MI-04 Control System

for Alternative-Fueled Off-Highway Vehicles

Applications

Woodward's MI-04 control system controls propane engines in forklifts and other alternative-fueled off-highway vehicles. The highly accurate closed-loop control system helps OEMs meet legislated TIER-2 emission levels, while maintaining excellent drivability and fuel economy. Woodward has a whole family of ECUs (engine control units) and continues to develop new applications as the market requirements change.

System Overview

The Woodward MI-04 LPG system consists of the following components:

- SECM
- High-pressure LPG shutoff valve
- High pressure LPG regulator
- LPG carburetor
- Drive-by-wire throttle
- Fuel control pressure solenoid
- O2 sensor
- Integrated temperature and manifold pressure sensor
- Smart coil

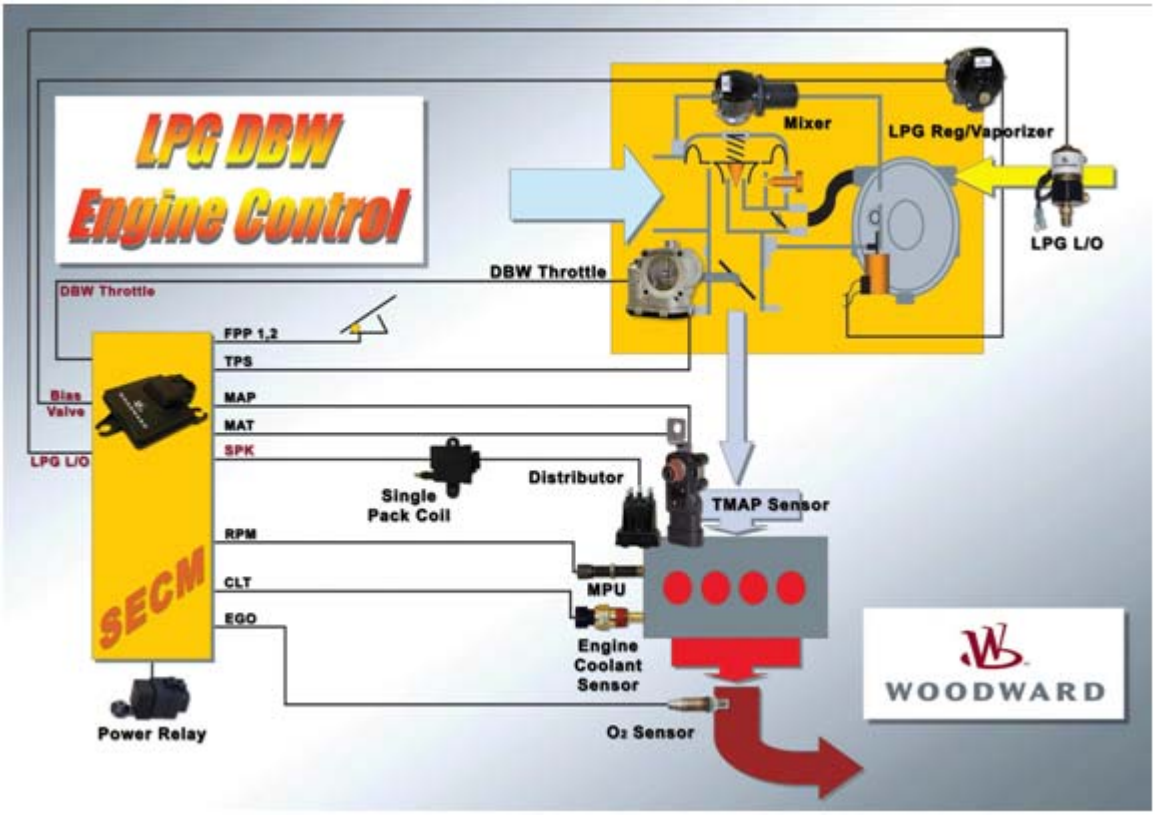
The MI-04 system is a fully integrated engine control solution. The Woodward SECM controller has full authority over spark, fuel, and air. This fully integrated approach permits precise governing and air/fuel ratio control while remaining flexible enough to handle transients. The control algorithms are model-based, feed-forward, adaptive strategies. Continual updates to the adaptive parameters allow for more responsive control. The control system “learns” where it needs to be instead of waiting for integrators to get the control where it should be.

Fuel control is accomplished by a PWM solenoid that biases the output pressure on the LPG fuel regulator. The feedback voltage from the O2 sensor determines the amount of bias applied to the regulator. Calibrating the O2 sensor target on a point-by-point basis optimizes emissions. Separate transient calibrations improve drivability.

Drive-by-wire based on a foot pedal input gives the control added authority. A foot pedal voltage commands a certain throttle position based on multiple inputs. Using the electronic throttle to perform min and max governing improves drivability and performance. Full spark and throttle control also permit a more comprehensive diagnostic and limp-home strategy. Spark and throttle are combined for advanced governing and load control.

- Closed-loop fuel control with adaptive-learn technology
- Model-based control strategy
- Full-authority drive-by-wire throttle system
- Diagnostics available via CAN
- Field-extractable fault codes
- Fail-safe limp-home feature

The following functional diagram shows how all the components are integrated into a system. As indicated in the diagram, the MI-04 can also accept inputs from existing engine sensors (such as coolant and oil pressure) and incorporate that data into the engine control and diagnostic strategies.



MI-04 Control System Features

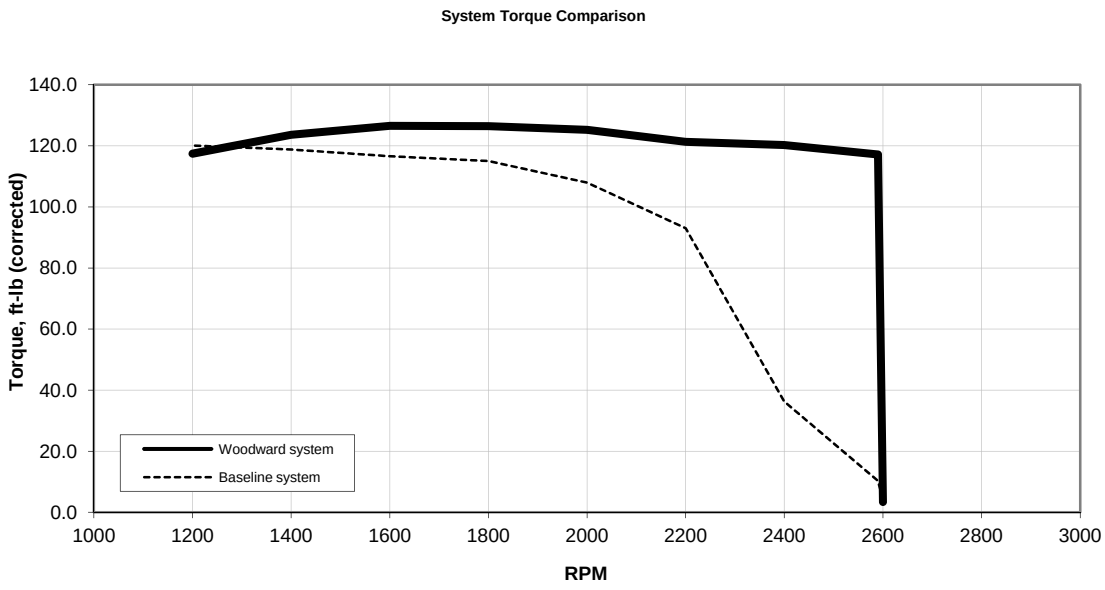
- Closed-loop, fuel control with adaptive-learn technology.
- Speed-density control strategy with advanced transient compensation (tau-x); provides improved transient fuel/air ratio tracking and durability over most mass-air flow based systems.
- Model-Based Control Strategy is used to compare actual engine operation with expected values.
- Full-authority drive-by-wire throttle system with min/max governing.
- Idle-speed control includes speed set-point modifications for coolant temperature and gear state.
- Diagnostic and vehicle serial links available via CAN.
- Many individual diagnostic codes capable of detecting functional faults, intermittent faults, sensor and actuator failures, and engine protection problems.
- Malfunction indicator lamp (MIL) with field-extractable fault code feature.
- Extensive engine protection features including limp-home and derate modes for inlet air temperature, engine coolant temperature, oil pressure, and overspeed.
- Fail-safe limp-home feature for all sensor failure modes.

MI-04 System Compared to IMPCO System

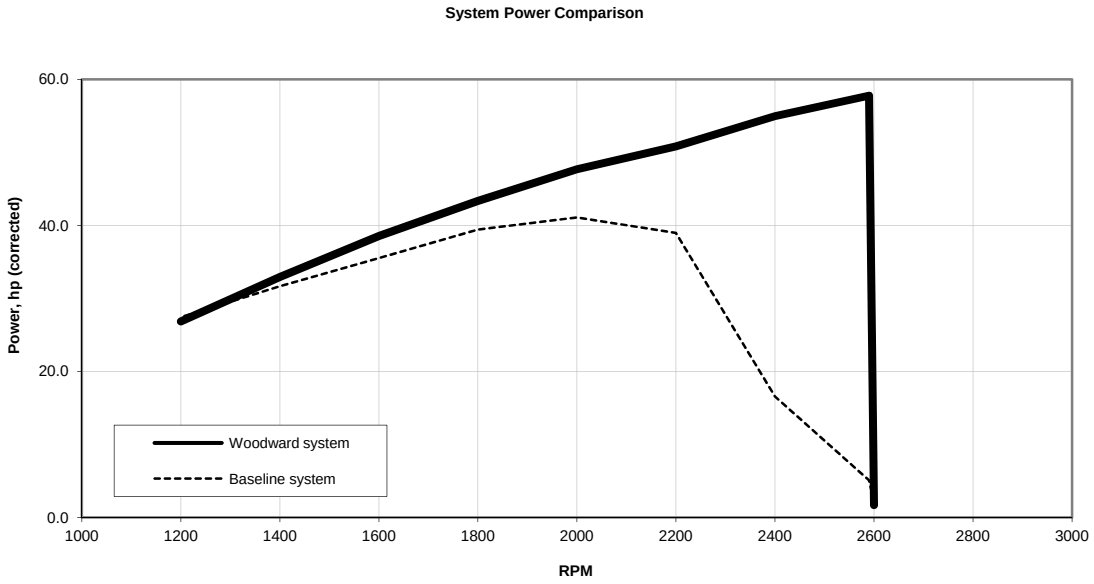
Woodward cannot compare to the TIER-2 Impco system because we are not aware that the final system has been defined. The Woodward MI-04 system is far superior to the existing Impco TIER-1 system. The MI-04 system has more authority over the fuel regulator. This allows the system to stay in compliance over a wider range of operating conditions. In addition, the control strategies controlling the PWM for the MI-04 fuel control solenoid are more robust. They incorporate the standard feed-forward, adaptive strategy present in all of Woodward's engine control systems. This permits faster response of the system as integrators do not have to "wind-up" to get to the desired operating point. The MI-04 system incorporates both spark control and drive-by-wire. As mentioned previously, these options enhance both drivability and diagnostic capability.

MI-04 System Compared to Baseline System

Woodward ran torque and power curves on an MHI 4G64 engine equipped with a Hoof governor, Nolff's 100, and stock ignition. Woodward then replaced the stock system with our complete MI-04 system, and re-ran the torque and power curves, achieving these results:



Torque vs RPM Curves (MI-04 compared to Baseline System)



Power vs RPM Curves (MI-04 compared to Baseline System)

The following table shows emissions data for the Woodward MI-04 system compared to industry data provided to us. The MI-04 system easily meets the TIER-2 emissions standards. The emissions levels are similar to other systems available. However, the Woodward system can meet these standards while providing superior drivability and fuel economy.

	MI-04 System	Brand X	2004 EPA Standard (after catalyst)	2007 EPA Standard (after catalyst)
BSCO [g/hp-hr]	0.664	0.677	37.3	3.28
BSTHC [g/hp-hr]	0.049	0.103		
BSNO$_x$ [g/hp-hr]	0.084	0.074		
No$_x$+THC [g/hp-hr]	0.132	0.177	2.98	2.01
BSFC, g/hp-hr @ max. torque	182.0	192.0		

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