraulics should also be at normal operating temperatures.
2. Apply a load to the engine while the engine is operating above idle speed. Torque converter stall is the preferred operating mode for this test. If a torque converter speed test cannot be performed, the engine can be run at another speed (max governor), but a load must be applied by using hydraulics.
3. The power valve should be adjusted (Figure 6-10) to obtain maximum torque converter stall speed.

NOTICE

While adjusting the power valve, do not hold engine at load point for longer than 5-10 seconds. Holding for a longer period will cause the fuel temperature to drop, which could adversely affect the power valve setting.

4. Once the power valve is set, bring the engine back to idle and verify the idle screw setting.

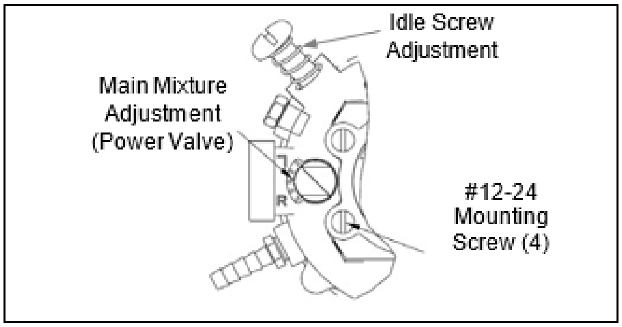


Figure 6-10. Main Mixture and Idle Screw Adjustment on Bottom of Mixer (partial view)

Chapter 7.
Basic Troubleshooting.

Preliminary Checks

MI-21 systems are equipped with built-in fault diagnostics. Detected system faults can be displayed by the Malfunction Indicator Lamp (MIL) and are covered in Chapter 8, Advanced Diagnostics. However, items such as fuel level, plugged fuel lines, clogged fuel filters, and malfunctioning pressure regulators may not set a fault code and usually can be corrected with the basic troubleshooting steps described on the following pages.

If engine or drivability problems are encountered with your MI-21 system, perform the checks in this section before referring to Advanced Diagnostics.

Note: Locating a problem in a propane engine is done the same as with a gasoline engine. Consider all parts of the ignition and mechanical systems as well as the fuel system.

Before Starting

1. Determine that the SECM and MIL light are operating. Verify operation by keying on engine and checking for flash of MIL light.
2. When the ignition key is turned on, the MIL will illuminate and remain on until the engine is started. Once the engine is started, the MIL lamp will go out unless one or more fault conditions are present. If a detected fault condition exists, the fault or faults will be stored in the memory of the SECM. Once an active fault occurs the MIL will illuminate and remain ON. This signals the operator that a fault has been detected by the SECM.
3. Determine that there are no diagnostic codes stored, or there is a diagnostic code but no MIL light.

Visual/Physical Checks

Several of the procedures call for a “Careful Visual/Physical Check” which should include:

- SECM grounds for being clean and tight
- Vacuum hoses for splits, kinks, and proper connection.
- Air leaks at throttle body mounting and intake manifold
- Exhaust system leaks
- Ignition wires for cracking, hardness, proper routing, and carbon tracking
- Wiring for pinches and cuts

Also check:

- Connections to determine that none are loose, cracked, or missing
- Fuel level in vehicle is sufficient
- Fuel is not leaking
- Battery voltage is greater than 11.5 volts
- Steering, brakes, and hydraulics are in proper condition and vehicle is safe to operate

NOTICE

The Visual/Physical check is very important, as it can often correct a problem without further troubleshooting and save valuable time.

Basic Troubleshooting

Intermittent

An intermittent fault is the most difficult to troubleshoot since the MIL flashes on at random, causing uncertainty in the number of flashes or the conditions present at the time of the fault. Also, the problem may or may not fully turn "ON" the MIL light or store a code.

Therefore, the fault must be present or able to be recreated to locate the problem. If a fault is intermittent, use of diagnostic code charts may result in the unnecessary replacement of good components. See Table 7-1 for corrective actions for intermittent faults.

Table 7-1. Corrective Action Table for Intermittent Faults

CORRECTIVE ACTION
Most intermittent problems are caused by faulty electrical connections or wiring. Perform careful visual/physical check for: • Poor mating of the connector halves or terminal not fully seated in the connector body (backed out) • Improperly formed or damaged terminal. All connector terminals in problem circuit should be carefully reformed or replaced to insure proper contact tension • Loose connections or broken wires • Poor terminal to wire connection crimp
If a visual/physical check does not find the cause of the problem, perform the following: 1. Drive the vehicle with a voltmeter or "Service" tool connected to a suspected circuit. Check if circuit is active and signal is reasonable. 2. Using the "Service" tool, monitor the input signal to the SECM to help detect intermittent conditions. 3. An abnormal voltage, or "Service" reading, when the problem occurs, indicates the problem may be in that circuit. 4. If the wiring and connectors check OK, and a diagnostic code was stored for a circuit having a sensor, check sensor.
An intermittent "Service Engine Soon" light with no stored diagnostic code may be caused by: • Ignition coil shortage to ground and arcing at spark plug wires or plugs • MIL light wire to ECM shorted to ground • SECM grounds (refer to SECM wiring diagrams).
Check for improper installation of electrical options such as lights, 2-way radios, accessories, etc.
EST wires should be routed away from spark plug wires, distributor wires, distributor housing, coil, and generator. Wires from SECM to ignition should have a good connection.

Surges and/or Stumbles

Engine power varies under steady throttle or cruise. Feels like the vehicle speeds up and slows down with no change in the acceleration pedal. See Table 7-2 for corrective actions for surges and/or stumbles.

Table 7-2. Corrective Action Table for Surges And/Or Stumbles

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter. Be sure driver understands vehicle operation as explained in the operator manual.

PROBABLE CAUSE	**CORRECTIVE ACTION**
Oxygen sensor malfunction	The fuel management should maintain a stoichiometric air-fuel ratio under all steady state operating conditions following engine warmup. Failure of the Pre-catalyst O2 sensor should cause an O2 sensor fault that can be diagnosed with the MIL lamp or Service Tool.
Fuel system malfunction	**NOTE:** To determine if the condition is caused by a rich or lean system, the vehicle should be driven at the speed of the complaint. Monitoring pre-catalyst O2 adapts*, dither valve duty cycle, or mechanical injector pulse width will help identify problem. Check fuel supply while condition exists. Check in-line fuel filter. Replace if dirty or plugged. Check fuel pressure.
Ignition system malfunction	Check for proper ignition voltage output using spark tester. Check spark plugs. • Remove spark plugs, check for wet plugs, cracks, wear, improper gap, burned electrodes, or heavy deposits. • Repair or replace as necessary. • Check condition of distributor cap, rotor and spark plug wires (where applicable). Check ignition timing. Refer to application manual for specs.
Component malfunction	Check vacuum lines for kinks or leaks. Check alternator output voltage. Repair if less than 9 or more than 16 volts.
Exhaust backpressure	Check condition of exhaust system. Check backpressure before catalyst. It should be less than 3.5 psig (24.13 kPa).

(*) Refer to **Table 1-1** for description of gaseous and liquid O2 adapts.

Related MIL Faults:

Pre-catalyst O2 sensor errors / O2 control errors
Dither valve DC faults / EST faults / ETC faults

Engine Cranking but Will Not Start / Difficult to Start

Engine cranks OK but does not start for a long time. Does eventually run or may start but immediately dies. See Table 7-3 for corrective actions for cranking with no/difficult start.

Table 7-3. Corrective Action Table for Cranking No/Difficult Start

PRELIMINARY CHECKS

Perform the visual checks as described at start of "Basic Troubleshooting" chapter. Be sure driver is using correct method to start engine as explained in operator's manual. Use "clear flood" mode during cranking by fully depressing the pedal and cranking the engine. If engine does not start, continue troubleshooting.

PROBABLE CAUSE	**CORRECTIVE ACTION**
Improper fuel selected	Verify "selected" fuel with Service Tool. Make sure fuel select switch is in proper position.
Fuel container empty	Check for LPG vapor from LPG liquid outlet valve on tank. Fill fuel container. Do not exceed 80% of liquid capacity.
Liquid valve closed	Slowly open liquid valve.
Propane excess flow valve closed	Reset excess flow valve in LPG tank. Close liquid valve. Wait for a "click" sound, slowly open liquid valve.
Plugged fuel line	Remove obstruction from the fuel line. • Close liquid fuel valve. • Using caution, disconnect the fuel line (some propane may escape). • Clear obstruction with compressed air. • Re-connect fuel line. • Slowly open liquid fuel valve. • Leak test.
Clogged fuel filter	Repair/replace as required. *See Chapter 4 Fuel Filter replacement.*
Faulty vapor connection between the pressure regulator/converter and the mixer	Check connection • Verify no holes in hose. • Clamps must be tight. • Look for kinked, pinched and/or collapsed hose.
Fuel lock-off malfunction	Repair/replace fuel lock-off. *See Chapter 4 Fuel Lock-off.*
Pressure regulator/converter malfunction	Test regulator/converter operation and pressure. *See Chapter 6 Tests and Adjustments.*
Incorrect AFR or ignition/spark control	*See Chapter 8 Advanced Diagnostics.*
No crankshaft position sensor signal	Verify the crankshaft position signal is present *See Chapter 8 Advanced Diagnostics.*

PROBABLE CAUSE	CORRECTIVE ACTION
SECM / control system malfunction	Check Coolant Temperature Sensor using the Service Tool; compare coolant temperature with ambient temperature on cold engine. If coolant temperature reading is 5° greater than or less than ambient air temperature on a cold engine, check resistance in coolant sensor circuit or sensor itself. Compare CTS resistance value to “Diagnostic Aids” chart at end of this section. Verify that there is no code for ETC spring check fault. Check for 0% APP during cranking. Cycle key ON and OFF and listen for throttle check (movement) on key OFF. Check for oil pressure switch faults. Check for sensor “sticking” faults. Check TPS for stuck binding or a high TPS voltage with the throttle closed.
Fuel system malfunction	Check fuel lock off (propane) or fuel pump relay gasoline operation: actuator should turn “ON” for 2 seconds when ignition is turned “ON”. Check fuel pressure. Check for contaminated fuel. Check both gasoline injector and lock off fuses (visually inspect). Check propane tank valve & pickup. A faulty in-tank fuel pump check valve will allow the fuel in the lines to drain back to the tank after engine is stopped. To check for this condition, perform fuel system diagnosis. Check FTV system for proper operation.
Ignition system malfunction	Check for proper ignition voltage output with spark tester. Check spark plugs. Remove spark plugs, check for wet plugs, cracks, wear, improper gap, burned electrodes, or heavy deposits. Repair or replace as necessary. Check for: • Moisture in distributor cap* • Bare or shorted wires • Worn distributor shaft/rotor* • Loose ignition coil ground • Pickup coil resistance and connections* (*) Where present

Related MIL Faults:
ETC spring check / ETC faults / EST faults / TPS conflict / APP faults
Encoder error / MAP faults / Injector faults / Oil pressure faults

Lack of Power, Slow to Respond / Poor High-Speed Performance / Hesitation During Acceleration

Engine delivers less than expected power. Little or no increase in speed when accelerator pedal is pushed down part way. Momentary lack of response as the accelerator is pushed down. Can occur at all vehicle speeds. Usually most severe when first trying to make vehicle move, as from a stop. May cause engine to stall. See Table 9 for corrective actions for lack of power, slow response, poor high-speed performance, and hesitation.

Table 7-4. Corrective Action Table for Lack Of Power, Slow Response, Poor High-Speed Performance, and Hesitation

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

Drive vehicle: verify problem exists.

Remove air filter and check for dirt or other means of plugging. Replace if needed.

PROBABLE CAUSE	**CORRECTIVE ACTION**
Fuel system malfunction	Check for restricted fuel filter. Check fuel supply. Check for LPG vapor from LPG liquid outlet valve on tank. Check for contaminated fuel. Check for clogged fuel filter and repair or replace as required. *See Chapter 4 Fuel Filter Replacement* Check for plugged fuel line and remove any obstruction from the fuel line: • Close liquid fuel valve. • Using caution, disconnect the fuel line (some propane may escape). • Clear obstruction with compressed air. • Re-connect fuel line. • Slowly open liquid fuel valve and leak test. Check for faulty vapor connection between pressure regulator/converter and mixer: • Verify that there are no holes in hose. • Observe that clamps are tight. • Look for kinked, pinched and/or collapsed hose. Monitor pre-catalyst O2 with Service Tool. Check for proper pressure regulator operation. *See Chapter 6 Test and Adjustments.* Check for proper air/fuel mixer operation.
Ignition system malfunction	Check spark advance for excessive retarded ignition timing. Use Service Tool. Check secondary voltage using an oscilloscope or a spark tester to check for a weak coil. Check spark plug condition. Check poor spark plug primary and secondary wire condition.

PROBABLE CAUSE	CORRECTIVE ACTION
Component malfunction	Check SECM grounds for cleanliness and secure connection. See SECM wiring diagrams. Check alternator output voltage. Repair if less than 9 volts or more than 16 volts. Check for clogged air filter and clean or replace as required. Check exhaust system for possible restriction. Refer to Chart T-1 on later pages. Inspect exhaust system for damaged or collapsed pipes. • Inspect muffler for heat distress or possible internal failure. • Check for possible plugged catalytic converter. Check backpressure by removing Pre-catalyst O2 sensor and measuring backpressure with a gauge.
Engine mechanical	*See Engine Manufacturer's Service Manual.* Check engine valve timing and compression Check engine for correct or worn camshaft.

Related MIL Faults:
EST faults
ETC faults
ETC spring check
TPS faults
APP faults
Encoder error
Delayed Shutdown faults

Detonation / Spark Knock

A mild to severe ping, usually worse under acceleration. The engine makes sharp metallic knocks that change with throttle opening (like the sound of hail striking a metal roof). See Table 10 for corrective actions for detonation/spark knock.

Table 7-5. Corrective Action Table for Detonation/Spark Knock

PRELIMINARY CHECKS
Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

PROBABLE CAUSE	CORRECTIVE ACTION
Fuel system malfunction	Check for proper fuel level: • Check for LPG vapor from LPG liquid outlet valve on tank. • Fill fuel container. Do not exceed 80% of liquid capacity. Check fuel pressure. To determine if the condition is caused by a rich or lean system, the vehicle should be driven at the speed of the complaint. Monitoring with the Service Tool will help identify problem.

PROBABLE CAUSE	CORRECTIVE ACTION
Cooling system malfunction	Check for obvious overheating problems: • Low engine coolant • Loose water pump belt • Restricted air flow to radiator, or restricted water flow through radiator • Inoperative electric cooling fan • Correct coolant solution should be a mix of anti-freeze coolant (or equivalent) and water • High coolant temperature
Ignition system malfunction	Check ignition timing. See application manual. Check spark module wiring.
Exhaust system malfunction	Check exhaust backpressure. Check for debris clogging the catalyst. Check that pre-catalyst O2 sensor is functioning.
Engine mechanical	Check for excessive oil in the combustion chamber and/or blow by from excessive PCV flow. Check combustion chambers for excessive carbon build up. Check combustion chamber pressure by performing a compression test. Check for incorrect basic engine parts such as cam, heads, pistons, etc.

Related MIL Faults:
EST faults
Encoder error
High coolant temperature faults

Backfire

Fuel ignites in intake manifold or in exhaust system, making loud popping noise. See Table for corrective actions for backfire.

Table 7-6. Corrective Action Table for Backfire

PRELIMINARY CHECKS
Perform the visual checks as described at start of “Basic Troubleshooting” chapter. Simulate condition by reviewing operation procedure practiced by vehicle operator.

PROBABLE CAUSE	CORRECTIVE ACTION
Fuel system malfunction	Perform fuel system diagnosis check: • Check for fuel leaks • Check for MIL faults • Check for damaged components

PROBABLE CAUSE	CORRECTIVE ACTION
Ignition system malfunction	Check proper ignition coil output voltage with spark tester. Check spark plugs. Remove spark plugs, check for wet plugs, cracks, wear, improper gap, burned electrodes, or heavy deposits. Repair or replace as necessary. Check spark plug wires for crossfire; also inspect distributor cap, spark plug wires, and proper routing of plug wires. Check ignition timing. Refer to application manual.
Engine mechanical	Check compression: look for sticking or leaking valves. Check intake and exhaust manifold for casting flash and gasket misalignment. Refer to Engine Manufacturer's Service Manual.

Related MIL Faults: EST faults / ETC faults / Encoder error
Pre-catalyst O2 sensor faults

Dieseling, Run-on

Engine continues to run after key is turned OFF but runs very roughly. If engine runs smoothly, check ignition switch and adjustment. See Table 11 for corrective actions for dieseling/run-on.

Table 7-6. Corrective Action Table for Dieseling/Run-On

PRELIMINARY CHECKS

Perform the visual checks as described at start of "Basic Troubleshooting" chapter.

PROBABLE CAUSE	CORRECTIVE ACTION
Fuel system malfunction	Check for fuel leaks or leaking injector.
Ignition switching	Make sure power to system is shut off when key is in OFF position.
Fuel lock off valve	Make sure lock off valve is closing properly.
Ignition system malfunction	Check spark advance at idle.

Related MIL Faults: EST faults / ETC faults / Pre-catalyst O2 sensor faults

Rough, Unstable, Incorrect Idle, or Stalling

Engine cranks OK but does not start for a long time. Does eventually run or may start but immediately dies. See Table 12 for corrective actions for rough, unstable, incorrect idle, or stalling.

Table 7-7. Corrective Action Table for Rough, Unstable, Incorrect Idle, Or Stalling

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

Check for vacuum leaks.

Check that SECM grounds are clean and tight. See SECM wiring diagram.

PROBABLE CAUSE	**CORRECTIVE ACTION**
Fuel system malfunction	Monitor oxygen feedback to help identify the cause of the problem. If the system is running lean or if the system is running rich evaluate further i.e. dither valve duty cycle and injector pulse width. Check for incorrect minimum idle speed that may be caused by foreign material accumulation in the throttle bore, on the throttle valve, or on the throttle shaft. Check that the injectors are clean and functioning. Check for liquid fuel in propane pressure regulator hose. If fuel is present, replace regulator assembly. The pre-catalyst oxygen (O2) sensor should respond quickly to different throttle positions. If it does not, then check the pre-catalyst O2 sensor for contamination. If the pre-catalyst O2 sensor is aged or contaminated, the SECM will not deliver correct amount of fuel, resulting in a drivability problem.
Fuel container empty	Check for LPG vapor from LPG liquid outlet valve on tank. Fill fuel container. Do not exceed 80% of liquid capacity.
Ignition system malfunction	Check ignition system; wires, plugs, rotor, etc.
LPG pressure regulator malfunction	Test regulator operation and pressure. *See Chapter 6 Tests and Adjustments.*
Air/fuel mixer malfunction	Check mixer.
Component malfunction	Check throttle for sticking or binding. Check PCV valve for proper operation by placing finger over inlet hole in valve end several times. Valve should snap back. If not, replace valve. Check alternator output voltage. Repair if less than 9 or more than 16 volts.
Engine mechanical	Perform a cylinder compression check. *See Engine Manufacturer’s Service Manual.*
Excess flow valve closed	Reset excess flow valve. • Close liquid valve. • Wait for a “click” sound. Slowly open liquid valve.
Clogged fuel filter	Repair/replace as required *See Chapter 4 Fuel Filter Replacement.*

PROBABLE CAUSE	**CORRECTIVE ACTION**
Plugged fuel line	Remove obstruction from the fuel line. • Close liquid fuel valve. • Using caution, disconnect the fuel line (some propane may escape). • Clear obstruction with compressed air. • Re-connect fuel line. • Slowly open liquid fuel valve & leak test.
Fuel lock-off malfunction	Repair/replace fuel lock-off. *See Chapter 4 Fuel Lock-Off.*
Faulty vapor connection between the pressure regulator/converter and the mixer	Check connection. • Verify no holes in hose. • Clamps must be tight. • Look for kinked, pinched and/or collapsed hose.
Pressure regulator freezes	Check level in cooling system: • Must be full, check coolant strength • -35 °F (-37 °C) minimum Check coolant hoses. • Watch for kinks and/or pinched hoses. • Verify one pressure hose and one return hose. Test regulator. *See Chapter 6 Tests and Adjustments.*
Vacuum leak	Check for vacuum leaks . . . • https://guest.ecamm.live

Related MIL Faults:
EST faults
ETC Sticking fault
Pre-catalyst adapts error

Cuts Out, Misses

Steady pulsation or jerking that follows engine speed, usually more pronounced as engine load increases, sometimes above 1500 rpm. The exhaust has a steady spitting sound at idle or low speed. See Table 13 for corrective actions for cut out/misses.

Table 7-8. Corrective Action Table for Cut Out/Misses

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

PROBABLE CAUSE	CORRECTIVE ACTION
Fuel system malfunction	Check fuel system specifically for plugged fuel filter, low pressure. Check for contaminated fuel. Check injector drivers. Disconnect all injector harness connectors. Use injector test light or equivalent 6-volt test light between the harness terminals of each connector and observe if light blinks while cranking. If test light fails to blink at any connector, it is a faulty injector drive circuit harness, connector, or terminal. Check lock off intermittent connection. Check dither valve operation.
Ignition system malfunction	Check for spark on the suspected cylinder(s) using a shop oscilloscope or spark tester or equivalent. If no spark, check for intermittent operation or miss. If there is a spark, remove spark plug(s) in these cylinders and check for cracks, wear, improper gap, burned electrodes, heavy deposits. If applicable, check spark plug wires by connecting ohmmeter to ends of each wire in question. If meter reads over 30,000 ohms, replace wire(s). If applicable, visually inspect distributor cap, rotor, and wires for moisture, dust, cracks, burns, etc. Spray cap and plug wires with fine water mist to check for shorts. Check engine ground wire for looseness or corrosion.
Component malfunction	Check for EMI. A missing condition can be caused by EMI on the reference circuit. EMI can usually be detected by monitoring engine rpm with Service Tool. A sudden increase in rpm with little change in actual engine rpm indicates EMI is present. If problem exists, check routing of secondary wires and check distributor ground circuit. Check intake and exhaust manifolds for casting flash or gasket leaks.
Engine mechanical	Perform compression check on questionable cylinders. If compression is low, repair as necessary. Check base engine. Remove rocker covers and check for bent pushrods, worn rocker arms, broken valve springs, worn camshaft lobes, and valve timing. Repair as necessary.

Related MIL Faults:
EST faults
ETC Sticking fault

Poor Fuel Economy / Excessive Fuel Consumption / LPG Exhaust Smell

Fuel economy, as measured during normal operation, is noticeably lower than expected. Also, economy is noticeably lower than what it has been in the past. Propane fuel smell near vehicle sets off carbon monoxide sensors. See Table 14 for corrective actions for poor fuel economy/excessive fuel consumption or LPG exhaust smell.

Table 7-9. Corrective Action Table for Poor Fuel Economy/Excessive Fuel Consumption or LPG Exhaust Smell

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

Verify operator complaint: identify operating conditions.

Check operator’s driving habits:

- Are tires at correct pressure?
- Are excessively heavy loads being carried? Is acceleration too much, too often?

Check air cleaner element (filter) for being dirty or plugged.

Visually (physically) check vacuum hoses for splits, kinks, and proper connections as shown on application manual.

PROBABLE CAUSE	CORRECTIVE ACTION
Fuel system malfunction	Check for faulty gasoline pressure regulator. Check for leaking injector. Check that dither valve duty cycle is < 15%. Check for too high propane pressure at mixer (> 1” positive pressure). Monitor Pre-catalyst O2 sensor with Service Tool.
Cooling system malfunction	Check engine coolant level. Check engine thermostat for faulty part (always open) or for wrong heat range.
Ignition system malfunction	Check ignition timing. Refer to application manual. Check for weak ignition and/or spark control. Check spark plugs. Remove spark plugs and check for wet plugs, cracks, wear, improper gap, burned electrodes, or heavy deposits. Repair or replace as necessary.
Component malfunction	Check for exhaust system restriction or leaks. Check induction system and crankcase for air leaks. Check for clogged air filter; clean or replace as required. Check FTV for housing cracks or obstructions; repair or replace as required. Check for vacuum leak. Check system vacuum hoses from regulator to FTV and mixer. Repair or replace as required.
Air/fuel mixer malfunction	Check mixer.
Pressure regulator malfunction / fuel pressure too high	Test regulator operation and pressure. *See Chapter 6 Tests and Adjustments.*
Engine mechanical	Check compression. *Refer to Engine Manufacturer’s Service Manual.*

Related MIL Faults:

Pre-catalyst O2 sensor faults / Low side driver / Dither valve duty cycle
EST faults / Fuel adapt faults / Low coolant temperature

High Idle Speed

Engine idles above the range of 700-1000 rpm. See Table for corrective actions for high idle speed.

Table 7-11. Corrective Action Table for High Idle Speed

PRELIMINARY CHECKS

Perform the visual checks as described at start of “Basic Troubleshooting” chapter.

PROBABLE CAUSE	**CORRECTIVE ACTION**
Incorrect idle speed control	Check all hoses and gaskets for cracking, kinks, or leaks. Verify that there are no vacuum leaks. *See Chapter 8 Advanced Diagnostics & Chapter 6 Tests and Adjustments.*
Throttle sticking	Replace throttle. *See Fault Code 461: ETC_Sticking.*
Foot pedal sticking or incorrect pedal signal	Check pedal return spring travel for binding. Check APP function with Service Tool. Verify smooth change of APP reading with pedal movement. *See Chapter 8 Advanced Diagnostics.*
Engine mechanical	Check for vacuum hose leak. Check for PCV malfunction. Check for defective intake gasket.

Related MIL Faults:

ETC Sticking fault
Idle adapt out of range
MAP Sticking fault
MAP high value

Excessive Exhaust Emissions or Odors

Vehicle has high CO emissions. See Table for corrective actions for excessive exhaust emissions or odors.

NOTE: Excessive odors do not necessarily indicate excessive emissions.

Table 7-12. Corrective Action Table for Excessive Exhaust Emissions Or Odors

PRELIMINARY CHECKS

Verify that no stored codes exist.

If emission test shows excessive CO and HC, check items that cause vehicle to run **rich**.

If emission test shows excessive NOx, check items that cause vehicle to run **lean** or too hot.

PROBABLE CAUSE	CORRECTIVE ACTION
Cooling system malfunction	If the Service tool indicates a very high coolant temperature and the system is running *lean*: • Check engine coolant level. • Check engine thermostat for faulty part (always open) or for wrong heat range. • Check fan operation
Fuel system malfunction	If the system is running *rich*, refer to “Diagnostic Aids” chart on the next page. If the system is running *lean* refer to “Diagnostic Aids” chart on the next page. Check for properly installed fuel system components. Check fuel pressure.
Ignition system malfunction	Check ignition timing. Refer to application manual. Check spark plugs, plug wires, and ignition components.
Component malfunction	Check for vacuum leaks. Check for contamination for catalytic converter (look for the removal of fuel filler neck restrictor). Check for carbon build-up. Remove carbon with quality engine cleaner. Follow instructions on label. Check for plugged PCV valve. Check for stuck or blocked PCV hose. Check for fuel in the crankcase.

Related MIL Faults:

Low side driver
Fuel adapt faults
EST faults

Diagnostic Aids for Rich / Lean Operation

Use Table 15 as an aid for diagnosing rich/lean operation.

Table 7-10. Diagnostic Aid for Rich/Lean Operation

SERVICE TOOL ITEM	**RICH**	**LEAN**
Pre-catalyst O2 A/ D counts	Consistently > 250	Consistently < 170
Pre-catalyst O2 sensor switching between high and low	Always high ADC	Always low ADC
Trim valve duty cycle	> 90%	< 10%
Fuel injector pulse width at idle *	< 1.0 msec.	> 8 msec.
Malfunction codes	• Pre-catalyst O2 sensor failed rich • Pre-catalyst O2 sensor high • Fuel adapts	• Pre-catalyst O2 sensor failed lean • Pre-catalyst O2 sensor low • Fuel adapts
Closed loop operation	Stuck in open loop	Stuck in open loop

(*) The duty cycle injector pulse width criteria for lean or rich operation apply only if the O2 sensor is functioning properly. If the sensor is not operating properly the criteria may be reversed.

Rich Operation

LP (Trim valve duty cycle>90%)

- Inspect hoses from AVV port (port on bottom of mixer) to trim valves and regulator for leaks or blockages, replace as necessary.
- Inspect in-line orifices for blockages (in wye), replace as necessary
- Check trim valves for proper operation, replace as necessary
- Check regulator out pressure, replace if out of spec
- Inspect fuel cone for damage, replace mixer assembly as necessary

Gasoline (Injector Pulse Width<1.0 msec)

- Check gasoline fuel pressure
- Check injectors for sticking, replace as necessary

Lean Operation

LP (Trim valve duty cycle<10%)

- Check for vacuum leaks, replace hoses, O-rings, and gaskets as necessary
- Check balance line for blockage, replace as necessary
- Check vapor hose for restrictions, replace as necessary
- Check trim valves for proper operation, replace as necessary
- Check regulator out pressure, replace if out of spec

Gasoline (Injector Pulse Width>8 msec)

- Check system voltage
- Check fuel pressure
- Check injectors for sticking or obstructions

Restricted Exhaust System Check

Proper diagnosis for a restricted exhaust system is essential before replacement of any components. The following procedures may be used for diagnosis, depending upon engine or tool used.

Check at Pre-Catalyst Oxygen (O2) Sensor

1. Carefully remove pre-catalyst oxygen (O2) sensor.
2. Install exhaust backpressure tester or equivalent in place of O2 sensor using Snap-On P/N EEVPV311A kit and YA8661 adapter or Mac tool (Figure 7-1).
3. After completing test described below, be sure to coat threads of O2 sensor with anti-seize compound prior to re-installation.

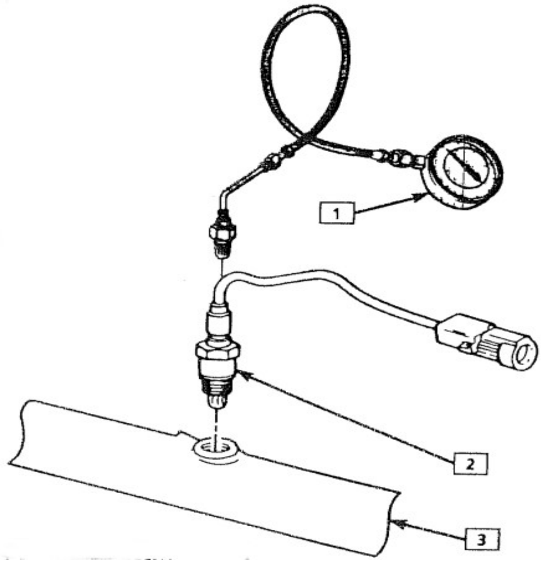


ILLUSTRATION NOTES

1. Backpressure gage
2. Pre-catalyst oxygen (O2) sensor
3. Exhaust manifold

Figure 7-1. Backpressure Check at O2 Sensor

Diagnosis:

1. With the engine idling at normal operating temperature, observe the exhaust system backpressure reading on the gage. Reading should not exceed 1.25 psig (8.61 kPa).
2. Increase engine speed to 2000 rpm and observe gage. Reading should not exceed 3 psig (20.68 kPa).
3. If the backpressure at either speed exceeds specification, a restricted exhaust system is indicated.
4. Inspect the entire exhaust system for a collapsed pipe, heat distress, or possible internal damage, split welds, or cracked pipe.
5. If there are no obvious reasons for the excessive backpressure, the catalytic converter is restricted and should be replaced using current recommended procedures.

Chapter 8.
Advanced Diagnostics

MI-21 systems are equipped with built-in fault diagnostics. Detected system faults can be displayed by the MIL as Diagnostic Fault Codes (DFC) or flash codes and viewed in detail with the use of the Service Tool software. See Table for the fault list definitions.

When the ignition key is turned on, the MIL will illuminate and remain on until the engine is started. Once the engine is started, the MIL lamp will go out unless one or more fault conditions are present. If a detected fault condition exists, the fault or faults will be stored in the memory of the SECM. Once an active fault occurs the MIL will illuminate and remain ON. This signals the operator that a fault has been detected by the SECM.

Reading Diagnostic Fault Codes

All MI-21 fault codes are three-digit codes. When the fault codes are retrieved (displayed) the MIL will flash for each digit with a short pause (0.5 seconds) between digits and a long pause (1.2 seconds) between fault codes. A code 12 is displayed at the end of the code list.

EXAMPLE: A code 461 (ETCSticking) has been detected and the engine has shut down and the MIL has remained **ON**. When the codes are displayed the MIL will flash four times (**4**), pause, then flash six times (**6**), pause, then flash one time (**1**) This identifies a four sixty-one (**461**), which is the ETCSticking fault. If any additional faults were stored, the SECM would again have a long pause, then display the next fault by flashing each digit. Since no other faults were stored there will be a long pause then one flash (**1**), pause, then two flashes (**2**). This identifies a twelve, signifying the end of the fault list. This list will then repeat.

Displaying Fault Codes (DFC) from SECM Memory

To enter code display mode, you must turn **OFF** the ignition key. Now turn **ON** the key but do not start the engine. As soon as you turn the key to the ON position you must cycle the foot pedal by depressing it to the floor and then fully releasing the pedal (pedal maneuver). You must fully cycle the foot pedal three (**3**) times within five (**5**) seconds to enable the display codes feature of the SECM. Simply turn the key **OFF** to exit display mode. The code list will continue to repeat until the key is turned **OFF**.

Note: As an option, you may also use your Service Tool to display and clear fault codes. See Connection of the MI-21 Service Tool section for details on how to connect to the ECU with the service tool.

Clearing Fault (DFC) Codes

To clear the stored fault codes from SECM memory you must complete the reset fault pedal maneuver.

IMPORTANT **Once the fault list is cleared it cannot be restored.**

First turn **OFF** the ignition key. Now turn **ON** the key but do not start the engine. As soon as you turn the key to the ON position you must cycle the foot pedal by depressing it to the floor and then fully releasing the pedal (pedal maneuver). You must fully cycle the foot pedal ten (**10**) times within five (**5**) seconds to clear the fault code list of the SECM. Simply turn the key **OFF** to exit the reset mode. The code list is now clear and the SECM will begin storing new fault codes as they occur.
Software released after level MI21_P070_1702_021****___***.wapp allows fault codes to be cleared while displaying the fault codes. You must fully cycle the foot pedal ten (**10**) times within five (**5**) seconds

to clear the fault code list of the SECM. The fault code list will continue to display until the end of the list is reached.

Fault Action Descriptions

Each fault detected by the SECM is stored in memory (FIFO) and has a specific action or result that takes place. Listed below are the descriptions of each fault action.

Engine Shutdown: The most severe action is an Engine Shutdown. The MIL will light, and the engine will immediately shutdown, stopping spark, closing the fuel lock-off, and turning off the fuel pump and fuel injectors.

Delayed Engine Shutdown: Some faults, such as low oil pressure, will cause the MIL to illuminate for 30 seconds and then shut down the engine.

Cut Throttle: The throttle moves to its default position. The engine will run at idle but will not accelerate.

Cut Fuel: Fuel flow will be turned off.

Turn on MIL: The MIL will light by an active low signal provided by the SECM, indicating a fault condition. May illuminate with no other action or may be combined with other actions, depending on which fault is active.

Soft Rev Limit / Medium Rev Limit / Hard Rev Limit: System will follow various sequences to bring engine speed back to acceptable levels.

Level 4 Power Limit / Level 3 Power Limit / Level 2 Power Limit / Level 1 Power Limit: The maximum engine power output will be limited to one of four possible levels. The engine power is calculated from measured engine parameters (e.g. MAP, rpm, fuel flow, etc.).

Disable Gas O2 Control: In LPG mode, closed loop correction of air fuel ratio based on the Pre-catalyst O2 sensor is disabled.

Disable Liquid O2 Control: In Gasoline mode, closed loop correction of air fuel ratio based on the Pre-catalyst O2 sensor is disabled.

Range Faults

All the analog sensors in the MI-21 system have input sensor range faults. Signals to these sensors are converted into digital counts by the SECM. A low/high range sensor fault is set when the converted digital counts reach the calibrated minimum or maximum (**1024 = 5.0 Vdc with ~ 204 counts per volt**). See Figure 8-1 for illustration.

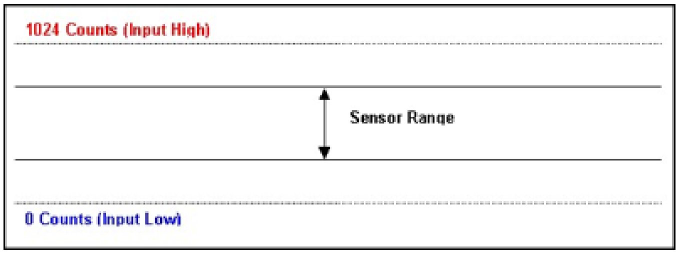


Figure 8-1. Sensor Range Illustration in Digital Counts

Additionally, the SECM includes software to learn the actual range of the pedal position and throttle position sensors to take full advantage of the sensor range. Faults are set if the learned values are outside of the normal expected range of the sensor (e.g. APP1AdaptLoMin).

Fault List Definitions

See Table 8-1 for a list of all possible faults in MI-21 along with default fault actions. Also included are recommended correction actions for each fault.

Table 8-1. Fault List Definitions

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
131	**651/4**	**Inj1Fault** Fuel Injector 1 open circuit, broken injector 1 wire or defective injector	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL DisableLiquidO2Ctrl DelayedEngineShutdown CheckEngineLight	Check INJ1 wiring for an open circuit SECM (Signal) Pin#34 to Injector 1 Pin A Switched 12V to Injector 1 Pin B Check that Injector 1 Resistance is 13-16 Ω @68°F(20°C)
132	**652/4**	**Inj2Fault** Fuel Injector 2 open circuit, broken injector 2 wire or defective injector	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL DisableLiquidO2Ctrl DelayedEngineShutdown CheckEngineLight	Check INJ2 wiring for an open circuit SECM (Signal) Pin#35 to Injector 2 Pin A Switched 12V to Injector 2 Pin B Check that Injector 2 Resistance is 13-16 Ω @68°F(20°C)
133	**653/4**	**Inj3Fault** Fuel Injector 3 open circuit, broken injector 3 wire or defective injector	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL DisableLiquidO2Ctrl DelayedEngineShutdown CheckEngineLight	Check INJ3 wiring for an open circuit SECM (Signal) Pin#1 to Injector 3 Pin A Switched 12V to Injector 3 Pin B Check that Injector 3 Resistance is 13-16 Ω @68°F(20°C)
134	**654/4**	**Inj4Fault** Fuel Injector 4 open circuit, broken injector 4 wire or defective injector	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL DisableLiquidO2Ctrl DelayedEngineShutdown CheckEngineLight	Check INJ4 wiring for an open circuit SECM (Signal) Pin#12 to Injector 4 Pin A Switched 12V to Injector 4 Pin B Check that Injector 4 Resistance is 13-16 Ω @68°F(20°C)

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
141	**110/4**	**ECTRangeLow** Coolant Sensor failure or shorted to GND	The ECU has been programmed such a way; it will take a default value of 88 degC that may leads to problem during cold starting. Reduction in fuel quantity may shows impact in drivability.	TurnOnMIL CheckEngineLight DelayedEngineShutdown	Check ECT sensor connector and wiring for a short to GND SECM (Signal) Pin#40 To ECT Pin 2 SECM (Sensor GND) Pin#32 to ECT Pin 1 SECM (System GND) Pin#32, Pin#69(or 70)
151	**110/3**	**ECTRangeHigh** Coolant sensor disconnected or open circuit	The ECU has been programmed such a way; it will take a default value of 88 degC that may leads to problem during cold starting. Reduction in thermal efficiency may shows impact in drivability.	TurnOnMIL DelayedEngineShutdown CheckEngineLight	Check if ECT sensor connector is disconnected or for an open ECT circuit SECM (Signal) Pin#40 to ECT Pin 2 SECM (Sensor GND) Pin#32 to ECT Pin 1
161	**110/0**	**ECTOverTempFault** Engine coolant temperature is high. The sensor has measured an excessive coolant temperature typically due to the engine overheating.	Possible low power or poor running by torque derating.	TurnOnMIL CheckEngineLight DelayedEngineShutdown	Check coolant system for radiator blockage, proper coolant level and for leaks in the system. Possible ECT short to GND, check ECT signal wiring SECM (Signal) Pin#40 To ECT Pin 2 SECM (Sensor GND) Pin#32 to ECT Pin 1 SECM (System GND) Pin#32, Pin#69(or 70)Check regulator for coolant leaks

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
171	**110/2**	**ECT_IR_Fault** Engine coolant temperature not changing as expected	Reduction in thermal efficiency may shows impact in drivability. Possible emissions issues by disabling Phi Closed Loop.	TurnOnMIL CheckEngineLight	Check for coolant system problems, e.g. defective or stuck thermostat Check faulty thermostat. Check coolant level. Check proper work on cooling fan. Check coolant temperature sensor for defective sensing. Check coolant temperature sensor connector for corrosion or loose pin. Check coolant temperature sensor for an open circuit or short to power.
181	**6317/7**	**FuelSelectConflict** Conflict in fuel select signals, normally set if both of the fuel select signals are shorted to ground	Engine cannot start.	TurnOnMIL CheckEngineLight DelayedEngineShutdown	Check fuel select switch connection for a short to GND SECM (Gas Fuel SIGNAL) Pin#27 SECM (Liquid Fuel SIGNAL) Pin#29 SECM (Sensor GND) Pin#32
191	**637/7**	**CamEdgesFault** No CAM signal when engine is known to be rotating, broken crankshaft sensor leads or defective CAM sensor	If the fault happens during cranking, it will trigger Fall back mode to get engine start with Crank sensor only. Possible engine shutdown when Crank sensor loss fault occurs.	TurnOnMIL CheckEngineLight	Check CAM sensor connections SECM (SIGNAL) Pin#30 to CAM sensor Pin 2 SECM (Sensor GND) Pin#32 to CAM sensor Pin 1 Switched 12V to CAM sensor Pin 3 Check for defective CAM sensor
192	**637/2**	**CamSyncFault** Loss of synchronization on the CAM sensor, normally due to noise on the signal or an intermittent	Possible engine starting issues. Possible ignition timing shifts.	TurnOnMIL CheckEngineLight	Check CAM sensor connections SECM (SIGNAL) Pin#30 to CAM sensor Pin 2 SECM (Sensor GND) Pin#32 to CAM sensor Pin 1

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
		connection on the CAM sensor			Switched 12V to CAM sensor Pin 3 Check for defective CAM sensor
193	**636/7**	**CrankEdgesFault** No crankshaft signal when engine is known to be rotating, broken crankshaft sensor leads or defective crank sensor	Possible engine starting issues. Possible engine shutdown when CAM sensor loss fault occurs.	TurnOnMIL CheckEngineLight	Check Crankshaft sensor connections SECM (SIGNAL) Pin#31 to Crank sensor Pin 2 SECM (Sensor GND) Pin#32 to Crank sensor Pin 1 Switched 12V to Crank sensor Pin 3 Check for defective Crank sensor
194	**636/2**	**CrankSyncFault** Crank Sensor Sync Fault. Crank sensor or CAM sensor signal shifts	Possible engine starting issues. Possible ignition timing shifts.	TurnOnMIL CheckEngineLight	Check Crank sensor installation if sensor sifts from correct position. Check CAM sensor installation if sensor sifts from correct position. Check CAM encoder installation if encoder sifts from correct position. Check Crank encoder for mechanical damage. Check CAM encoder for mechanical damage.
221	**51/4**	**TPS1RangeLow** TPS1 sensor voltage out of range low, normally set if the TPS1 signal has shorted to ground, circuit has opened or sensor has failed	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector connection and TPS1 sensor for an open circuit or short to GND SECM Pin#28 (signal) to ETC Pin 6 SECM Pin#48 (sensor5V) to ETC Pin 3 SECM Pin#32 (sensor GND) to ETC Pin 2

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					SECM (system GND) Pin#69, 70
222	**3673/4**	**TPS2RangeLow** TPS2 sensor voltage out of range low, normally set if the TPS2 signal has shorted to ground, circuit has opened or sensor has failed	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector connection and TPS2 sensor for an open circuit or short to GND SECM Pin#24 (signal) to ETC Pin 5 SECM Pin#32 (sensor GND) to ETC Pin 2 SECM (system GND) Pin#69, 70
231	**51/3**	**TPS1RangeHigh** TPS1 sensor voltage out of range high, normally set if the TPS1 signal has shorted to power or the ground for the sensor has opened	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector and TPS1 sensor wiring for a shorted circuit SECM Pin#28 (signal) to ETC Pin 6 SECM Pin#32 (sensor GND) to ETC Pin 2
232	**3673/3**	**TPS2RangeHigh** TPS2 sensor voltage out of range high, normally set if the TPS2 signal has shorted to power or the ground for the sensor has opened	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector and TPS1 sensor wiring for a shorted circuit SECM Pin#24 (signal) to ETC Pin 5 SECM Pin#32 (sensor GND) to ETC Pin 2
241	**51/1**	**TPS1AdaptLoMin** Learned closed throttle end of TPS1 sensor range lower than expected	Possible increasing engine idle speed due to TPS1 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS1 voltage with minimum throttle position to find TPS1 drifting or mechanical failure.

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
242	**3673/1**	**TPS2AdaptLoMin** Learned closed throttle end of TPS2 sensor range lower than expected	Possible increasing engine idle speed due to TPS2 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS2 voltage with minimum throttle position to find TPS2 drifting or mechanical failure.
251	**51/16**	**TPS1AdaptHiMax** Learned WOT end of TPS1 sensor range higher than expected	Possible increasing engine idle speed due to TPS1 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS1 voltage with maximum throttle position to find TPS1 drifting or mechanical failure.
252	**3673/16**	**TPS2AdaptHiMax** Learned WOT end of TPS2 sensor range higher than expected	Possible increasing engine idle speed due to TPS2 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS2 voltage with maximum throttle position to find TPS2 drifting or mechanical failure.
271	**51/18**	**TPS1AdaptHiMin** Learned WOT end of TPS1 sensor range lower than expected	Possible increasing engine idle speed due to TPS1 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS1 voltage with maximum throttle position to find TPS1 drifting or mechanical failure.
272	**3673/18**	**TPS2AdaptHiMin** Learned WOT end of TPS2 sensor range lower than expected	Possible increasing engine idle speed due to TPS2 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS2 voltage with maximum throttle position to find TPS2 drifting or mechanical failure.

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
281	**51/0**	**TPS1AdaptLoMax** Learned closed throttle end of TPS1 sensor range higher than expected	Possible unstable idle speed due to TPS1 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS1 voltage with minimum throttle position to find TPS1 drifting or mechanical failure.
282	**3673/0**	**TPS2AdaptLoMax** Learned closed throttle end of TPS2 sensor range higher than expected	Possible unstable idle speed due to TPS2 drifting.	TurnOnMIL CheckEngineLight CutThrottle	Check throttle connector to find loose pin, damaged pin or corrosion. Check TPS2 voltage with minimum throttle position to find TPS2 drifting or mechanical failure.
291	**51/7**	**TPS_Sensors_Conflict** TPS sensors differ by more than expected amount **NOTE:** The TPS is not a serviceable item and can only be repaired by replacing the DVEV throttle assembly.	Possible low power and poor running caused by torque derating.	TurnOnMIL CutThrottle CheckEngineLight	If DFC 221, 222, 231, 232, 241, 242, 251, 252, 271, 272, 281 or 282 occurred, resolve that fault before DFC291 troubleshooting. Check the throttle connector and pins for corrosion. Check TPS1 voltage change with traveling throttle position to confirm TPS1 tracking with throttle position. Check TPS2 voltage change with traveling throttle position to confirm TPS2 tracking with throttle position.

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
292	**51/2**	**TPS_Intermittent** Signal from the SECM to the throttle position sensor power or ground is not continuous	Possible low power and poor running caused by torque derating.	TurnOnMIL	Check throttle body connector and pins for corrosion Check continuity between throttle body Pin 3 and SECM Pin#48 (XDRP +5Vdc) Check continuity between throttle body Pin 2 and SECM Pin#32 (sensor ground) Check continuity on TPS1: between throttle body Pin 6 and SECM Pin#28 Check continuity on TPS2: between throttle body Pin 5 and SECM Pin#24 *Note: move wires around when checking for continuity to duplicate intermittent signal
331	**102/17**	**MAPTimeRangeLow** Manifold Absolute Pressure sensor input is low, normally set if the TMAP pressure signal wire has been disconnected or shorted to ground or the circuit has opened to the SECM	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check TMAP connector and MAP signal wiring for an open circuit TMAP Pin 4 to SECM Pin#44 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) TMAP Pin 3 to SECM Pin#48 (XDRP +5 Vdc) Check the MAP sensor by disconnecting the TMAP connector and measuring at the sensor: TMAP Pin 1(GND) to Pin 4 (pressure signal KPA) [approx. 3.81K Ω ± 20% @ 68 °F (20 °C)] TMAP Pin 3 (power) to Pin 4 (pressure signal KPA) [approx. 2.39K Ω ± 20% @ 68 °F (20 °C)]

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
332	**102/4**	**MAPRangeLow** Manifold Absolute Pressure sensor input is low, normally set if the TMAP pressure signal wire has been disconnected or shorted to ground or the circuit has opened to the SECM	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL EngineShutdown CheckEngineLight	Check TMAP connector and MAP signal wiring for an open circuit TMAP Pin 4 to SECM Pin#44 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) TMAP Pin 3 to SECM Pin#48 (XDRP +5 Vdc) Check the MAP sensor by disconnecting the TMAP connector and measuring at the sensor: TMAP Pin 1(GND) to Pin 4 (pressure signal KPA) [approx. 3.81K Ω ± 20% @ 68 °F (20 °C)] TMAP Pin 3 (power) to Pin 4 (pressure signal KPA) [approx. 2.39K Ω ± 20% @ 68 °F (20 °C)]
341	**102/15**	**MAPTimeRangeHigh** Manifold Absolute Pressure Sensor Input is High, normally set if the TMAP pressure signal wire has become shorted to power, shorted to the IAT signal, the TMAP has failed or the SECM has failed.	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check TMAP connector and MAP signal wiring for a shorted circuit TMAP Pin 4 to SECM Pin#44 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) TMAP Pin 3 to SECM Pin#48 (XDRP +5 Vdc) Check the MAP sensor by disconnecting the TMAP connector and measuring at the sensor: TMAP Pin 1(GND) to Pin 4 (pressure signal KPA) [approx. 3.81K Ω ± 20% @ 68 °F (20 °C)]

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					TMAP Pin 3 (power) to Pin 4 (pressure signal KPA) [approx. 2.39K Ω ± 20% @ 68 °F (20 °C)]
342	**102/3**	**MAPRangeHigh** Manifold Absolute Pressure Sensor Input is High, normally set if the TMAP pressure signal wire has become shorted to power, shorted to the IAT signal, the TMAP has failed or the SECM has failed	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL EngineShutdown CheckEngineLight	Check TMAP connector and MAP signal wiring for a shorted circuit TMAP Pin 4 to SECM Pin#44 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) TMAP Pin 3 to SECM Pin#48 (XDRP +5 Vdc) Check the MAP sensor by disconnecting the TMAP connector and measuring at the sensor: TMAP Pin 1(GND) to Pin 4 (pressure signal KPA) [approx. 3.81K Ω ± 20% @ 68 °F (20 °C)] TMAP Pin 3 (power) to Pin 4 (pressure signal KPA) [approx. 2.39K Ω ± 20% @ 68 °F (20 °C)]

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
351	**102/0**	**MAP_IR_HI** MAP sensor indicates higher pressure than expected	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check for vacuum leaks. Check that TMAP sensor is mounted properly. Possible defective TMAP sensor.

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
352	**102/1**	**MAP_IR_LO** MAP sensor indicates lower pressure than expected	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Possible defective TMAP sensor.
353	**102/2**	**MAP_STICKING** MAP sensor not changing as expected	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check that TMAP sensor is mounted properly. Possible defective TMAP sensor.
371	**105/4**	**IATRangeLow** Intake Air Temperature Sensor Input is Low normally set if the IAT temperature sensor wire has shorted to chassis ground or the sensor has failed.	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check TMAP connector and IAT signal wiring for a shorted circuit TMAP Pin 2 to SECM Pin#39 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) To check the IAT sensor of the TMAP disconnect the TMAP connector and measure the IAT resistance Resistance is approx 2400 ohms @ 68 °F (20 °C)
381	**105/3**	**IATRangeHigh** Intake Air Temperature Sensor Input is High normally set if the IAT temperature sensor wire has been disconnected or the circuit has opened to the SECM.	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check TMAP connector and IAT signal wiring for a shorted circuit TMAP Pin 2 to SECM Pin#39 (signal) TMAP Pin 1 to SECM Pin#32 (sensor GND) To check the IAT sensor of the TMAP disconnect the TMAP connector and measure the IAT resistance Resistance is approx 2400 ohms @ 68 °F (20°C)

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
391	**105/2**	**IAT_IR_Fault** Intake Air Temperature not changing as expected	The fueling will not be accurate, Possible low power or poor performance	TurnOnMIL CheckEngineLight	Check connections to TMAP sensor. Check that TMAP sensor is properly mounted to manifold.
421	**1268/3**	**EST1_Fault** EST1 output open, possibly open EST1 signal or defective spark module	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL CheckEngineLight	Check coil driver wiring and connector for open circuit SECM Pin#6 (EST1) to OEM ignition system. See application note. Verify GND on ignition module Pin A (of both connectors) Verify +12 Vdc on ignition module Pin B (of both connectors) Refer to application manual for specific engine details.
422	**1269/3**	**EST2_Fault** EST2 output open, possibly open EST2 signal or defective spark module	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL CheckEngineLight	Check coil driver wiring and connector for open circuit SECM Pin#8 (EST2) to OEM ignition system. See application note. Verify GND on ignition module Pin A (of both connectors) Verify +12 Vdc on ignition module Pin B (of both connectors) Refer to application manual for specific engine details.
DFC	**SPN/ FMI**	**Fault Name and Description**	**Operational Consequence**	**Fault Action**	**Corrective Action: Check First**
423	**1270/3**	**EST3_Fault** EST3 output open, possibly open EST3 signal or defective spark module	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL CheckEngineLight	Check coil driver wiring and connector for open circuit SECM Pin#11 (EST3) to OEM ignition system. See application note. Verify GND on ignition module Pin A (of both connectors) Verify +12 Vdc on ignition

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					module Pin B (of both connectors) Refer to application manual for specific engine details.
424	**1271/3**	**EST4_Fault** **EST4 output open, possibly open EST4 signal or defective spark module**	Occurring misfire. Possible low power or poor running by torque derating. Possible cause damage to catalyst.	TurnOnMIL CheckEngineLight	Check coil driver wiring and connector for open circuit SECM Pin#21 (EST4) to OEM ignition system. See application manual. Verify GND on ignition module Pin A (of both connectors) Verify +12 Vdc on ignition module Pin B (of both connectors) Refer to application manual for specific engine details.
461	**3464/7**	**ETC_Sticking** Electronic Throttle Control is sticking. This can occur if the throttle plate (butterfly valve) inside the throttle bore is sticking. The plate sticking can be due to some type of obstruction, a loose throttle plate, or worn components shaft bearings. **NOTE: The throttle assembly is not a serviceable item and can only be repaired by replacing the DV-EV throttle assembly.**	Possible low power and poor running caused by torque derating. Possible high engine speed running or over speeding when disengaged clutch or transmission due to uncontrollable throttle position.	TurnOnMIL CheckEngineLight CutThrottle EngineShutdown	Check for debris or obstructions inside the throttle body • Perform the throttle test using the Service Tool and re-check for fault • Check throttle-plate shaft for bearing wear Check the ETC driver wiring for an open circuit SECM Pin#52 to ETC + Pin 1 SECM Pin#51 to ETC - Pin 4 Check the ETC internal motor drive by disconnecting the throttle connector and measuring the motor drive resistance at the throttle Pin 1 (+DRIVER) to Pin 4 (-DRIVER) - Not open circuit (OL or ∞ Ohm) - Not short coil (<1 Ohm)

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
471	**3464/5**	**ETC_Open_Fault** Electronic Throttle Control Driver has failed, normally set if driver signals have failed open or become disconnected, electronic throttle or SECM is defective.	Possible low power and poor running caused by torque derating. Possible engine can be run at a little bit higher speed than idle speed by throttle null position.	TurnOnMIL CheckEngineLight CutThrottle	Check the ETC driver wiring for an open circuit SECM Pin#52 to ETC + Pin 1 SECM Pin#51 to ETC - Pin 4 Check the ETC internal motor drive by disconnecting the throttle connector and measuring the motor drive resistance at the throttle Pin 1 (+DRIVER) to Pin 4 (-DRIVER) - Not open circuit (OL or ∞ Ohm) - Not short coil (<1 Ohm)
481	**3464/2**	**ETCSpringTest** Electronic Throttle Control Spring Return Test has failed. The SECM will perform a safety test of the throttle return spring following engine shutdown. If the drive mechanism is damaged, or the return spring has lost tension the throttle will fail the test and set the fault. **NOTE: The throttle assembly is not a serviceable item and can only be repaired by replacing the DV-EV throttle assembly.**	Possible engine shutdown or overspeeding when occurring throttle motor driver shutdown.	TurnOnMIL CheckEngineLight EngineShutdown	Perform throttle spring test by cycling the ignition key and recheck for fault

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
491	**3464/6**	**HbridgeFault_ETC** Electronic Throttle Control Driver has failed. Indeterminate fault on Hbridge driver for electronic throttle control. Possibly either ETC+ or ETC- driver signals have been shorted to ground	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check ETC driver wiring for a shorted circuit SECM Pin#52 to ETC + Pin 1 SECM Pin#51 to ETC - Pin 4 • Perform the throttle test using the Service Tool and re-check for fault Check the ETC internal motor drive by disconnecting the throttle connector and measuring the motor drive resistance at the throttle Pin 1 (+DRIVER) to Pin 4 (-DRIVER) - Not open circuit (OL or ∞ Ohm) - Not short coil (<1 Ohm)
521	**100/2**	**LowOilPressureFault** Low engine oil pressure	Vehicle will be running with torque limit resulting in low power.	TurnOnMIL DelayedEngineShutdown CheckEngineLight	Check engine oil level Check electrical connection to the oil pressure switch SECM Pin 59 to Oil Pressure Switch
531	**158/4**	**SysVoltRangeLow** System voltage too low	Possible re-start failure.	TurnOnMIL CheckEngineLight	Check battery voltage • Perform maintenance check on electrical connections to the battery and chassis ground • Check battery voltage during starting and with the engine running to verify charging system and alternator function • Measure battery power at SECM with a multimeter (with key on) SECM Pin#67 (DRVP) to SECM Pin#69 (DRVG) SECM Pin#67 (DRVP) to SECM Pin#70 (DRVG)

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
541	**158/3**	**SysVoltRangeHigh** System voltage too high	Possible ignition system failure.	TurnOnMIL CheckEngineLight DelayedEngineShutdown	Check battery and charging system voltage • Check battery voltage during starting and with the engine running • Check voltage regulator, alternator, and charging system • Check battery and wiring for overheating and damage • Measure battery power at SECM with a multimeter (with key on) SECM Pin#67 (DRVP) to SECM Pin#69 (DRVG) SECM Pin#67 (DRVP) to SECM Pin#70 (DRVG)
551	**1079/4**	**SensVoltRangeLow** Sensor reference voltage XDRP too low	Possible shifting XDRP related sensor calibration.	TurnOnMIL DelayedEngineShutdown CheckEngineLight	Measure transducer power at the TMAP connector with a multimeter TMAP Pin 3 XDRP +5 Vdc to TMAP Pin 1 XDRG GND Verify transducer power at the SECM with a multimeter SECM Pin Pin#48 +5 Vdc to SECM Pin#32 XDRG GND Verify transducer power to the foot pedal with a multimeter.
561	**1079/3**	**SensVoltRangeHigh** Sensor reference voltage XDRP too high	Possible shifting XDRP related sensor calibration.	TurnOnMIL DelayedEngineShutdown CheckEngineLight	Measure transducer power at the TMAP connector with a multimeter TMAP Pin 3 XDRP +5 Vdc to TMAP Pin 1 XDRG GND Verify transducer power at the SECM with a multimeter SECM Pin#48 +5 Vdc to SECM Pin#32 XDRG GND Verify transducer power to the foot pedal with a multimeter.

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
571	**190/0**	**HardOverspeed** Engine speed has exceeded the third level (3 of 3) of overspeed protection	None after Engine Speed returns to normal	TurnOnMIL HardRevLimit CheckEngineLight EngineShutdown	Usually associated with additional ETC faults • Check for ETC Sticking or other ETC faults Verify if the lift truck was motored down a steep grade
572	**190/16**	**MediumOverspeed** Engine speed has exceeded the second level (2 of 3) of overspeed protection	None after Engine Speed returns to normal	TurnOnMIL MediumRevLimit CheckEngineLight DelayedEngineShutdown	Usually associated with additional ETC faults • Check for ETC Sticking or other ETC faults Verify if the lift truck was motored down a steep grade
573	**190/15**	**SoftOverspeed** Engine speed has exceeded the first level (1 of 3) of overspeed protection	None after Engine Speed returns to normal	TurnOnMIL SoftRevLimit CheckEngineLight	Usually associated with additional ETC faults • Check for ETC Sticking or other ETC faults Verify if the lift truck was motored down a steep grade
611	**91/4**	**APP1RangeLow** APP1 sensor voltage out of range low, normally set if the APP1 signal has shorted to ground, circuit has opened or sensor has failed	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight	Check foot pedal connector • Check APP1 signal at SECM Pin#22 • Required 2 key cycle for normal pedal operation after pedal self-healing
612	**29/4**	**APP2RangeLow** APP2 sensor voltage out of range low, normally set if the APP2 signal has shorted to ground, circuit has opened or sensor has failed	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight	Check foot pedal connector • Check APP2 signal at SECM Pin#42 • Required 2 key cycle for normal pedal operation after pedal self-healing
621	**91/3**	**APP1RangeHigh** APP1 sensor voltage out of range high, normally set if the APP1 signal has shorted to power or the	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight	Check foot pedal connector • Check APP1 signal at SECM Pin#22 • Required 2 key cycle for normal pedal operation after pedal self-healing

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
		ground for the sensor has opened			
622	**29/3**	**APP2RangeHigh** APP2 sensor voltage out of range high, normally set if the APP2 signal has shorted to power or the ground for the sensor has opened	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight	Check foot pedal connector Check APP2 signal at SECM Pin#42 • Required 2 key cycle for normal pedal operation after pedal self-healing
631	**91/1**	**APP1AdaptLoMin** Learned idle end of APP1 sensor range lower than expected	Possible increasing engine idle speed due to APP1 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP1 signal at SECM Pin#22 • Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP1Raw_Adpt_Low to 300
632	**29/1**	**APP2AdaptLoMin** Learned idle end of APP2 sensor range lower than expected	Possible increasing engine idle speed due to APP2 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP2 signal at SECM Pin#42 • Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP2Raw_Adpt_Low to 300
641	**91/16**	**APP1AdaptHiMax** Learned full pedal end of APP1 sensor range higher than expected	Possible increasing engine idle speed due to APP1 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP1 signal at SECM Pin#22

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					• Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP1Raw_Adpt_Hi to 300
642	**29/16**	**APP2AdaptHiMax** Learned full pedal end of APP2 sensor range higher than expected	Possible increasing engine idle speed due to APP2 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP2 signal at SECM Pin#42 • Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP2Raw_Adpt_Hi to 300
651	**91/18**	**APP1AdaptHiMin** Learned full pedal end of APP1 sensor range lower than expected	Possible increasing engine idle speed due to APP1 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP1 signal at SECM Pin#22 • Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP1Raw_Adpt_Low to 300
652	**29/18**	**APP2AdaptHiMin** Learned full pedal end of APP2 sensor range lower than expected	Possible increasing engine idle speed due to APP2 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP2 signal at SECM Pin#42• Required 2 key cycle for normal pedal operation after pedal self-healing • Required Manual update APP2Raw_Adpt_Hi to 300
DFC	**SPN/ FMI**	**Fault Name and Description**	**Operational Consequence**	**Fault Action**	**Corrective Action: Check First**

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
661	**91/0**	**APP1AdaptLoMax** Learned idle end of APP1 sensor range higher than expected	Possible unstable idle speed due to APP1 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP1 signal at SECM Pin#22 • Required 2 key cycle for normal pedal operation after pedal self-healing
662	**29/0**	**APP2AdaptLoMax** Learned idle end of APP2 sensor range higher than expected	Possible unstable idle speed due to APP2 drifting.	TurnOnMIL	Check APP connector and pins for corrosion Cycle the pedal several times and check APP2 signal at SECM Pin#42 • Required 2 key cycle for normal pedal operation after pedal self-healing
691	**91/7**	**APP_Sensors_Conflict** APP position sensors do no not track well, intermittent connections to APP or defective pedal assembly	Possible low power and poor running caused by torque derating.	TurnOnMIL CheckEngineLight CutThrottle	Check APP connector and pins for corrosion . Cycle the pedal several times and check APP1 signal at SECM Pin#22 Cycle the pedal several times and check APP2 signal at SECM Pin#42
711	**6658/5**	**LSDFault_Dither1** Dither Valve 1 Fault, signal has opened or shorted to ground or power or defective dither 1 valve	Possible low power and poor running caused by inaccurate fuel control.	TurnOnMIL DisableGasO2Ctrl CheckEngineLight DisableGasPostO2Ctrl	Check FTV1 for an open wire or FTV connector being disconnected FTV1 Pin 1 (signal) to SECM Pin#7 FTV1 Pin 2 (power) to SECM (DRVP) Pin#67 Check FTV1 for an open coil by disconnecting the FTV connector and measuring the resistance (17.2Ω ± 2Ω @ 23 ± 5degC)
712	**6659/5**	**LSDFault_Dither2** Dither Valve 2 Fault, signal has opened or shorted to ground or power or defective dither 2 valve	Possible low power and poor running caused by inaccurate fuel control.	TurnOnMIL DisableGasO2Ctrl CheckEngineLight DisableGasPostO2Ctrl	Check FTV1 for an open wire or FTV connector being disconnected or signal shorted to GND FTV2 Pin 1 (signal) to SECM Pin#10 FTV2 Pin 2 (power) to SECM (DRVP) Pin#67 Check FTV1 for an open coil by

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					disconnecting the FTV connector and measuring the resistance (17.2Ω ± 2Ω @ 23 ± 5degC)
713		**LSDFault_CSValve** Cold Start Valve Fault, signal has opened or shorted to ground or power or defective cold start valve	Possible engine starting issues.		N/A
714	2648/5	**LSDFault_CheckEngine** Check Engine Lamp Fault, signal has opened or shorted to ground or power or defective check engine lamp	Vehicle will not indicate correct Check Engine condition by lamp indicator.	TurnOnMIL CheckEngineLight	Check 'Check Engine Lamp' for an open wire or shorted to GND
715	677/5	**LSDFault_CrankDisable** Crank Disable Fault, signal has opened or shorted to ground or power or defective crank disable relay	ECU will not be able to control Starter. Possible vehicle cannot start engine. Possible starter motor damage.	TurnOnMIL CheckEngineLight	N/A
DFC	**SPN/ FMI**	**Fault Name and Description**	**Operational Consequence**	**Fault Action**	**Corrective Action: Check First**
716	6719/5	**LSDFault_FuelPump** Fuel Pump Circuit Fault, signal has opened, shorted to ground or power, or defective relay or fuel pump	Possible low power and poor running caused by low fuel pressure. Engine cannot start.	TurnOnMIL CheckEngineLight	Check fuel pump circuit for an open wire or connector being disconnected or signal shorted to GND Fuel Pump Pin B (ground) from Engine Ground SECM Pin# 69,70 Fuel Pump Pin A (power) from relay4 output Fuel Pump Relay ground to SECM Pin#20 Fuel Pump Relay power to DRVP Pin#67 or Main relay2 Check fuel pump circuit for an open

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
					coil by disconnecting the fuel pump connector and measuring the resistance Check for 12V to fuel pump
717	632/4	**LSDFault_LockOff** Fuel Lock Off Valve Fault, signal has opened or shorted to ground or power or defective fuel lock off valve	Possible shutdown engine.	TurnOnMIL CheckEngineLight	Check fuel lock off valve for an open wire or connector being disconnected or signal shorted to GND Lock off Pin B (signal) from SECM Pin#15 Lock off Pin A (power) from main relay 1 or Pin#67(DRVP) Check lock off valve for an open coil by disconnecting the lock off valve connector and measuring the resistance (~20-29 Ω) Check for 12V to lock off valve
718	1213/4	**LSDFault_MIL** Malfunction Indicator Lamp Fault, signal has opened or shorted to ground or power or defective MIL lamp	Vehicle will not indicate MIL condition by lamp indicator.	TurnOnMIL CheckEngineLight	Check ‘OBD MIL’ for an open wire or shorted to GND
721	1695/18	**GasFuelAdaptRangeLow** In LPG mode, system had to adapt rich more than expected	Engine may run richer than desired. Engine may poor running caused by too much fuel.	TurnOnMIL CheckEngineLight DisableGasO2Ctrl DisableGasPostO2Ctrl	Check for vacuum leaks. Check fuel trim valves, e.g. leaking valve or hose Check for missing orifice(s).
731	1695/16	**GasFuelAdaptRangeHi** In LPG mode, system had to adapt lean more than expected	Engine may run leaner than desired. Engine may misfire or stall if too lean.	TurnOnMIL CheckEngineLight DisableGasO2Ctrl DisableGasPostO2Ctrl	Check fuel trim valves, e.g. plugged valve or hose. Check for plugged orifice(s).

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
741	**1118/2**	**GasO2NotActive** Pre-catalyst O2 sensor inactive on LPG, open O2 sensor signal or heater leads, defective O2 sensor	Possible low power or poor running.	TurnOnMIL DisableGasO2Ctrl CheckEngineLight DisableGasPostO2Ctrl	Check that Pre-catalyst O2 sensor connections are OK. O2 (signal) Pin 3 to SECM Pin# 66 O2 Pin 2 (HEATER) to SECM Pin#5 O2 Pin 1 (HEATER PWR) to SECM (DRVP + 12V) Pin#67 Verify O2 sensor heater circuit is operating by measuring heater resistance (3.6-4.6Ω @ 68 °F [20 °C])) O2 Pin 1 to Pin 2
742	**3227/8**	**GasPostO2NotActive** Post-catalyst O2 sensor inactive on LPG, open O2 sensor signal or heater leads, defective O2 sensor.	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableGasPostO2Ctrl	Check that Post-catalyst O2 sensor connections are OK. O2 (signal) Pin 3 to SECM Pin#50 O2 Pin 2 (HEATER) to SECM Pin#4 O2 Pin 1 (HEATER PWR) to SECM (DRVP +12V) Pin#67. Verify O2 sensor heater circuit is operating by measuring heater resistance (3.6-4.6Ω @ 68 °F [20 °C]) O2 Pin 1 to Pin 2
751	**1118/17**	**GasO2FailedLean** Pre-catalyst O2 sensor indicates extended lean operation on LPG	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableGasO2Ctrl DisableGasPostO2Ctrl	Check for vacuum leaks. Check fuel trim valves, e.g. leaking valve or hose. Check for missing orifice(s).
752	**3227/17**	**GasPostO2FailedLean** Pre-catalyst O2 sensor indicates extended lean operation on LPG	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableGasPostO2Ctrl	Correct other faults that may contribute to 752 (e.g. faults pertaining to fuel trim valves, Pre-Cat O2, Post Cat O2 sensor) Check for vacuum leaks Check for leaks in exhaust, catalytic converter, HEGO sensors; repair leaks. Check all sensor connections (see fault 742 corrective actions).

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
771	**1118/15**	**GasO2FailedRich** Pre-catalyst O2 sensor indicates extended rich operation on LPG	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableGasO2Ctrl DisableGasPostO2Ctrl	Check fuel trim valves, e.g. plugged valve or hose. Check for plugged orifice(s).
772	**3227/15**	**GasPostO2FailedRich** Pre-catalyst O2 sensor indicates extended rich operation on LPG	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableGasPostO2Ctrl	Correct other faults that may contribute to 772 (e.g. faults pertaining to FTVs, Pre-Cat O2, Post Cat O2 sensor) Look for leaks in exhaust, catalytic converter, HEGO sensors; repair leaks. Check all sensor connections (see fault 742 corrective actions).
821	**1695/16**	**LiqFuelAdaptRangeHi** In Gasoline mode, system had to adapt lean more than expected	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiquidO2Ctrl DisableLiqPostO2Ctrl	Check for vacuum leaks. Low gasoline fuel pressure, perform gasoline pressure test. Injector problems, e.g. plugged, defective injector
831	**1695/18**	**LiqFuelAdaptRangeLow** In Gasoline mode, system had to adapt rich more than expected	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiquidO2Ctrl DisableLiqPostO2Ctrl	Low gasoline fuel pressure, perform gasoline pressure test Injector problems, e.g. leaking, defective injector
841	**1118/2**	**LiqO2NotActive** Pre-catalyst O2 sensor inactive on gasoline, open O2 sensor signal or heater leads, defective O2 sensor	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiquidO2Ctrl DisableLiqPostO2Ctrl	Check that Pre-catalyst O2 sensor connections are OK. O2 (signal) Pin 3 to SECM Pin#66 O2 Pin 2 (HEATER) to SECM Pin#5 O2 Pin 1 (HEATER PWR) to SECM (DRVP + 12V) Pin#67 Verify O2 sensor heater circuit is operating by measuring heater resistance (3.6-4.6Ω @ 68 °F [20 °C]) O2 Pin 1 to Pin 2

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
842	**3227/8**	**LiqPostO2InActive** Post-catalyst O2 sensor inactive on gasoline, open O2 sensor signal or heater leads, defective O2 sensor.	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiqPostO2Ctrl	Check that Post-catalyst O2 sensor connections are OK. O2 (signal) Pin 3 to SECM Pin#50 O2 Pin 2 (HEATER) to SECM Pin#4 O2 Pin 1 (HEATER PWR) to SECM (DRVP +12V) Pin#67. Verify O2 sensor heater circuit is operating by measuring heater resistance (3.6-4.6Ω @ 68 °F [20 °C]) O2 Pin 1 to Pin 2
851	**1118/17**	**LiqO2FailedLean** Pre-catalyst O2 sensor indicates extended lean operation on gasoline	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL DisableLiquidO2Ctrl CheckEngineLight DisableLiqPostO2Ctrl	Check for vacuum leaks. Low gasoline fuel pressure, perform gasoline pressure test. Injector problems, e.g. plugged, defective injector
852	**3227/17**	**LiqPostO2FailedLean** Pre-catalyst O2 sensor indicates extended lean operation on gasoline	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiqPostO2Ctrl	Correct other faults that may contribute to 852 (e.g. faults pertaining to Injectors, MAP, IAT, Pre-Cat O2, Post Cat O2 sensor. Look for leaks in exhaust, catalytic converter, HEGO sensors; repair leaks. Check all sensor connections (see fault 842 corrective actions).
871	**1118/15**	**LiqO2FailedRich** Pre-catalyst O2 sensor indicates extended rich operation on gasoline	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL DisableLiquidO2Ctrl CheckEngineLight DisableLiqPostO2Ctrl	High gasoline fuel pressure, perform gasoline pressure test Injector problems, e.g. leaking, defective injector
872	**3227/15**	**LiqPostO2FailedRich** Pre-catalyst O2 sensor indicates extended rich operation on gasoline	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiqPostO2Ctrl	Correct other faults that may contribute to 872 (e.g. faults pertaining to Injectors, MAP, IAT, Pre-Cat O2, Post Cat O2 sensor. Look for leaks in exhaust, catalytic converter, HEGO sensors; repair leaks. Check all sensor connections (see fault 842 corrective actions).

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
911	**724/4**	**O2RangeLow** Pre-catalyst O2 sensor voltage out of range low, sensor signal shorted to ground	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL DisableLiquidO2Ctrl DisableGasO2Ctrl CheckEngineLight	Check continuity between ECU PreO2 signal pin 3 to SECM Pin#66.
912	**3227/4**	**O2_PostCatRangeLow** Post-catalyst O2 sensor voltage out of range low, sensor signal shorted to ground	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiqPostO2Ctrl DisableGasPostO2Ctrl	Check continuity between ECU PostO2 signal pin 3 to SECM Pin#50.
921	**724/3**	**O2RangeHigh** Pre-catalyst O2 sensor voltage out of range high, sensor signal shorted to power	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL DisableLiquidO2Ctrl DisableGasO2Ctrl CheckEngineLight	Check if O2 sensor installed before catalyst is shorted to +5Vdc or battery. O2 (signal) Pin 3 to SECM Pin# 66 SECM (XDRP + 5V) Pin#48 SECM (DRVP + 12V) Pin#67
922	**3227/3**	**O2_PostCatRangeHigh** Post-catalyst O2 sensor voltage out of range low, sensor signal shorted to ground	Possible low power or poor running due to open loop air fuel ratio control.	TurnOnMIL CheckEngineLight DisableLiqPostO2Ctrl DisableGasPostO2Ctrl	Check if O2 sensor installed after catalyst is shorted to +5Vdc or battery. O2 (signal) Pin 3 to SECM Pin#50 Possible voltage sources: SECM (XDRP + 5V) Pin#48 and SECM (DRVP + 12V) Pin#67
931	**3468/4**	**FuelTempRangeLow** Fuel Temperature Sensor Input is Low normally set if the fuel temperature sensor wire has shorted to chassis ground or the sensor has failed.	Possible low power or poor running.	TurnOnMIL CheckEngineLight	Check fuel temp sensor connector and wiring for a short to GND SECM (signal) Pin#41 to FTS Pin 2 SECM (sensor GND) Pin#32 to FTS Pin 1 SECM (system GND) Pin#69, 70
932	**3468/3**	**FuelTempRangeHigh** Fuel Temperature Sensor Input is High normally set if the fuel temperature sensor wire has been disconnected or the circuit has opened to the SECM.	Possible low power or poor running.	TurnOnMIL CheckEngineLight	Check if fuel temp sensor connector is disconnected or for an open FTS circuit SECM (signal) Pin#41 to FTS Pin 2 SECM (sensor GND) Pin#32 to FTS Pin 1

DFC	SPN/ FMI	Fault Name and Description	Operational Consequence	Fault Action	Corrective Action: Check First
933	**177/3**	**TransOilTemp** Excessive transmission oil temperature	Engine will be shutdown with default fault action	TurnOnMIL DelayedEngineShutdown	Refer to drivetrain manufacturer's transmission service procedures.

(*) Fault actions shown are default values specified by the OEM.

Chapter 9.
Parts Description.

LP Fuel System Components for 2.4L HMC Engines

Table lists the MI-21 components required for a 2.4L HMC engine operating on LP fuel. Components shown with part numbers are supplied by Woodward as part of the MI-21 system package. Components shown with a dot (•) are supplied by customer.

Table 9-1. Table of MI-21 system components

PART NO.		DESCRIPTION	QTY
Certified System	Non-Certified System		
8923-2584	8923-2584	Engine Control Module (SECM 70)	1
•	•	Camshaft Position Sensor	1
•	•	Crankshaft Position Sensor	1
•	•	TMAP Sensor	1
1689-1336	•	Fuel Temperature Sensor	1
•	•	Transmission Oil Temperature Switch	1
•	•	Oxygen Sensors	2
•	•	Coolant Sensor	1
•	•	Engine Oil Pressure Switch	1
1309-6281	•	Fuel Trim Valve	2
•	•	Ignition Coils	4
1311-1011	1311-1011	Fuel Lock Off Solenoid	1
5233-1018	N-2001-RSA	Regulator	1
8062-1123	7740-1011	CA100 Mixer	1
6945-5002	6945-5002	Throttle-DV-E5 32mm	1
•	•	Inline Fuel Filter	1
•	•	Inline Thermostat for Regulator	1

Mixers for Certified & Non-Certified Systems

CA100 Mixer for Certified Engine Systems

Refer to Figure 9-1 and Table for a parts list and exploded view of CA100 mixer (8062-1123).

Parts List: P/N 8062-1123 CA100 Mixer (Certified)

Table 9-2. Parts List for CA100 Mixer (8062-1123)

REF NO.	DESCRIPTION	QTY
1	Torx Screws (T-25) #10-24 x 5/8”	4
2	Lockwashers (T-210) #10 SST	4
3	Mixer Cover	1
4	Mixer Spring	1
5	Diaphragm	1
6	Air Valve Assembly	1
7	Gas Valve Cone (part of air valve assembly)	1
8	Mixer Body	1
9	Expansion Plug Cap Ø 1/2” x 1/16” thick (Ø 12.7mm x 27mm)	1
10	Fuel Inlet	1
11	Air Horn Gasket	1
12	Air Horn Adapter 2-1/16” (52.37mm)	1
13	Fillister Head Screws SEMS Lockwasher 10-24 UNC x 5/8”	4
14	Throttle Body Gasket	1
15	Fillister Head Screws SEMS Split Lockwasher #12-24 x 5/8”	4

Exploded View P/N 8062-1123 CA100 Mixer (Certified)

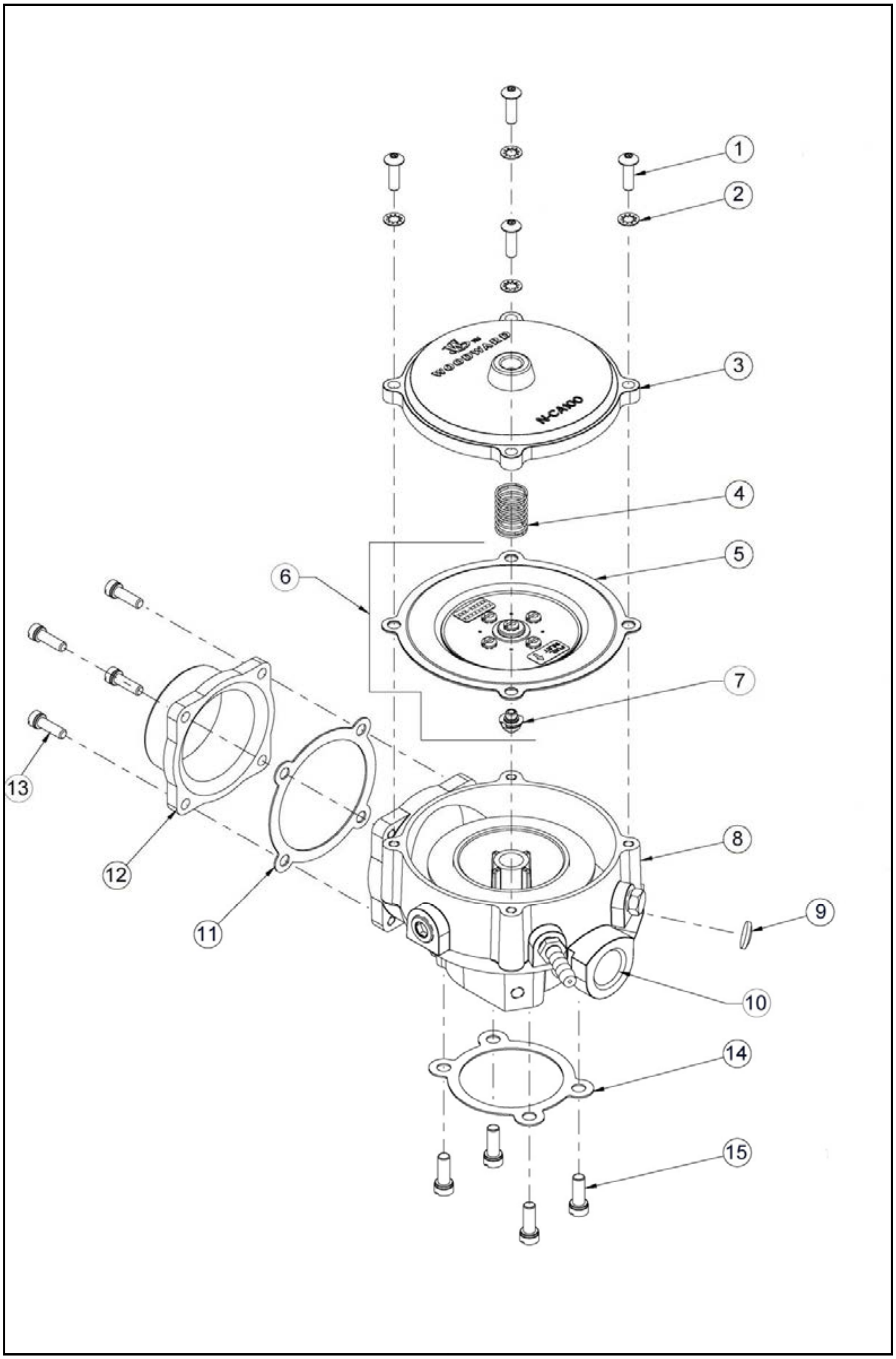


Figure 9-1. CA100 Certified Mixer (8062-1123) Exploded View

CA100 Mixer for Non-Certified Engine Systems

Refer to Figure 9-2 and Table for a parts list and exploded view of CA100 mixer (7740-1011).

Parts List: P/N 7740-1011 CA100 Mixer (Non-Certified)

Table 9-3. Parts List for CA100 Mixer (7740-1011)

REF NO.	DESCRIPTION	QTY
1	Screws 10-24 x 5/8” SEMS	4
2	Mixer Cover	1
3	Air Valve Spring	1
4	Screws 6-32 x 1/4” SEMS	5
5	Plate Backup	1
6	Diaphragm, Silicone	1
7	Air Valve Ring	1
8	Air Valve Assembly	1
9	Idle Screw 3/8-16 x 1-1/4”	1
10	Idle Screw Spring	1
11	Plugs, 1/8” Pipe Hex Head	2
12	Mixer Body Assembly	1
13	Screws, 1/4-28 x 5/16”	2
14	Plug, 1/4” Pipe	1
15	Screws 10-24 x 5/8” SEMS	4
16	Air Horn	1
17	Air Horn Gasket	1
18	Throttle Body to Mixer Gasket	1

Exploded View P/N 7740-1011 CA100 Mixer (Non-Certified)

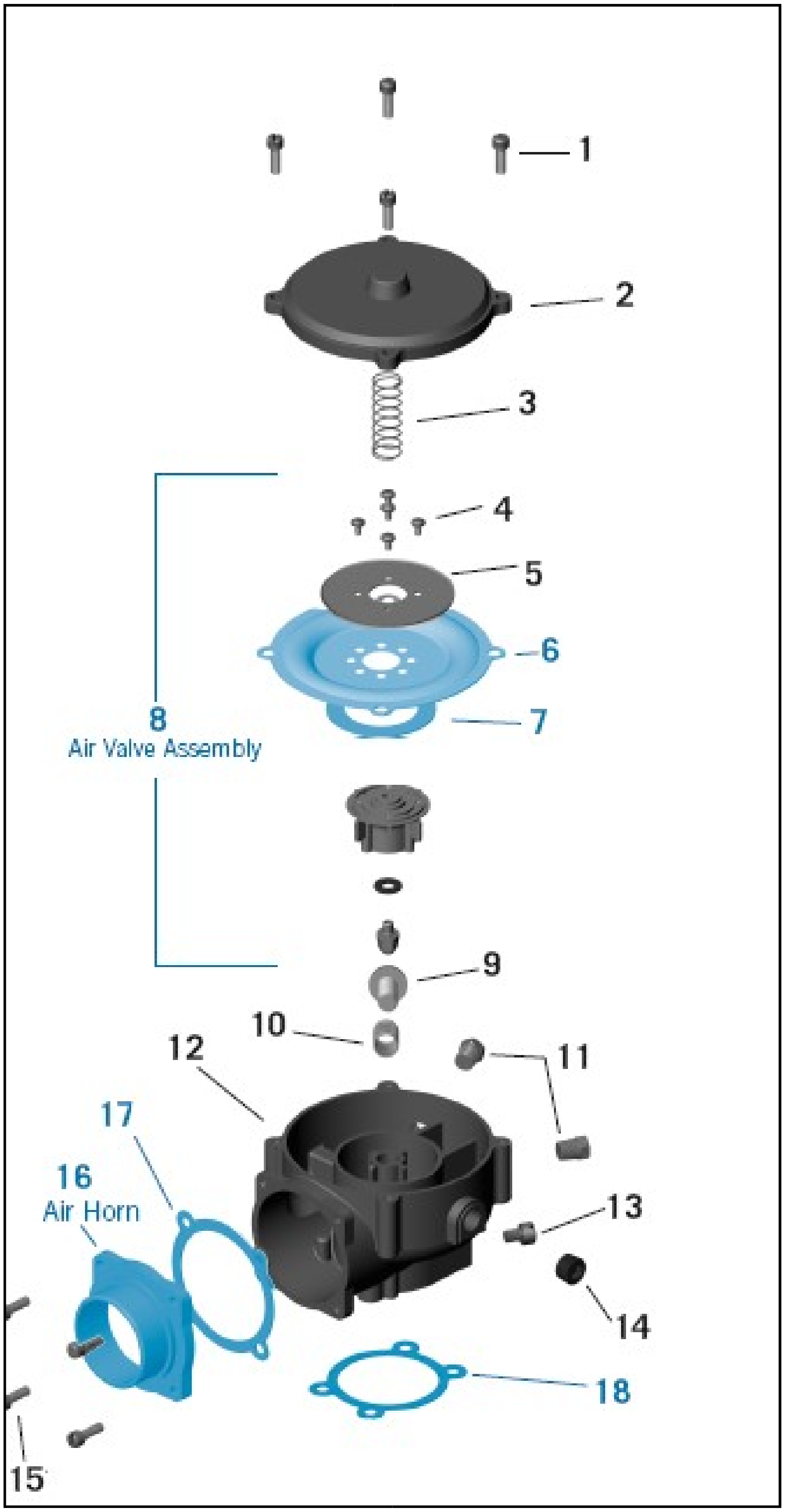


Figure 9-2. CA100 Non-Certified Mixer (7740-1011) Exploded View

Regulators for Certified & Non-Certified Systems

N-2007 Regulator for Certified Engine Systems

Refer to Figure 9-3 and Table for a parts list and exploded view of N-2007 regulator.

Parts List: P/N 5233-1018 N-2007 Regulator (Certified)

Table 9-4. Parts list for N-2007 regulator

REF NO.	DESCRIPTION	QTY
1	Torx Screws (T-15) #8-32 x 5/8”	6
2	Lockwasher, Int. Tooth (T-210) #8 SST	6
3	Cover, Secondary Diaphragm	1
4	Diaphragm, Secondary Assembly	1
5	Pan Head Screw SEMS Ext. Tooth Lockwasher #12-24 x 1/4”	1
6	Dowel Pin Ø 0.094” x 1” L (Ø 2.39mm x 25.4mm L) Hardened Steel	1
8	Seat, Secondary	1
9	Spring, Secondary Seat, Red	1
10	Fillister Head Screws SEMS Split Lockwasher #12-24 x 5/8”	6
11	Cover, Primary Assembly	1
12	Springs, Primary Assembly	2
13	Diaphragm, Primary Assembly	1
14	N-2007 Body	1
15	Body Gasket	1
16	Back Plate	1
17	O-ring, Size 107 GLT Viton®	1
18	Valve Primary	1
19	O-ring	1
20	Plate Cover	1
21	Fillister Head Screws SEMS Split Lockwasher #12-24 x 1-3/8”	6
22	Lockwasher 1/4 Split, Steel, Zinc	4
23	Hex Head Screws SEMS Split Lockwasher 1/4-20 x 5/8”	4

Exploded View P/N 5233-1018 N-2007 Regulator (Certified)

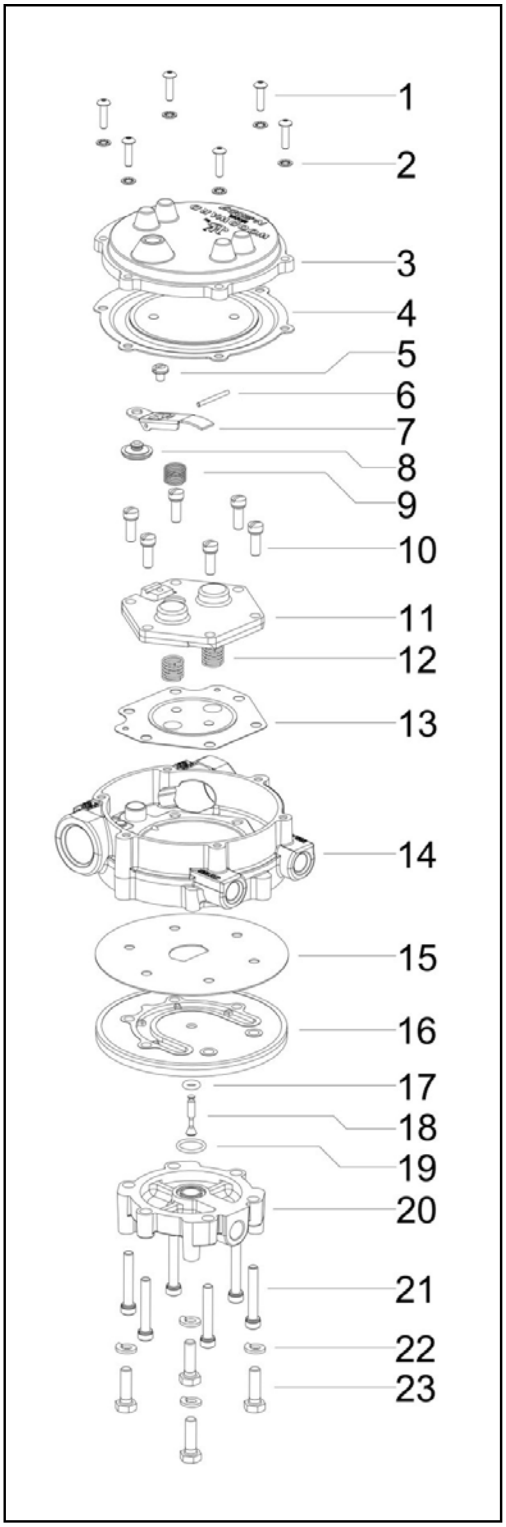


Figure 9-3. N-2007 Regulator Exploded View

N-2001 Regulator for Non-Certified Engine Systems

Refer to Figure 9-4 and Table 16 for a parts list and exploded view of N-2001-RSA regulator.

Parts List: P/N N-2001-RSA Regulator (Non-Certified)

Table 9-1. Parts List for N-2001-RSA Regulator

REF NO.	DESCRIPTION	QTY
1	Cover Screws 8-32 x 5/8” SEMS	4
2	Torx Screws (T-15) 8-32 x 5/8” Tamper Resistant	2
3	Lockwasher #8 Internal Tooth	2
4	Secondary Cover	1
5	Secondary Diaphragm Assembly	1
6	Pan Head Screw 10-24 x 1/4” w/Star Washer	1
7	Secondary Lever	1
8	Secondary Valve	1
9	Secondary Lever Fulcrum Pin	1
10	Red Secondary Spring	1
11	Pilot Valve Lever	1
12	Pilot Valve Lever Fulcrum Pin	1
13	Internal Hex Head Set Screw 8-32 x 1/4”	1
14	Cover Screws 12-24 x 5/8” SEMS	6
15	Primary Diaphragm Cover	1
16	Primary Regulator Springs	2
17	Primary Diaphragm Assembly	1
18	1/8 NPT Hex Pipe Plug Fitting	1
19	Body Assembly	1
20	Body Seal O-ring	1
21	Body Gasket	1
22	Regulator Back Plate	1
23	Primary Seal O-Ring	1
24	Primary Regulator Valve	1
25	Cover Screws 12-24 x 5/8” SEMS	6
26	Inlet Seal O-Ring	1
27	Inlet Plug	1
28	Hex Head Screws 1/4-20 UNC-2A x 5/8” SEMS	2

Exploded View P/N N2001-RSA Regulator (Non-Certified)

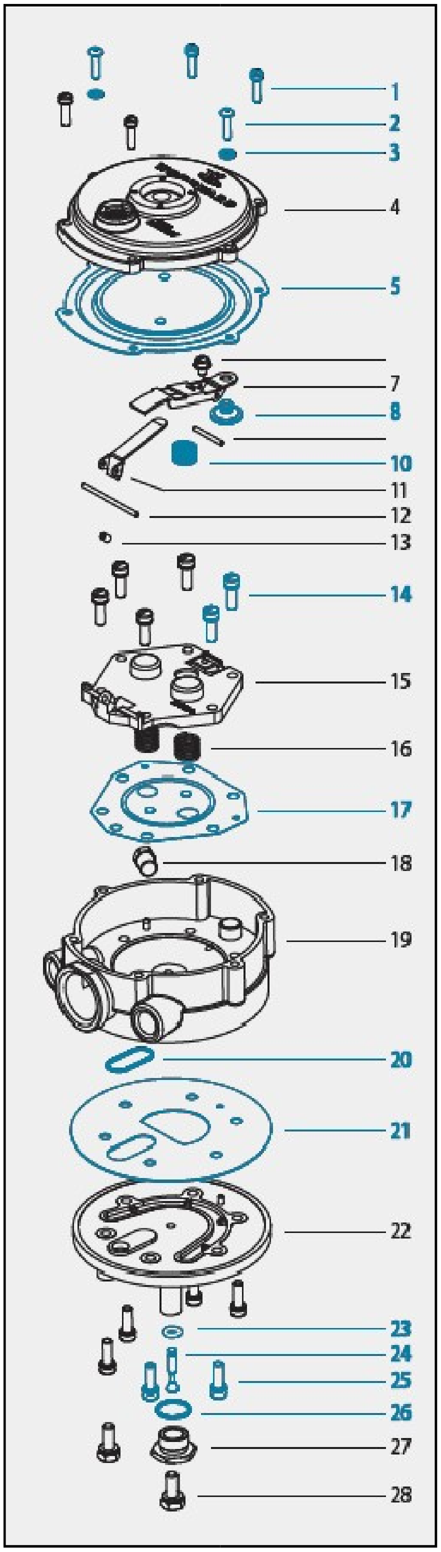


Figure 9-4. N-2001-RSA Regulator Exploded View

Chapter 10.
Product Support and Service Options

Product Support Options

If you are experiencing problems with the installation, or unsatisfactory performance of a Woodward product, the following options are available:

1. Consult the troubleshooting guide in the manual.
2. Contact the **OE Manufacturer or Packager** of your system.
3. Contact the **Woodward Business Partner** serving your area.
4. Contact Woodward technical assistance via email (**EngineHelpDesk@Woodward.com**) with detailed information on the product, application, and symptoms. Your email will be forwarded to an appropriate expert on the product and application to respond by telephone or return email.
5. If the issue cannot be resolved, you can select a further course of action to pursue based on the available services listed in this chapter.

OEM or Packager Support: Many Woodward controls and control devices are installed into the equipment system and programmed by an Original Equipment Manufacturer (OEM) or Equipment Packager at their factory. In some cases, the programming is password-protected by the OEM or packager, and they are the best source for product service and support. Warranty service for Woodward products shipped with an equipment system should also be handled through the OEM or Packager. Please review your equipment system documentation for details.

Woodward Business Partner Support: Woodward works with and supports a global network of independent business partners whose mission is to serve the users of Woodward controls, as described here:

- A **Full-Service Distributor** has the primary responsibility for sales, service, system integration solutions, technical desk support, and aftermarket marketing of standard Woodward products within a specific geographic area and market segment.
- An **Authorized Independent Service Facility (AISF)** provides authorized service that includes repairs, repair parts, and warranty service on Woodward's behalf. Service (not new unit sales) is an AISF's primary mission.
- A **Recognized Engine Retrofitter (RER)** is an independent company that does retrofits and upgrades on reciprocating gas engines and dual-fuel conversions, and can provide the full line of Woodward systems and components for the retrofits and overhauls, emission compliance upgrades, long term service contracts, emergency repairs, etc.

A current list of Woodward Business Partners is available at **www.woodward.com/directory**.

Product Service Options

Depending on the type of product, the following options for servicing Woodward products may be available through your local Full-Service Distributor or the OEM or Packager of the equipment system.

- Replacement/Exchange (24-hour service)
- Flat Rate Repair
- Flat Rate Remanufacture

Replacement/Exchange: Replacement/Exchange is a premium program designed for the user who is in need of immediate service. It allows you to request and receive a like-new replacement unit in minimum time (usually within 24 hours of the request), providing a suitable unit is available at the time of the request, thereby minimizing costly downtime.

This option allows you to call your Full-Service Distributor in the event of an unexpected outage, or in advance of a scheduled outage, to request a replacement control unit. If the unit is available at the time of the call, it can usually be shipped out within 24 hours. You replace your field control unit with the like-new replacement and return the field unit to the Full-Service Distributor.

Flat Rate Repair: Flat Rate Repair is available for many of the standard mechanical products and some of the electronic products in the field. This program offers you repair service for your products with the advantage of knowing in advance what the cost will be.

Flat Rate Remanufacture: Flat Rate Remanufacture is very similar to the Flat Rate Repair option, with the exception that the unit will be returned to you in “like-new” condition. This option is applicable to mechanical products only.

Returning Equipment for Repair

If a control (or any part of an electronic control) is to be returned for repair, please contact your Full-Service Distributor in advance to obtain Return Authorization and shipping instructions.

When shipping the item(s), attach a tag with the following information:
- return number;
- name and location where the control is installed;
- name and phone number of contact person;
- complete Woodward part number(s) and serial number(s);
- description of the problem;
- instructions describing the desired type of repair.

Packing a Control

Use the following materials when returning a complete control:
- protective caps on any connectors;
- antistatic protective bags on all electronic modules;
- packing materials that will not damage the surface of the unit;
- at least 100 mm (4 inches) of tightly packed, industry-approved packing material;
- a packing carton with double walls;
- a strong tape around the outside of the carton for increased strength.

NOTICE

To prevent damage to electronic components caused by improper handling, read and observe the precautions in Woodward manual 82715, *Guide for Handling and Protection of Electronic Controls, Printed Circuit Boards, and Modules*.

Replacement Parts

When ordering replacement parts for controls, include the following information:
- the part number(s) (XXXX-XXXX) that is on the enclosure nameplate;
- the unit serial number, which is also on the nameplate.

Engineering Services

Woodward's Full-Service Distributors offer various Engineering Services for our products. For these services, you can contact the Distributor by telephone or by email.

- Technical Support
- Product Training
- Field Service

Technical Support is available from your equipment system supplier, your local Full-Service Distributor, or from many of Woodward's worldwide locations, depending upon the product and application. This service can assist you with technical questions or problem solving during the normal business hours of the Woodward location you contact.

Product Training is available as standard classes at many Distributor locations. Customized classes are also available, which can be tailored to your needs and held at one of our Distributor locations or at your site. This training, conducted by experienced personnel, will assure that you will be able to maintain system reliability and availability.

Field Service engineering on-site support is available, depending on the product and location, from one of our Full-Service Distributors. The field engineers are experienced both on Woodward products as well as on much of the non-Woodward equipment with which our products interface.

For information on these services, please contact one of the Full-Service Distributors listed at **www.woodward.com/directory**.

Contacting Woodward's Support Organization

For the name of your nearest Woodward Full-Service Distributor or service facility, please consult our worldwide directory at **www.woodward.com/directory**, which also contains the most current product support and contact information.

You can also contact the Woodward Customer Service Department at one of the following Woodward facilities to obtain the address and phone number of the nearest facility at which you can obtain information and service.

Products Used in Electrical Power Systems

Facility	Phone Number
Brazil	+55 (19) 3708 4800
China	+86 (512) 6762 6727
Germany:	
Kempen	+49 (0) 21 52 14 51
Stuttgart	+49 (711) 78954-510
India	+91 (124) 4399500
Japan	+81 (43) 213-2191
Korea	+82 (51) 636-7080
Poland	+48 12 295 13 00
United States	+1 (970) 482-5811

Products Used in Engine Systems

Facility	Phone Number
Brazil	+55 (19) 3708 4800
China	+86 (512) 6762 6727
Germany	+49 (711) 78954-510
India	+91 (124) 4399500
Japan	+81 (43) 213-2191
Korea	+82 (51) 636-7080
The Netherlands	+31 (23) 5661111
United States	+1 (970) 482-5811

Products Used in Industrial Turbomachinery Systems

Facility	Phone Number
Brazil	+55 (19) 3708 4800
China	+86 (512) 6762 6727
India	+91 (124) 4399500
Japan	+81 (43) 213-2191
Korea	+82 (51) 636-7080
The Netherlands	+31 (23) 5661111
Poland	+48 12 295 13 00
United States	+1 (970) 482-5811

Technical Assistance

If you need to contact technical assistance, you will need to provide the following information. Please write it down here before contacting the Engine OEM, the Packager, a Woodward Business Partner, or the Woodward factory:

General

Your Name

Site Location

Phone Number

Fax Number

Prime Mover Information

Manufacturer

Engine Model Number

Number of Cylinders

Type of Fuel (gas, gaseous, diesel, dual-fuel, etc.)

Power Output Rating

Application (power generation, marine, etc.)

Control/Governor Information

Control/Governor #1

Woodward Part Number & Rev. Letter

Control Description or Governor Type

Serial Number

Control/Governor #2

Woodward Part Number & Rev. Letter

Control Description or Governor Type

Serial Number

Control/Governor #3

Woodward Part Number & Rev. Letter

Control Description or Governor Type

Serial Number

Symptoms

Description

If you have an electronic or programmable control, please have the adjustment setting positions or the menu settings written down and with you at the time of the call.

Appendix.
LPG & LPG Fuel Tanks

Liquefied petroleum gas (LPG) consists mainly of propane, propylene, butane, and butylenes in various mixtures. LPG is produced as a by-product of natural gas processing or it can be obtained from crude oil as part of the oil refining process. LPG, like gasoline, is a compound of hydrogen and carbon, commonly called hydrocarbons.

In its natural state, propane is colorless and odorless; an odorant (ethyl mercaptan) is added to the fuel so its presence can be detected. Typically, two grades of propane are available in the United States. A propane grade designation of HD5 (not exceeding 5% propylene), is used for internal combustion engines while much higher levels of propylene (HD10) are used as commercial grade propane along with a commercial propane/butane mixture. Typical composition of HD5 propane is shown in Table In European countries there are generally two grades of propane. One is a summer blend designated Fuel A (approximately 30% propane/70% butane) and one is a winter blend designated Fuel B (approximately 85% propane/15% butane).

Table A-1. Approximate Composition of HD5 Propane by Volume%

Propane (C3H8)	**Propylene**	**Butane (C4H10)**	**Iso-Butane**	**Methane (CH4)**	**TOTAL**
90.0% min.	5% max.	2.0%	1.5%	1.5%	100%

An advantage of LPG is the ability to safely store and transport the product in the liquid state. In the liquid state propane is approximately 270 times as dense as it is in a gaseous form. By pressurizing a container of LPG we can effectively raise the boiling point above -44° F (-42° C), keeping the propane in liquid form. The point at which the liquid becomes a gas (boiling point) depends on the amount of pressure applied to the container.

This process operates similarly to an engine coolant system where water is kept from boiling by pressurizing the system and adding a mixture of glycol. For example, water at normal atmospheric pressure will boil at 212° F (100°) C. If an engine’s operating temperature is approximately 230° F (110° C) then the water in an open un-pressurized cooling system would simply boil off into steam, eventually leaving the cooling system empty and overheating the engine. If we install a 10-psig cap on the radiator, pressurizing the cooling system to 10 psig, the boiling point of the water increases to 242° F (117° C), which will cause the water to remain in liquid state at the engine’s operating temperature.

The same principle is applied to LPG in a container, commonly referred to as an LPG tank or cylinder. Typically, an LPG tank is not filled over 80% capacity to allow for a 20% vapor expansion space. Outside air temperature affects an LPG tank and must be considered when using an LPG system. Figure A-1 shows the relationship between pressure and temperature in a LPG tank at a steady state condition.

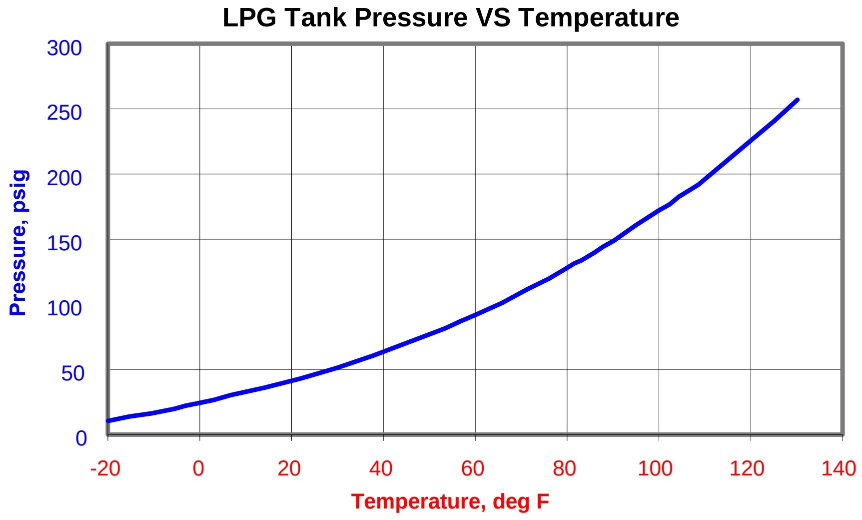


Figure A-1. LPG Tank Pressure vs Temperature

With 128 psig vapor pressure acting against the liquid propane (Figure A-2), the boiling point has been raised to slightly more than 80° F (27° C).

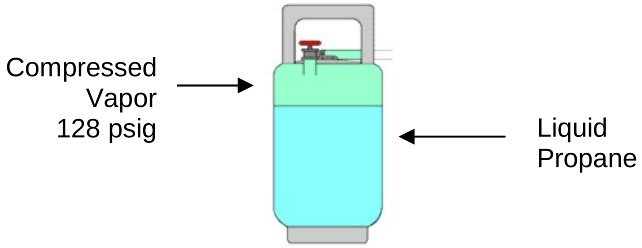


Figure A-2. Vapor Pressure Effect on Boiling Point of Propane

IMPORTANT **Vapor pressure inside an LPG tank depends on the propane temperature, not the amount of liquid inside the tank. A tank that is 3/4 full of liquid propane at 80°F (27°C) will contain the same vapor pressure as a tank that is only 1/4 full of liquid propane.**

LPG’s relative ease of vaporization makes it an excellent fuel for low-rpm engines on start-and-stop operations. The more readily a fuel vaporizes, the more complete combustion will be. Because propane has a low boiling point (-44° F [-42° C]), and is a low carbon fuel, engine life can be extended due to less cylinder wall wash down and little, if any, carbon build up.

LPG Fuel Tanks

The MI-21 system requires a liquid draw tank. The two styles of LPG storage containers available for industrial use and lift truck applications are portable universal cylinders and permanently mounted tanks. Portable universal cylinders are used primarily for off-highway vehicles and are constructed in accordance with the DOT-TC (United States Department of Transport – Transport Canada). The cylinders are referred to as universal because they can be mounted in either a vertical or horizontal position (Figure A-3). If these regulations don’t apply, make sure to follow local regulatory guidelines for LPG fuel tanks.

Figure A-3. Portable Universal LPG Cylinder

NOTICE **A 375-psig relief valve is used on a DOT forklift tank. The relief valve must be replaced with a new valve after the first 12 years and every 10 years thereafter.**

The tank must be discarded if the collar is damaged to the point that it can no longer protect the valves. It must also be replaced if the foot ring is bent to the point where the tank will not stand or is easily knocked over.

Installing LPG Fuel Tanks

When installing a tank on a lift truck, the tank must be within the outline of the vehicle to prevent damage to the valves when maneuvering in tight spaces.

Horizontal tanks must be installed on the saddle that contains an alignment pin, which matches the hole in the collar of the tank. When the pin is in the hole, the liquid withdrawal tube is positioned to the bottom of the tank. A common problem is that often these guide-pins are broken off, allowing the tank to be mounted in any position. This creates two problems: (1) Exposure of the liquid withdrawal tube to the vapor space may give a false indication that the tank is empty, when it is not. (2) The safety relief valve may be immersed in liquid fuel. If for any reason the valve must vent, venting liquid can cause a serious safety problem.

⚠CAUTION **Exchange empty tank with a pre-filled replacement tank. Wear safety glasses and gloves when exchanging a tank.**

LPG Fuel Tank Components

The components of a typical LPG fuel tank are shown in Figure A-4 .

- Fuel Gauge
- 80% Stop Bleeder
- Pressure Relief Valve
- Service Valve (Tank end male coupling)
- Filler Valve
- Alignment Pin
- Vapor Withdrawal Tube (used only with vapor withdrawal)
- 80% Limiter Tube
- Liquid Withdrawal Tube

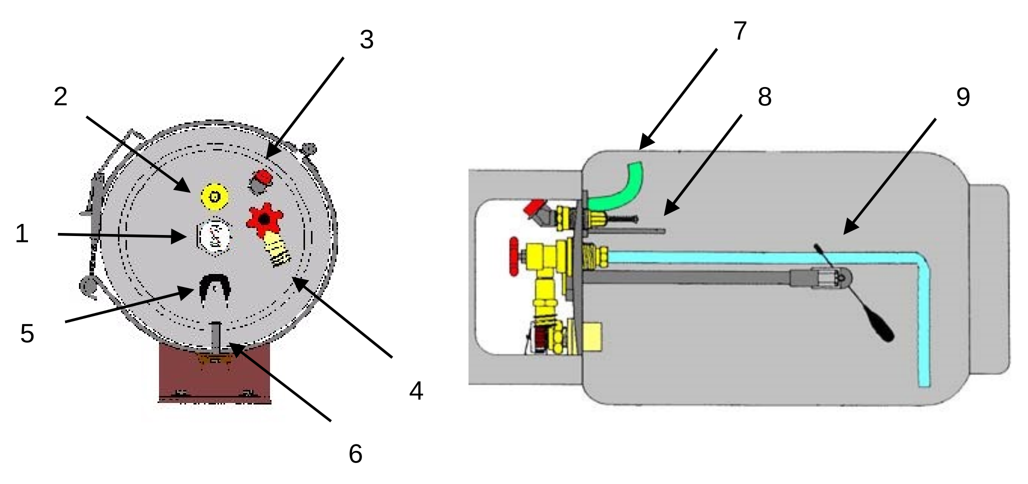


Figure A-4. LPG Fuel Tank Components

Fuel Gauge

In Figure a visual fuel gauge is used to show the fuel level in the tank. A mechanical float mechanism detects the liquid propane level. A magnet on the end of the float shaft moves a magnetic pointer in the fuel gauge. Some units have an electronic sending unit using a variable resistor, installed in place of a gauge for remote monitoring of the fuel level. The gauge may be changed with fuel in the tank.

IMPORTANT **Do not remove the four large flange bolts that retain the float assembly when fuel is in the tank.**

IMPORTANT **It is not a legal practice to fill the tank through the liquid contents gauge.**

In some applications a fixed tube fuel indicator is used in place of a float mechanism. A fixed tube indicator does not use a gauge and only indicates when the LPG tank is 80% full. The fixed tube indicator is simply a normally closed valve that is opened during refueling by the fueling attendant. When opened during refueling and the tanks LPG level is below 80%, a small amount of vapor will exit the valve. When the LPG tank level reaches 80% liquid propane will begin exiting the valve in the form of a white mist (Always wear the appropriate protective apparel when refueling LPG cylinders). In order for this type of gauge to be accurate, the tank must be positioned properly. When full (80% LPG) the valve is closed by turning the knurled knob clockwise. Typically, a warning label surrounds the fixed tube gauge which reads STOP FILLING WHEN LIQUID APPEARS.

Pressure Relief Valve

A pressure relief valve is installed for safety purposes on all LPG tanks. Portable fuel tank safety pressure relief valves are a normally closed spring-loaded valve and are calibrated to open at 375 psig tank pressure. This will allow propane vapor to escape to the atmosphere. When tank pressure drops below the preset value the valve closes.

Service Valve

The service valve is a manually operated valve using a small hand wheel to open and close the fuel supply to the service line (fuel supply line). The service valve installs directly into the tank and has two main categories, liquid and vapor service valves. Liquid service valves used on portable LPG tanks use a 3/8” NPT) male pipe thread on the service valve outlet for attachment of a quick disconnect coupler.

An excess flow valve is built into the inlet side of the service valve (Figure A-5) as a safety device in case of an accidental opening of the service line or damage to the service valve itself. The excess flow valve shuts off the flow of liquid propane if the flow rate of the liquid propane exceeds the maximum flow rate specified by the manufacturer.

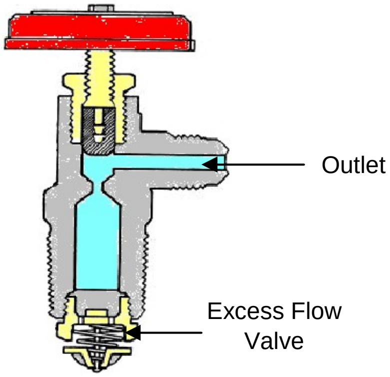


Figure A-5. LPG Tank Service Valve

IMPORTANT

The service valve should be completely open when the tank is in use. If the valve is partly open, the vehicle may not get enough fuel to operate efficiently.

In addition to possibly starving the engine for fuel, a partly open valve may restrict the flow enough to prevent the excess flow valve from closing in the event of a ruptured fuel line.

Most liquid service valves have an internal hydrostatic relief valve and are usually labeled LIQUID WITH INTERNAL RELIEF. The hydrostatic relief valve protects the fuel service line between the tank and the lock off from over pressurization. The internal hydrostatic relief valve has a minimum opening pressure of 375 psig and a maximum pressure of 500 psig. These relief valves have an advantage over external relief valves because the propane is returned to the tank in the event of an over pressurization instead of venting the propane to the atmosphere.

Quick Disconnect Coupling

The liquid withdrawal or service valve on a DOT tank has male threads and accepts the female portion of a quick disconnect coupling (Figure A-6). The female portion is adapted to the liquid hose going to the fuel system. Both halves are equipped with 100% shutoffs, which open when coupled together to allow fuel flow. The coupler has two seals. One is an O-ring and the other is a flat washer. The O-ring prevents leakage from the shaft on the other coupling and the flat washer seals when the coupler is fully connected.

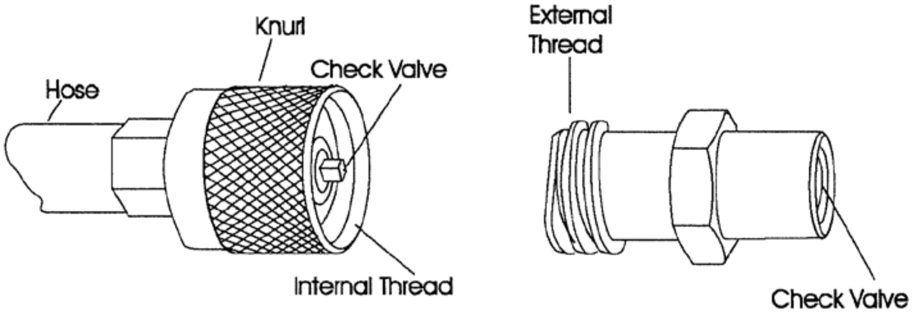


Figure A-6. Quick Disconnect Coupling

NOTICE

The flat seal and/or the O-ring will sometimes pop off when disconnecting and slide up the shaft of the mating connector, causing the valve not to open when fully mated. Remove the extra washer or O-ring from the shaft and reconnect the coupling.

Filler Valve

The liquid filler valve (Figure A-7) has a male thread to receive a fuel nozzle and typically has a plastic or brass screw on cap that is retained with a small chain or plastic band to keep debris out of the filler valve. The filler valve is a one-way flow device that uses two check valves to allow fuel to enter the tank but prevent it from exiting. Both check valves are backpressure type check valves, designed so that backpressure from the tank assists the check valves own spring pressure to close the valve. The first valve uses a neoprene on metal seal and the second valve uses a metal on metal seal.

A weakness ring (Figure A-7) is machined into the filler valve just above the check valves and will allow the filler valve to shear off in case of an accident. The valve will break or shear off above the check valves so that the tank will be sealed, and no liquid propane can escape.

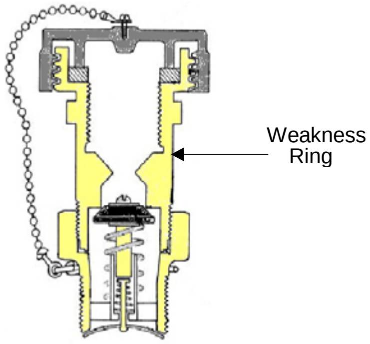


Figure A-7. Liquid Filler Valve

Revision History

New Manual—

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Declarations

We appreciate your comments about the content of our publications.

Send comments to: icinfo@woodward.com

Please reference publication 35187.

WOODWARD

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