Automotive Electronics: Computerized Engine Control

Haunted by the twin specters of public concern over, and federal regulation of, fuel economy and automotive emissions, automobile makers have been taking a hard look at the use of microelectronics technology for precise control of the internal combustion engine. For the 1977 model year, two of the Big Three car manufacturers are offering (and the third soon will offer) vehicles equipped with engines that are partially electronically controlled. By and large, however, the prospect of the computerized car, interest in which has been heightened by the advent of the microcomputer, still lies some time in the 1980's.

When Congress passed the Clean Air Act of 1970 with its gradually tightening restrictions on vehicle emissions, Detroit first faced the prospect of having to design its engines to satisfy a fixed schedule of federal performance standards. Although the early approaches did substantially reduce tailpipe emissions, the tactics also had the unfortunate side effects of decreasing fuel economy and drivability. Beginning in 1975, the use of catalytic converters further reduced emissions and at the same time restored engine performance.

But in December 1975, Congress passed the Energy Policy and Conservation Act. Beginning in 1978, the law mandates certain minimum fuel economies, as determined by averages over all the vehicles produced by a given manufacturer, culminating in a minimum fuel economy of 27.5 miles per gallon by 1985. The present statutory standards for the 1978 model year for both fuel economy (18 miles per gallon) and tailpipe emissions seem to require the precise control of engine parameters that only electronics can provide, although the schedule set by law will apparently not be met. Auto makers say that systems advanced enough to meet these standards are still in the research stage.

By now electronics is no stranger to the automobile. According to a recent speech by Trevor Jones, director of the General Motors proving grounds, there are 15 electronic subsystems available as standard or optional items on current cars and trucks, exclusive of the late, but unlamented, seat belt interlock. In a few vehicles, the electronics can account for more than 10 percent of the total cost. And Ford Motor Company president Lee Iacocca has pointed out that Detroit is already spending about $150 million on electronics this year.

The advantages of using electronics to control the engine combustion include precision, sophistication, and flexibility. One example is the problem of determining when to ignite the air-fuel mixture in the cylinder to obtain the best engine performance. Until recently this determination was made by mechanical devices that respond to only two variables (engine speed and intake manifold vacuum).

But the optimum time to fire the spark is a function of many more variables, including temperature, and varies with the settings of other parts of the engine, such as the air-fuel ratio in the carburetor. For example, the annoying hesitation in some recent model cars when accelerating occurs because the mechanical system is not sophisticated enough to know it should be changing the spark timing.

An electronic system has the capabilities of taking into account as many variables as needed (subject to the cost and feasibility of sensors to measure them) and making hundreds of calculations each second. Such systems generally consist of several sensors to measure the values of various parameters and convert them into electrical signals, a circuit to compute a control signal from the sensors' inputs, and actuators to carry out the instructions of the control unit.

Electronic Spark Timing

In the midst of the 1976 model year, for example, the Chrysler Corporation introduced an electronic spark timing control, as part of their Lean Burn system, which senses eight variables before computing the best time for spark firing. Appearing as a no-cost option on a 400-cubic-inch V-8 engine last year, the Lean Burn is now available on a much wider variety of engines. Up to 400,000 Lean Burn–equipped automobiles may be sold this model year, according to Earl Meyer, chief engineer at Chrysler.

The variables sensed include the ambient air temperature, engine coolant temperature, manifold vacuum, engine speed, throttle position, and rate of change of the throttle position. The control circuit comprises two modules containing a total of about 200 electronic components mounted in an air-cooled plastic box on the air cleaner. The first module calculates when combustion should begin to achieve the best balance of power, fuel economy, and emissions. The circuit is essentially a small analog computer, but it cannot be reprogrammed without physically reconnecting its components. The second module receives instructions from the analog computer and, using these, actuates firing of the spark plugs.

The air-fuel ratio is maintained by a conventional carburetor at a value of about 18 : 1. Since many automobile engines run on an air-fuel ratio of about 16 : 1, Chrysler's mixture is said to be lean, from which the name of the system follows. Operation at the 18 : 1 ratio has resulted in about a 5 percent increase in fuel economy, but the biggest gain has been in reducing the amount of emissions. Originally, Chrysler had hoped to eliminate catalytic converters with the use of the Lean Burn–equipped engines, but the 1977 emission standards are enough tougher than those of 1976 not to allow this luxury at present. Exhaust gas recirculation, one of the early techniques for lowering emissions of oxides of nitrogen, has been eliminated, however, and the engine compartment is much less cluttered than previously.

Futuristic speculation about the computerized car has centered on the progressively increasing sophistication and decreasing cost of the microprocessor, the integrated circuit that serves as the central processor unit of a digital microcomputer. Automotive engineers have insisted, however, that these glamor devices of the microelectronics world are still too expensive for widespread use in automobiles. Inexpensive sensors and actuators that are rugged enough to withstand the extremes in temperature, the vibration, and the harsh chemical environment of the auto engine remain an even greater problem, because development of these devices has lagged behind that of microprocessors.

Microprocessors do, however, offer the flexibility of being able to rapidly alter the control system to respond to additional variables or to control additional functions simply by changing the program. While separate, analog control systems could be designed to handle each job, the cost would rapidly mount. Since one central control unit based on a microcomputer can control several functions, automotive engineers foresee widespread use of these devices in the coming years when such multifunction control becomes needed.

The Oldsmobile Division of General Motors has already announced that it is using a digital microcomputer to control spark timing in its 1977 Toronado. Termed MISAR (microprocessed sensing and automatic regulation), the microcomputer-controlled system will be standard, but since only about 12,000 of the relatively expensive Toronados are sold each year, MISAR must be considered much more of a limited-volume trial to gain field experience than the Chrysler Lean Burn.

The GM microcomputer comprises two integrated circuit chips: a microprocessor and a 10,240-bit read-only memory that contains the instructions that operate the computer and a table of 350 data points. The computer compares information received from sensors measuring manifold vacuum, engine coolant temperature, engine speed, and crankshaft position with the data in the table before computing the proper instant for ignition. The spark timing is recalculated 100 times each second. The computer can also interpolate between data points of the table. The microcomputer was essentially custom designed for the automobile application by the Microelectronic Product Division of Rockwell International and thus differs in some respects from more conventional devices. For example, it has a 10-bit word length as compared to the more usual 4-, 8-, or 16-bit word lengths.

Results of test runs with MISAR-equipped Toronados indicate about a 9 percent improvement in fuel economy (15 versus 13.8 miles per gallon) as compared with an otherwise identical noncomputerized car. General Motors officials emphasize, however, that in their view the real significance of MISAR is in the fact of putting a microcomputer in an automobile with the concomitant options of expanding its capabilities to control other engine functions in the future. In a recent speech, GM president Elliott Estes discussed an electronically controlled antiknock system that would enable a car engine to operate on the border line between maximum fuel economy and the onset of knocking.

Last month, Ford announced that it was working on a different way to use electronics to control engine fuel economy and emissions, which it would make available on certain light trucks some time this year or next. Called a dual displacement engine, the truck's engine is electronically activated to run on only three of its six cylinders at times when the torque available from three cylinders is adequate, which is a substantial fraction of the time.

Sensors measure the engine temperature, the manifold vacuum, the throttle position, and what gear the transmission is in, and relay this information to an analog computer. For example, if the truck is cruising at 45 miles per hour or less, or is decelerating, the computer signals electromechanical devices (solenoids) on three of the cylinders to hold the cylinders' valves closed, thus preventing them from operating.

Since the three operating cylinders have to work twice as hard to carry the load of six, fuel savings are far less than 50 percent, the naively expected value. In actual tests, fuel economy improvements have been about 10 percent and occur because, up to a point at least, the efficiency of a cylinder increases somewhat as its work load grows larger. Ford has also tested an eight-cylinder dual displacement engine on passenger cars, but has not committed itself to produce these on a commercial scale. Problems said to be still unsolved include a rough idle in three-cylinder operation, a somewhat too noticeable shift from six to three cylinders, and an increased emission of oxides of nitrogen.

All of the control systems so far described are called open loop systems. Control action is obtained from a preprogrammed function of several variables. However, to meet the increasingly stringent fuel economy and tailpipe emissions standards with electronics, automotive engineers are examining closed loop systems—that is, systems in which some parameter of the actual performance of the car is fed back to the control circuit, which can then alter its control signal in the direction needed to obtain the optimal output.

Closed Loop Feedback Control

The most likely first application of electronic feedback control will be in adjusting the air-fuel ratio to provide a constant mixture of gases in the exhaust. The motivation for this application is that all of the Big Three are considering the use of a new kind of catalyst called a three-way catalyst, possibly as early as later this model year. Present catalytic converters reduce carbon monoxide and hydrocarbons only; oxides of nitrogen are limited by preventing their formation. The three-way catalyst will handle all three pollutants, but only under conditions of a stable exhaust gas composition.

This spring, for example, the Holley Carburetor Division of Colt Industries announced plans to produce an electronically controlled carburetor for closed loop fuel metering. The Holley announcement indicated the carburetor will appear as original equipment on one or more unnamed 1978 model vehicles in the United States.

The Holley feedback system uses a modified carburetor of the type currently found in production cars and trucks. An oxygen sensor located just in front of the catalytic converter sends a signal to an analog circuit. Depending on the oxygen partial pressure, the electronic control unit activates a vacuum control valve, which can either increase or decrease the air-fuel ratio in the carburetor as needed. Preliminary tests conducted by Holley have shown large reductions in all three types of emissions, although apparently not enough to meet the 1978 standards. Improvements in fuel economy were also obtained under some conditions.

Feedback fuel monitoring can also be used in conjunction with electronically controlled fuel injection. Fuel injection is a venerable technique that grew up with the diesel engine. In the electronic version, as applied to the spark-fired internal combustion engine, sensors monitor the manifold vacuum, throttle position, engine coolant temperature, intake air temperature, and engine speed. An analog computer or electronic control unit computes the desired air-fuel ratio for best engine performance and sends signals to fuel injectors at each cylinder.

In the United States, a system such as this designed by the Bendix Corporation's Electronics and Engine Control Systems Group has been an optional item on most Cadillac models since 1975. Electronic fuel injection's major drawback is its expense, adding about $700 to the price of a Cadillac. The major advantage is that the same precisely determined air-fuel mixture goes to each cylinder, whereas with a carburetor, each cylinder may receive a slightly different mixture. The fuel-injected engine thus runs better on the lean air-fuel mixtures used for emissions control.

Volvo and Saab have announced that they will sell cars equipped with three-way catalysts and feedback-controlled fuel injection in California this year. Tests by the Environmental Protection Agency have shown that these cars can meet the 1978 emissions standards when averaged over 50,000 miles. Only a few thousand of the cars will be made, however, and they will be expensive. Moreover, the catalyst uses large amounts of rhodium, a metal that, at least at present, is not produced in sufficient quantity to supply the U.S. automobile market for even 1 year.

Most auto makers are still in the stage of demonstrating that electronic engine controls can help meet fuel and emissions standards in low-volume applications. The next step, which may be taken before the end of the decade, is integrating several engine control functions, such as spark timing, air-fuel ratio, and (if needed) exhaust gas recirculation. Thus, the appearance of the fully computerized car, such as GM's experimental Alpha V, which has 34 automotive functions under the control of a central microcomputer, is far in the future, and the age of the microcomputer is just beginning.—ARTHUR L. ROBINSON