Electronic Control for One-cylinder Engines

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Small engine manufacturers are starting to feel pressure, from government regulatory agencies around the world, to increase the efficiency and reduce the emissions from their products. To accomplish this, the engine control system must undergo a fundamental change from mechanical to electronic control. Some lessons learned from the conversion of the automotive engine from mechanical to electronic control can be applied to the small engine. Recent circuit integration efforts have been undertaken to enable small engine manufacturers to develop electronic controls that make their products "Greener". This article outlines some of the changes that are necessary and what Freescale is doing to help make this transition simple, easy and cost effective.

INTRODUCTION

Two recent events have emerged that are causing small engine manufacturers to consider replacing their traditional mechanical engine controls with newer, more effective electronic controls.

ENVIRONMENTAL CONCERNS

The high levels of pollution in urban areas and the growing significance of "greenhouse effect" causing gas emissions from two wheel vehicles and other small engine driven products is forcing many governments to enact stricter emission regulations. These new regulations are starting to specifically target small internal combustion engines. In order to satisfy the new exhaust emission levels contained in these regulations, the manufacturers will need to replace traditional mechanical engine controls with electronic controls, but the strict target costs and size requirements for small engine control systems will require manufacturers to seek innovative design solutions to implement these electronic controls.

FUEL EFFICIENCY

The cost of a gallon of gasoline has risen from 20 cents in 1956 to a recent high point of almost 4 dollars. Instability, in the crude oil producing regions of the world, is being blamed for the price volatility of this essential commodity. The supply of crude oil, once thought to be limitless, is predicted by the oil companies, to be running out. To extend the life of this fuel supply and to reduce engine operating costs means that all engines, large or small, will need to be designed to become more fuel efficient.
2 OR 4 STROKE ENGINES

One of the primary differences between certain small engines and their larger counterparts is the number of "strokes" or times the piston travels up or down in the cylinder to complete one cycle. While it is beyond the scope of this article to discuss the various good and bad points of both kinds of engine, suffice it to say that most existing low-cost, fuel and oil burning, 2 stroke engines will have to be radically redesigned to meet the requirements contained in this new emission legislation.

MECHANICAL CONTROLS

In the traditional internal combustion engine, invented in 1876 by Nicholas Otto, the operation is dependent upon three elements: air, fuel and combustion. In the cylinder of the engine, a precisely timed spark ignites an air/fuel mixture resulting in the combustion that pushes the piston, within the cylinder, down, causing the engine crankshaft to turn. The mechanical control system in a small internal combustion engine consists of two mechanical parts and one electrical part. The first mechanical part, the carburetor, uses the vacuum created in the cylinder, as the engine is initially cranked via the starter motor, pull cord or kick starter, to draw in and atomize the fuel and mix it in the correct proportion with air. This fuel/air mixture is drawn into the cylinder, at the proper time, through the second mechanical part, the intake valve.

The only electrical component is a device called a "magneto" which is used to generate the correctly timed spark determined by the location of two magnets on the flywheel attached to the rotating crankshaft. This mechanical control system is essentially an "open loop" control system, meaning there is no information fed back from the engine to indicate that the mechanical control system is operating properly or to correct it, if it is not. To increase efficiency and to reduce emissions a "closed loop" type of control system is essential. While it may be theoretically possible to design a closed loop mechanical feedback system, it is not a realistic goal in light of new microcomputer controlled electronic systems which are already used today in the automotive market.

ELECTRONIC CONTROLS

The effort to convert from mechanical control system to electronic control system focuses on two specific areas: spark control and fuel control. It also introduces the concept of closed loop control with the addition of a feedback signal from an oxygen (O2) sensor that monitors the engine exhaust. The presence of oxygen, in the exhaust gas, indicates that either the cylinder combustion reaction did not contain that the proper ratio, 14.7:1 of air to fuel, or that for some other reason the combustion reaction failed to complete.

SPARK CONTROL

The change from a simple magneto driven spark generating system to a microcomputer controlled spark ignition system is the biggest change that must occur in the transition from mechanical to electronic control.
A magneto is basically a 100:1 step-up transformer with a switched primary. Magnets, embedded in the engine flywheel induce a current in the primary as the flywheel turns and the first magnet passes by the magneto’s core. The second magnet causes the primary switch to open. The resultant collapsing magnetic field generates a 200 volt pulse in the primary. The 100:1 step-up ratio of the magneto’s primary to secondary causes the 200 volt pulse to be raised to a 20,000 volt pulse in the secondary which causes a spark to appear across the spark plug gap. The magneto is both simple and reliable but the spark output in time is impossible to control without physically moving the magnet positions or the magneto position.

A spark coil is similar to a magneto, in that it is also a step-up transformer, however instead of using magnets, a battery/alternator is used to supply the primary current needed to create the magnetic field that produces the high voltage pulse. Also, instead of using a magnetically triggered primary switch to break the primary current and collapse the magnetic field, a semiconductor device, either a Darlington bipolar junction transistor or, more recently, an insulated gate bipolar transistor (IGBT) is used.

In the magneto system, the magnets embedded in the flywheel also provide the required timing signal to generate the spark at a fixed time in the engine's compression cycle. In a spark coil based system, a multi-toothed wheel attached to the crankshaft, with a pickup coil called a "variable reluctance sensor" (VRS) provides a reference timing signal to the microcomputer which can then issue the spark signal at the best time for any given engine speed, load, and temperature to maximize efficiency and reduce pollutants. Variations in the fuel quality can also be compensated for by varying this spark timing. Calibration tables, stored in the microcomputer's memory provide a way for the microcomputer to look-up the proper time to generate the spark based on inputs from the various engine parameter monitoring sensors.

**FUEL CONTROL**

The carburetor has over 100 years of evolution, so most small engine manufacturers are reluctant to replace it with a relatively recent development, the fuel injector. The current trend for smaller engines is to use a hybrid approach called an electronic carburetor. It eliminates several of the purely mechanical components of the traditional carburetor with electronically controlled solenoids or motors. Unlike the change from magneto to spark coil and microcomputer ignition control, the change from carburetor to fuel injector simplifies many aspects of the fuel system design. Rather than rely on engine vacuum to deliver the fuel air mixture to the cylinder, the fuel injector relies on fuel pressure from a pump to atomize the fuel through the solenoid controlled injector. Dispensing the fuel in pulses, controlled by a microcomputer, allows more accurate control of the fuel quantity and optimized fuel delivery timing to increase the efficiency of the combustion process. It also allows the microcomputer to adjust the richness or leanness of the fuel/air mixture based on feedback from the O2 and other engine parameter sensors.

**ELECTRONIC ENGINE CONTROL UNIT**

The electronic Engine Control Unit or ECU is a module that contains a microcomputer (MCU) and all the analog and digital interface circuitry necessary to implement the engine control strategy. A block diagram of a typical one-cylinder ECU is shown below:
The MCU is typically a CMOS 8 or 16 bit device which can easily handle the required arithmetic and logical functions. Because of the voltage and current drive limitations of the MCU's outputs and the sensitivity of its inputs, analog circuitry is required to provide the interface between the various sensors and electromechanical actuators in the engine and the I/O pins on the MCU. Analog circuitry is also required to provide power supply conditioning and the required reset signals for the MCU.

The challenge for small engine ECU designers is to be able to shrink the ECU down to a size that can be mounted on a small engine. While this is not a problem for a large motorcycle or an industrial generator, small hand-held power tools such as weed whackers and leaf blowers require the ECU's size and weight to be a small fraction of that of the whole tool. To achieve this size and weight reduction, the number of discrete components in the ECU must be minimized. Since the digital part of the ECU, the MCU, is a small part of the size and weight, the remaining analog components must undergo similar integration to achieve this size and weight reduction.

**ASSP FOR SINGLE CYLINDER ENGINES**

Freescale Semiconductor has recently introduced one of the first application specific standard products (ASSP) IC designed with this goal, to integrate several analog functions for small engines into one chip. The part number of this IC is MCZ33812 and it is targeted at small single or dual cylinder engines. It integrates into a single IC, the power supply regulator for the MCU, the reset and the watchdog functions, a serial ISO9141 interface for diagnostic communication, an ignition pre-driver, an injector driver and two additional low-side drivers that can be used for driving a relay or second injector and a malfunction indicator lamp. It is a very fundamental feature set, but for just this reason it can be used in a large number of high volume single cylinder small engine ECUs.
MCZ33812 DETAILED DESCRIPTION

The MCZ33812 integrates several analog functions into one small 32 pin package. The interface between the MCU and this IC is via 10 parallel 5V logic level lines. The reason for choosing a simple parallel interface was to ensure that the circuit would be easy to understand for even neophyte electronic designers who may be converting from a mostly mechanical design background. The circuit is designed to operate from a standard 12 volt battery but will withstand voltages up to 36V and all the external outputs are protected against shorts to battery, over current, over temperature and ESD. The features of the included functions are briefly described below:

Power Supply

This module is a linear voltage regulator pre-driver that provides a stable 5V supply to power the MCU. It is designed to supply regulated 5V from any input voltage from 6.4V to 36V and track the input voltage supply from 6.4V down to 4.5V. As a pre-driver it drives the base of an external PNP transistor, to produce 5V +/- 2% at the collector. The VCCSENS input pin is connected to the PNP collector, which monitors the output voltage providing the feedback which regulates the collector to 5V.

Reset and Safety Functions
To guarantee the proper behavior of the MCU some safety functions have been included in this IC. The first is a reset circuit with an output pin, RESETB, capable of driving the MCU’s reset input pin. Altogether, there are three different events which can cause the reset signal to occur. The reset module contains three input pins, one, VCCSENS, is used to sense the external 5V voltage, the next, WDRFSH, is used to provide a periodic refresh signal to the watchdog timer from the MCU and the last, WD_INH, is used to select whether the watchdog function is enabled or disabled.

The first event which can drive the reset signal is the power on reset. When the device is first powered up, the RESETB signal is held low, ensuring that the MCU is held in a reset state until the power supply voltage has reached its minimum working value. When the 5V voltage exceeds this minimum level, the RESETB signal is kept low for another 128 sec, giving the MCU’s internal logic time to stabilize.

After this 128 sec period, the RESETB signal is brought high allowing the MCU to begin program execution. The second condition which can assert the RESETB signal is the under voltage reset, which occurs when the 5V voltage drops below the minimum operating value for the MCU. This ensures that the MCU is never operating outside its recommended operating voltage range. The last condition, that produces a RESETB signal, is the watchdog circuit timeout reset. When the watchdog circuit is enabled, it expects a periodic refresh signal from the MCU on the WDRFSH pin. Failure of the MCU to provide this periodic refresh signal is an indication that something has gone wrong in the flow of program instructions or that the MCU is “hung up”. The maximum watchdog time period is determined by the duration of the first pulse supplied by the MCU on the WDRFSH pin, after any RESETB has occurred.

![Fig. 3 Block Diagram of MCZ33812 Reset circuit - For higher resolution, click here](image-url)
The ignition pre-driver can drive either an IGBT or a Darlington transistor. It has two output lines, IGNOUTH and IGNOUTL, controlled by a single parallel input pin IGNIN. The choice of which type of transistor is being used is made by connecting the IGNSUP pin to either 5V for driving a Darlington or to 12V for driving an IGBT. While most new automotive designers chose use IGBT’s, some small engine ECU designers still design in Darlington because of previous CDI ECU designs that previously used Darlington. The Ignition pre-driver detects the fault conditions of open circuit or short to battery and a fault indicating signal, IGNFLT, is provided to the MCU.

Low-Side Drivers

There are three low side drivers, all controlled with the related parallel input pins. They have been designed respectively to drive a fuel injector, a relay (or second fuel injector) and a warning lamp or other load.

The low side drivers are all turned off during overvoltage and under voltage events and they are all protected against over current, short to battery and over temperature conditions. For the injector and relay drivers, the fault conditions of open load or short to battery are detected. The injector and relay drivers provide fault reporting signals to the MCU.

The relay driver has the same electrical characteristics as the injector driver so it can also be used to drive other higher current devices like fuel pumps.

The lamp driver has no fault indication signal, but it is protected against over current, over voltage, over temperature and short to battery. Because it doesn't have a pin to provide fault information to the microcontroller, when a fault condition is detected, the driver turns off and it tries to turns on again when the fault condition goes away. However it has been designed to drive an incandescent lamp and for this reason it has a maximum current limit of 3 Amps, instead of the 6 Amp limits of the two other drivers.

ISO-9141 Communication Interface

An ISO-9141 serial interface is included to allow the MCU to send and receive diagnostic information to an external test set.

MCZ33812 REFERENCE DESIGN

In order to demonstrate the capabilities of this first analog IC for small engine ECUs, an ECU reference design has been produced.
It is based on MCZ33812 and a MC9S12P128 16 bit MCU with, 128 Kbytes of Flash memory. It is a complete ECU designed as an example of the use of MCZ33812 in an actual application for a single cylinder, four stroke, engine and because of the basic feature set of MCZ33812, some additional analog functions have been implemented with discrete components. On this board is also mounted a stepper motor driver for the idle speed management, a VRS conditioning circuit and an O2 sensor heater driver. Some examples of software code and device drivers are provided, with the hardware.

The signals available on the Reference Design's connectors are the following:
Input signals:

1. VSRP - Variable Reluctance Sensor Positive
2. VRSN - Variable Reluctance Sensor Negative
3. MAP - Manifold Air Pressure Sensor
4. TPS - Throttle Position Sensor
5. ATEMP - Outside Air Temperature Sensor
6. ETEMP - Engine Temperature Sensor
7. O2IN - Oxygen Sensor
8. OPSR - Oil Pressure Sensor
9. ENGSTOP " Engine shutoff Switch
10. TILSW " Signal indicating that the engine is in a safe orientation to run.

Output signals:

1. TPMD - Throttle Position Stepper Motor output D
2. TPMC - Throttle Position Stepper Motor output C
3. TPMB - Throttle Position Stepper Motor output B
4. TPMA - Throttle Position Stepper Motor output A
5. INJOUT - Injector LS Driver output
6. COIL - Ignition Coil LS Driver output
7. +5V - Voltage supply output
8. LAMPOUT - Malfunction Lamp LS Driver output

9. ROUT1 - Relay LS Driver output 1

10. ROUT2 - Relay LS Driver output 2

11. O2HOUT - O2 Sensor Heater LS Driver output

The remaining connections are:

1. VBAT - 12 Volt Battery Positive input

2. GND - 12 Volt Battery Negative input

3. ISO9141 " Diagnostic Input/Output

4. GND " 4 additional ground connections

Included in the Reference Design kit is the circuit board with cables and connectors, a BDM programming module, a DVD with the Code warrior development software, and an actual working software example with complete source code and documentation that can be used to run a small engine. The Reference Design comes complete with everything needed to run an actual one or two cylinder engine and to begin developing the engine "calibration" tables necessary to increase efficiency and reduce emissions.

CONCLUSION

The time to convert small gasoline powered engines from mechanical to electronic control is upon us. The legislation to reduce pollution and increase efficiency is being enacted by governments worldwide.

In order to reduce the size and cost of the ECU, the integration of most discrete components will be necessary. Freescale has, once again, taken the lead by providing the first ASSP to integrate a large portion of the analog functions into a single chip. It has also provided a Reference Design to give ECU designers a major first step, up the learning curve, to help them meet the new requirements and enable small gasoline engines to become "Green".

The first IC to integrate analog functions for these small engine ECUs available from Freescale has been presented.
DEFINITIONS, ACRONYMS, ABBREVIATIONS

ASIC: Application Specific Integrated Circuit

ASSP: Application Specific Standard Product

CDI: Capacitive Discharge Ignition

CPU: Central processing Unit

ECU: Engine Control Unit

IC: Integrated Circuit

IGBT: Insulated Gate Bipolar Transistor

I/O: Input/Output

MCU: Microcontroller Unit (Microcomputer)

VRS: Variable Reluctance Sensor.

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