A MICROCOMPUTER EMISSIONS CONTROL SYSTEM

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ABSTRACT

A single chip microcomputer system has been developed to control and protect three-way catalyst equipped 6 cylinder vehicles. The system incorporates a carburetor mounted stepper motor actuator, secondary air control and self-diagnostics. A unique scheme has been used to sense various engine modes which does not require an analog to digital converter.

This paper presents a description of these features, a brief outline of present program strategy and future development considerations.

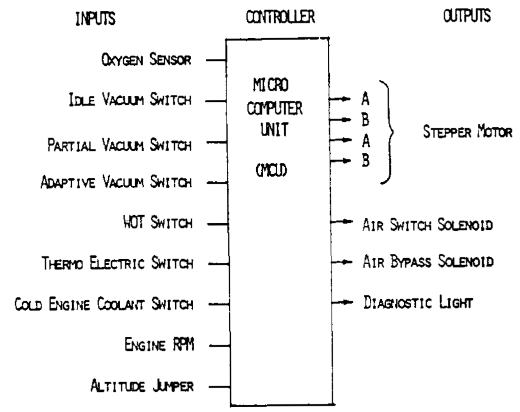

Fig. 2 Fuel Feedback System Schematic

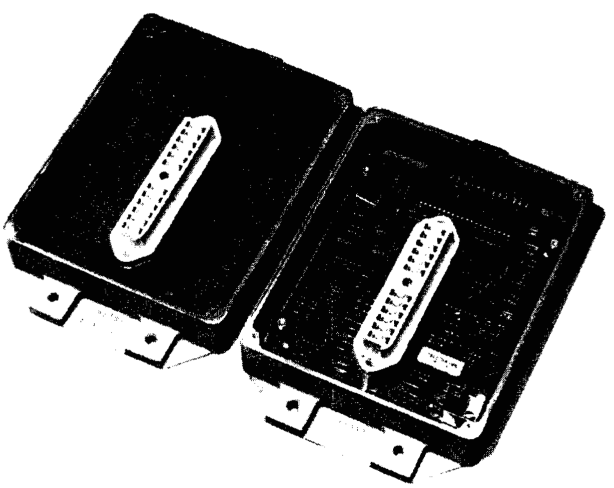

Fig. 1 Microcomputer Control Unit (MCU)

AMERICAN MOTORS USAGE of electronics is unique from other American automobile manufacturers because AMC does not manufacture electronic components but does have a requirement for high technology state-of-the-art systems. Specifically, in the area of engine-related electronic controls systems, the systems which are released for production must have demonstrated advantages over conventional mechanical systems in their ability to meet emissions, fuel economy and driveability objectives. AMC usage of electronic hardware currently in production or concurrently being developed for other manufacturers has several advantages. These include: (1) cost savings that occur from using available capacity from high volume tooling; (2) high reliability components with 100% automated supplier final inspection; (3) reduced assembly plant component testing and (4) confidence in the systems application without extensive prior year pilot programs.

A development program which exemplifies a typical AMC application is the 1981 microcomputer emission control system for 6 cylinder nationwide passenger car and California 4-wheel-drive vehicles. This system utilizes a closed-loop control of the carburetor's air/fuel mixture to maintain stoichiometric conditions for optimum three-way catalyst performance and durability.

SYSTEM COMPONENTS

The 1981 fuel feedback (FFB) system components can be subdivided into three categories: the controller, system inputs and system outputs.

Controller

The controller (Fig. 1) is a purchased microcomputer unit (MCU) containing a program developed by AMC. The MCU determines various engine operating modes through eight digital input circuits as shown in Fig. 2. The inputs monitor engine functions including exhaust air/fuel (A/F) mixture, engine rpm, throttle location, manifold and ported vacuum, engine coolant, and carburetor air temperature. The input circuits are switch sensing devices which determine the open or closed state of external switches.

The program strategy allows the MCU to use the input information to make logical decisions with regard to the engine state. The decisions are transmitted to the eight output ports which are capable of varying carburetor A/F mixture and controlling secondary air. The output circuitry includes two quad driver devices, containing four switching transistors capable of sinking up to 200 ma each. Presently, AMC is using seven of the eight available outputs.

The microcomputer unit construction is rugged and capable of withstanding underhood environment. The circuitry, housed in a cast metal case, is tested at -40°F and 230°F. A successfully tested unit is then covered with sand and potting material for protection. This rugged construction and testing is designed to insure that the MCU will survive in the harshest vehicle environment, such as the Jeep underhood mounting application.

System Inputs

The MCU receives input information from a number of sensors located in the engine compartment. The following paragraphs describe the components used to provide this information to the MCU.

The most critical input sensor for the closed loop system is the oxygen sensor. The sensor is a hollow cone shaped zirconia ceramic covered with a platinum electrode on both sides. The overall effect of the plating is to create an electrochemical cell that develops a potential difference between the electrodes. The sensor's output voltage is a logarithmic function of the partial pressures of oxygen on either side of the cell wall. One side of the cell is exposed to exhaust gas and the other to atmospheric air. When the engine is operating in a lean mode, the exhaust gas oxygen increases and the partial pressures of oxygen on both sides of the ceramic are almost equal, causing the sensor's output voltage to be near zero volts. As the exhaust gas is enriched, it passes stoichiometry (14.6 A/F), which is the ideal burn point. Just beyond stoichiometry, a dramatic increase of oxides occurs, (like CO and hydrogren) which increases the pressure differential across the electrolyte, causing a voltage to be generated (approximately 1 volt).

The oxygen sensor's purpose is to monitor the exhaust gas mixture and to give the MCU accurate information on the status of the exhaust gas content while the vehicle is operating. This allows the MCU to vary the A/F mixture around stoichiometry thus increasing catalyst efficiency, prolonging catalyst life as well as offering improved fuel economy. In order that this cycle be carried out with maximum efficiency, the oxygen sensor has been placed in a position, in the exhaust manifold, where it can quickly respond to exhaust changes with minimal lag time. (See Fig. 3).

Additional information is provided to the MCU by a vacuum switch assembly (Fig. 4) which is mounted in the engine compartment. The three switches - idle, partial throttle and adaptive - detect different levels of manifold or ported vacuum. Each vacuum switch contains a conventional single-pole, double-throw microswitch that is actuated by an adjustable vacuum diaphragm.

To detect wide-open-throttle (WOT), a mechanical limit switch (WOT switch in Fig. 8) is placed on the carburetor. The single-pole, double-throw switch is actuated by a cam connected to the carburetor throttle shaft when the throttle approaches WOT.

The MCU also uses two sensors to detect vehicle operating temperatures. The first is a small round snap disk switch located in the air cleaner called the thermo-electric switch (See Fig. 5). This switch is activated when the air to the carburetor is below 55°F. This signal is used by the MCU to provide a slightly richer mixture to produce better cold driveability.

To sense cold engine coolant, a cantilever design temperature switch (Fig. 6) is used. The switch contains two independent sets of contacts that change state at about 160°F. One set provides a normally open input for the MCU, and the other normally closed set actuates a manifold heater system. Two other inputs used by the MCU are: engine rpm which is determined by a signal provided from the primary of the ignition coil; and an altitude jumper which is used to implement special programming to compensate for usage at higher altitudes.

The input switches are connected as shown in Fig. 7. This arrangement requires only six of the MCU inputs to obtain the information of eight switches. (the rpm and oxygen sensor are read continuously and are not shown in the input switch hierarchy.) The binary information provided by this arrangement is interpretted by the MCU as shown in Table 1. Only the modes shown in the table are acceptable. The end-of-line diagnostic and MCU manufacturer's test require forcing the inputs to be in this mode and cannot occur during normal vehicle operation. Other switch combin-

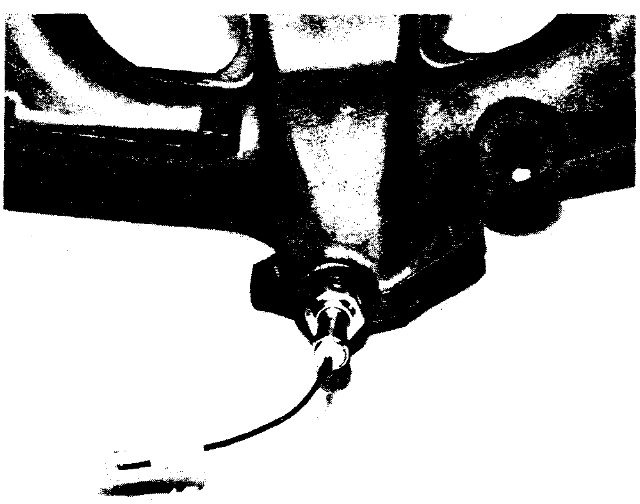

Fig. 3 Oxygen Sensor in Exhaust Manifold Location

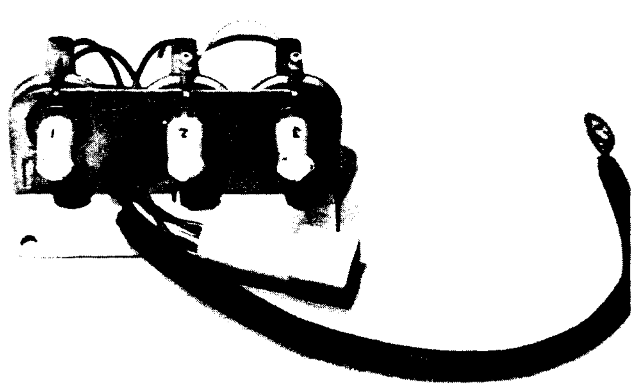

Fig. 4 Vacuum Switch Assembly

ations that are not in the table and cannot occur in normal vehicle operation are not used to trigger diagnostic codes. This strategy will be explained later.

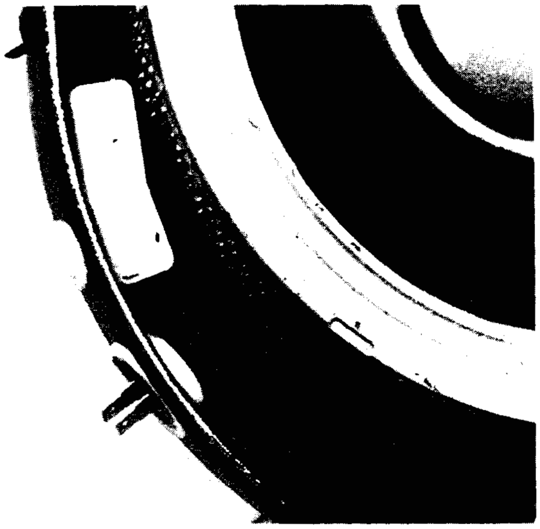

Fig. 5 Thermo-Electric Switch (TES) in Air Cleaner Location

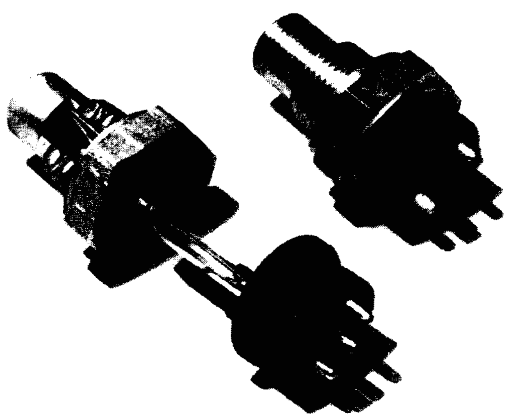

Fig. 6 Temperature Switch With Cutaway View

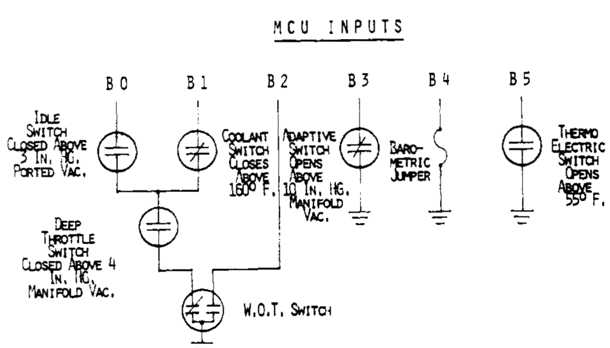

Fig. 7 Input Switch Hierarchy

System Outputs

The FFB system has three different types of outputs all actuated from two quad drivers which are directly interfaced to the microcomputer chip. The outputs are: (1) stepper motor for air/fuel control (four outputs); (2) vacuum switch solenoids for air management control (two outputs); and (3) a light for diagnostics (one output).

The stepper motor (Fig. 8) has a permanent magnet rotor and a 4-phase stator consisting of two bifilar (parallel) wound coils and 24 poles. The stator coils are center tapped and half of each coil is always energized. Application of a specific sequence of pulses to the stator winding (Fig. 9) extends or retracts a worm screw producing linear motion.

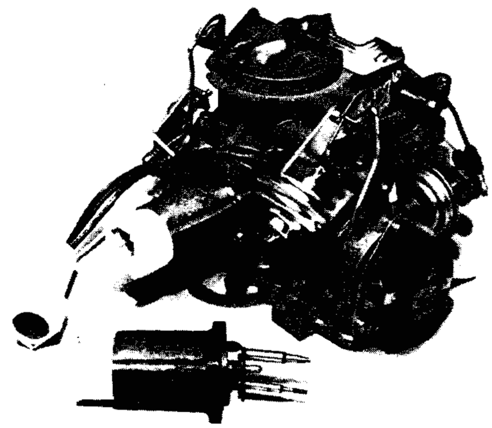

Fig. 8 Stepper Motor, WOT Switch And Carburetor Assembly

MOTOR PHASING SEQUENCE											INCHES TRAVELLED TOWARD MAXIMUM SHAFT EXTENSION
EXTEND						RETRACT					
STEP	TERMINAL					STEP	TERMINAL				
	4/A	3/B	2/A'	1/B'			4/A	3/B	2/A'	1/B	
1	G	G	-	-		1	-	-	G	G	.004
2	-	G	G	-		2	-	G	G	-	.008
3	-	-	G	G		3	G	G	-	-	.012
4	G	-	-	G		4	G	-	-	G	.016
5	G	G	-	-		5	-	-	G	G	.020

G INDICATES GROUND - TERMINALS ARE ELECTRONICALLY GROUNDED BY CONTROL UNIT.

Fig. 9 Stepper Motor Phasing Sequence

This linear motion is applied to two tapered pins that control air bleeds in an otherwise conventional carburetor. A total of 100 steps of .004 inch increments are possible. As calibrated, the stepper motor has a four air-fuel ratio range of authority.

Two vacuum switching solenoids (air switch and air by-pass, Fig. 10) are used to control secondary air injection in the exhaust system. As such, they have major authority over the emission system. When the air switch routes air upstream, the catalyst system functions entirely as an oxidizing system. In that mode, the oxygen sensor cannot be meaningfully interrogated, so the

Air/Fuel control is placed in an open loop mode. Similarly, in that mode, reduction cannot occur in the catalyst system, so NO_x control results from relatively rich A/F metering and EGR addition.

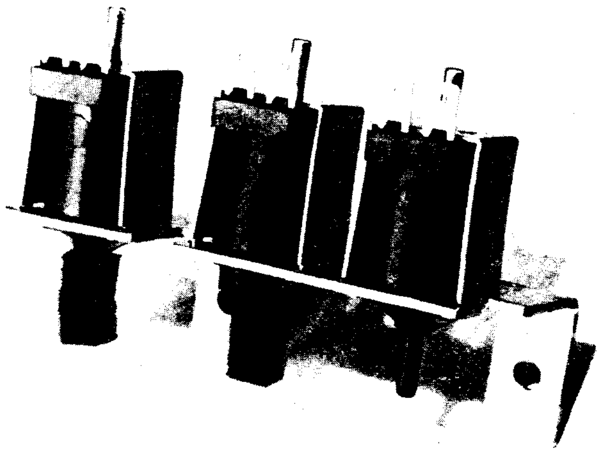

Fig. 10 Vacuum Switch Solenoids

When the air switch routes the secondary air to the mid-bed of the catalyst, the front bed of the catalyst can function as a three-way while the rear bed serves as the clean-up oxidizer. In this mode, the oxygen sensor is read and the A/F is continually cycled back-and-forth about stoichiometry to maintain three-way activity in the front bed of the catalyst.

The mixture of closed-loop three-way operation and open-loop oxidizing operation is a calibration tool available to match the emissions system performance to the particular needs of the engine, carburetor, vehicle and emission standards under consideration.

The by-pass function mentioned above is available to divert secondary air to atmosphere. In selected critical modes, the air is dumped to atmosphere as a catalyst over-temperature protection step.

The diagnostic light is used to indicate system functioning at start up, to indicate a detected error to driver and service technician during usage and to indicate assembly problems for manufacturing quality control.

STRATEGY

The microcomputer unit (MCU) that AMC is using controls a number of vehicle functions, including air/fuel ratio, vehicle and system diagnostics, and secondary air. At the heart of the controller is an 8049 single chip microcomputer. This computer chip possesses 2048 words of read only memory which contains the program of strategy. In addition to the read only memory, there are 128 words of read/write memory which are used to hold data constants that are modified during operation. The 8049 contains 27 input/output lines used for communication purposes between the computer and the outside world. Some of these lines leave the controller and supply input data or drive actuators in the system being controlled. The remaining lines terminate at "jumpers" which are used to invoke various calibration values placed in the basic programming. Thus, the MCU is a universal device which can be calibrated for various vehicle and emission requirements. Each jumper configuration receives a different part number for the controller and specifies vehicle type, i.e., manual or automatic transmission.

To accomplish its goal of controlling vehicle and system performance, the computer's program must respond to real time inputs. These inputs monitor the vehicle's current mode of operation and allow the strategy to determine the proper course of action. To accomplish this end, the program is divided into two portions: the background and real time interrupt.

Every 1.28 ms the real time portion is enabled using the microcomputer's clock. The real time program scans the various inputs and determines the vehicle's current mode of operation (cruise, WOT, idle, decel, diagnostic, etc.) and stores it in read/write memory for the background program's use.

In addition to these inputs, the oxygen sensor's output is read and filtered. During this time, various timers used by the background are also updated. When the real time program is completed, the condition of the vehicle is stored in memory. During the background portion of the strategy, which runs whenever the real time portion is inactive, the proper course of action is determined and instituted. It is in the background program that the diagnostic tests are performed, the air/fuel ratio modified and secondary air routed to its proper destination. Greater detail on these operations appear later in the paper.

Using the switch hierarchy inputted during the real time program, the background program determines the vehicle's operating requirement and institutes the proper action. Of the total 10 input codes, 8 refer to normal vehicle driving situations, and 2 refer to vehicle diagnostics. The following paragraphs describe these two situations more fully.

Normal Drive Mode

When the vehicle is in the normal drive mode of operation, the strategy will be controlling air/fuel mixture, secondary air switching, and continuous vehicle diagnostic. The air/fuel mixture is modified according to three different algorithms as a function of the vehicle's operating mode as determined by the switches. The three modes and a brief description are:

Absolute Open Loop - The stepper motor is placed at a fixed position irrespective of the vehicle's current or past operating conditions. The position used is determined during vehicle development using quantitative testing and analysis. Typically this mode is enabled on a cold engine.

Closed Loop - The stepper motor is moved to give a stoichiometric air/fuel mixture. This is accomplished by reading and filtering the oxygen sensor signal and then continually moving the stepper motor to maintain a stoichiometric mixture. Typical operating modes include acceleration modes, deceleration modes, and cruise modes.

Compensated Open Loop - The stepper motor is placed at a position that is determined by the vehicle's prior operation. Typically the position is a constant amount rich of the most recent stoichiometric position. This mode is available during WOT operation to provide controlled power enrichment.

Along with fuel control, the vehicle's mode of operation as determined by the switch hierarchy controls secondary air switching. The normal mode of operation is to supply air downstream to the clean-up oxidizing catalyst. During certain conditions which produce high HC or CO levels, and during certain start up conditions, air is sent "upstream" to the exhaust ports so that the front or three-way catalyst also functions as an oxidizing catalyst. When the system determines that secondary air may be harmful to the catalyst, the air is diverted to atmosphere.

Diagnostics

Three different types of diagnostics are currently being implemented. Two types can be invoked by the "switch hierarchy" to aid manufacturing or service personnel. The third diagnostic operates continually during normal vehicle operation. A brief description follows:

MCU Manufacturer's Test is invoked when the module sees a specific code on the input lines (Table 1) that could not occur during normal vehicle operation. During the test, the MCU's input and output lines are connected to an external minicomputer for testing and monitoring purposes. The minicomputer issues a command which causes the MCU to perform some given function. This function is monitored by the external minicomputer and compared to the expected result. If the results agree, this portion of the test is recorded as a pass and a new test portion is instituted. Utilizing this procedure, the manufacturer verifies the integrity of the MCU. MCU's that fail any of the sub-tests can then be identified and rejected. This diagnostic only tests the MCU and is performed at point of MCU manufacture.

End-of-Line Diagnostic can be invoked by impressing a special code on the input lines. The diagnostic is used normally on a total vehicle and attempts to find any problems within the feedback system. During the test, the operator follows a vehicle drive sequence which has been pre-defined. During the drive, the program monitors the status of the inputs and looks for proper sequence. In addition, the program engages certain outputs and looks for the proper effect on an input. An example would be to move the stepper motor to the full rich position and look for a rich oxygen sensor signal. This would be an indication that the stepper motor and oxygen sensor were working properly.

TABLE 1 TRUTH TABLE FOR INPUT LOGIC

B0	B1	B2	B3	B4	B5	
0	0	0	X	X	X	End of line diagnostic feature
0	0	1	1	X	1	Idle circuit (close loop 1)
0	0	1	0	X	1	Main circuit (close loop 2)
0	1	0	0	0	0	MCU manufacturer's test routine
0	1	1	X	X	1	Cold Engine (OL1)
1	1	1	1	X	1	Cold Engine Idle
1	0	1	1	X	1	Idle/Decel Mode (OL3)
1	1	0	0	X	1	Mechanical W.O.T.
1	1	1	0	X	1	Deep Throttle (0L4)
X	X	X	X	X	0	Cold Air

Note: B4 inplements strategy changes but does not influence drive modes.

Key

0 - Closed circuit
1 - Open Circuit
X - Don't care

Continuous Vehicle Diagnostics are performed on the feedback system whenever the vehicle is operating in its normal driving mode. This testing is referred to as continuous vehicle diagnostics. Whenever the vehicle is operating, the strategy looks for abnormal or improbable events on the input lines. Such an abnormality indicates a failure in one or more of the feedback system components and displays it to the driver via a flashing light on the instrument panel. The flashing code displayed is intended to lead service personnel to a given area of the feedback system for analysis. Typical abnormal events might include: cold coolant temperature for more than 20 minutes, throttle switch indicating wide open throttle while manifold vacuum is at high level, lack of oxygen sensor transitions, etc. While these tests would not check every component, they should find a majority of problems.

FUTURE DEVELOPMENT CONSIDERATIONS

The single chip microcomputer in the FFB system has the capability of being applied to perform other control functions in addition to the current A/F and secondary air control. Areas under consideration at AMC are:

Idle speed control
- Open loop (with a 3-position actuator)
- Closed loop (with a DC servo motor).

Transmission Lock-up control

Altitude compensation of A/F, secondary air, spark advance

Spark control
- Open loop (programmed advance/retard about a conventional spark curve based on table look-up values and engine operating conditions)
- Closed loop (about a conventional spark curve based on the presence or absence of knock as sensed by an engine mounted accelerometer)

PCV Control

EGR Control

Intake manifold heater control

Philosophically, automotive engineers tend to also add the following usages to such a list:

Fuel shut-off during decels

Variable displacement control

Transmission shift schedule control (auto. trans.)

Cruise Command control

Such a list clearly demonstrates that the application of on-board computers in the name of emissions/fuel economy/driveability is not suffering from lack of potential usages. On-board computers are, however, limited by the availability of memory space and input-output lines at a cost effective price.

Idle Speed Control

A stand-alone electronic control unit was developed for idle speed control of 1981 6 cylinder engines because of software timing considerations.

The system (Fig. 11) consists of a carburetor-mounted 3-position actuator, vacuum solenoid, carburetor air temperature switch, idle control unit and four voltage inputs. The system allows a 100 rpm reduction in the basic idle setting over previous model years, with a resulting gain of 0.5 mpg. When the manifold heater, air conditioning system or heated backlight are on, the actuator provides a second, higher rpm to prevent excessive idle discharge of the battery. If the carburetor air temperature is particularly cold, or if engine speed drops below a set rpm, the actuator increases the rpm to a third highest setting. When low rpm triggers a speed step-up, a single occurrence causes a 1.0 second step-up while a second occurrence latches at the higher rpm. Exceeding an upper set point resets the control circuit.

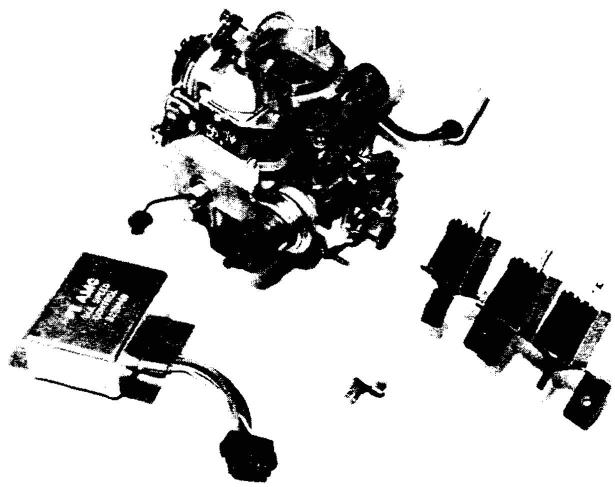

Fig. 11 Idle Speed System Components

A microcomputer has been programmed to replace the stand-alone control system. The temperature and rpm are already inputs of the 1981 system, so no additional input lines are required. However, one additional output would be required to actuate the vacuum solenoid. A separate diode trio can be used to provide the intermediate speed step-up for battery discharge protection. This approach would yield a more cost effective method than the stand-alone electronic module.

Manifold Heater Control

The system of Fig. 12 is used in 1981 6 cylinder engines to provide supplemental heat to the intake manifold during cold vehicle operation for early fuel evaporation (EFE). The microcomputer can be programmed to power the relay directly using only 1 additional output instead of using the existing external switching means. The combined function switch could then be replaced by a single function temperature switch since the same temperature switch point is already an input to the microcomputer.

Transmission Lock-up Control

A microcomputer has been programmed to inhibit the lock-up of a lock-up torque converter transmission under conditions where lock-up may not be desirable. Existing microcomputer inputs allow sufficient interpretation of vehicle conditions to optimize the use of the lock-up function and only 1 output would be required for this function.

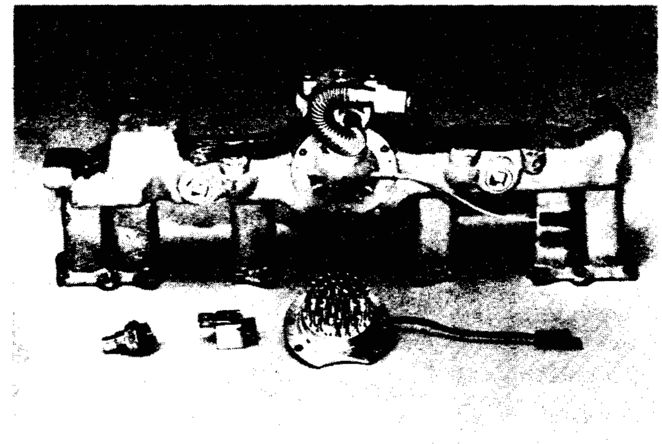

Fig. 12 Early Fuel Evaporation (EFE) System

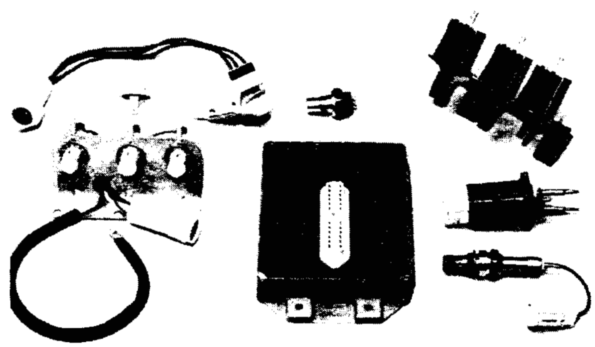

Fig. 13 1981 Fuel Feedback (FFB) System

Knock Control (Closed Loop Spark Control)

Hardware modifications have been made to the microcomputer to allow processing of the output signal from a piezoelectric knock sensor. The addition of an output which interfaces the microcomputer to an ignition control unit allows the microcomputer to perform spark retard under conditions when spark knock is present.

Positive Crankcase Vent PCV Shut-Off

The microcomputer has been programmed to control a specially designed PCV solenoid. This reduces PCV flow at idle, creating a more stable idle quality. This type of control was found to be necessary when lower idle settings are used.

Electronic Advance/Retard (Open Loop Spark Control)

The microcomputer can be programmed to provide limited control over spark timing without requiring a knock sensor input. Existing vehicle inputs and possibly the addition of an over temperature switch or barometric switch can be used to make step modifications to the vehicle's advance curve. This approach may allow adequate control for certain applications and represent a significant cost saving over other options.

Other Electronic Systems

AMC's usage of a microcomputer has expanded from a 5 input/4 output system requiring 1K of memory in 1980 to a 7 input/7 output system requiring 2K of memory in 1981. Future expansion of the usage of the microcomputer is currently software limited by the unavailability of microcomputers with 2K and larger EPROM's as well as 4K and larger MROMS. EPROM availability is essential to cope with the long turnaround time for a masked program for production start-up while continuing to develop strategy. In the absence of 2K EPROM microcomputers, emulators have been used for development purposes. However, this is not desirable for future programs. To a lesser extent, hardware limitations occur due to the limited number of accessible I/O lines from the microcomputer

To obtain features that cannot be incorporated into the existing microcomputer system because of these limitations, stand-alone electronics systems are being pursued. Some of the previous functions can continue to be obtained separate from the microcomputer. Other applications that may necessitate new electronic usage include a combined idle and knock control, and single point throttle body fuel injection.

SUMMARY

AMC's 1981 6 cylinder fuel feedback (FFB) system has been derived from the development program described here. The system, which is shown in Fig. 13, has demonstrated durability over extended mileage while maintaining conformance to statutory emission levels of 0.41 HC, 3.4 CO, and 1.5 NO_x. Current plans call for this same system to be used for statutory NO_x levels of 1.0 gpm. Thus, such a system has a relatively long life expectancy in passenger cars and trucks certified to the Federal Emissions Standards.

This system's viability at NO_x levels of 0.7 and 0.4 gpm has yet to be demonstrated. However, the real challenge for this type of controller is in the fuel economy and driveability domains.

The fuel economy standards which currently exist are a monumental engineering challenge. The challenge becomes particularly monumental when an automobile manufacturer attempts to market vehicles which have been downsized in weight and package size without sacrificing comfort, luxury, safety, and utility. Success with this engineering challenge will come from making the most of the laws of physics. Specifically, success will come from controlling the engine to its most efficient state at all times.

Existing microcomputer systems are already allowing the emissions engineer to more thoroughly control the engine's metabolism. However, there are many more areas which still merit electronic control. Unfortunately, the control of these other areas is not limited by the emissions engineers' ingenuity but by the electronics themselves. The specific realities which hamper the expansion of microcomputer control of the engine and powertrain are:

- Limited ROM size (i.e., 1K, 2K, 4K ROM microcomputers are memory limited)
- Lack of EPROM for development work
- Extremely long lead times for production MROM units (i.e., 40+ weeks)
- Limited mathematical operators which can be used in programming
- Immunity to the automotive environment
- Piece cost

Timely responses to these limitations will insure further expansion of on-board computer usage.

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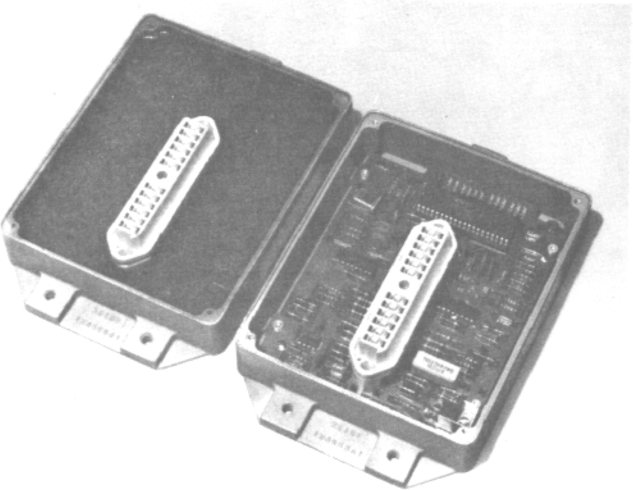

Fig. 1 Microcomputer Control Unit (MCU)

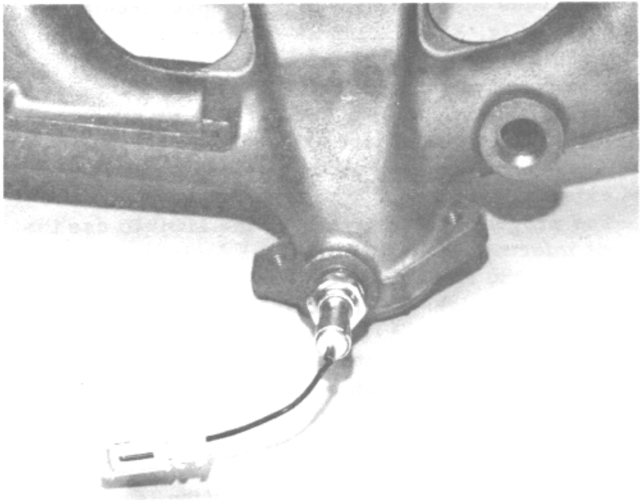

Fig. 3 Oxygen Sensor in Exhaust Manifold Location

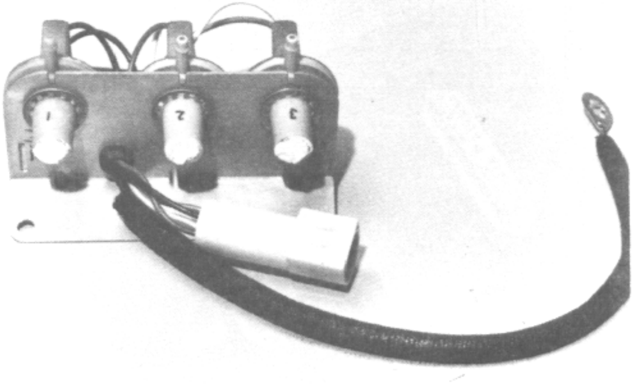

Fig. 4 Vacuum Switch Assembly

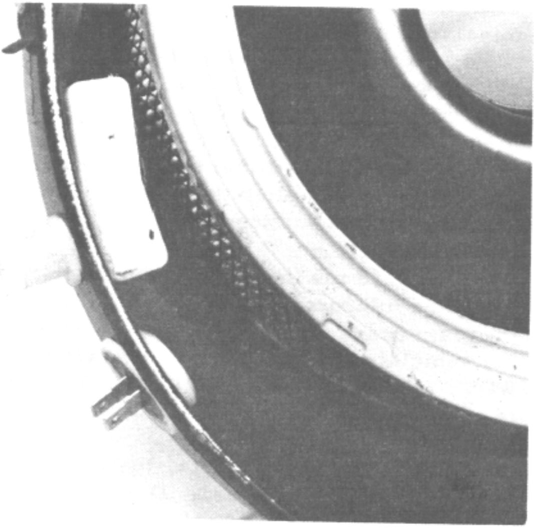

Fig. 5 Thermo-Electric Switch (TES)
in Air Cleaner Location

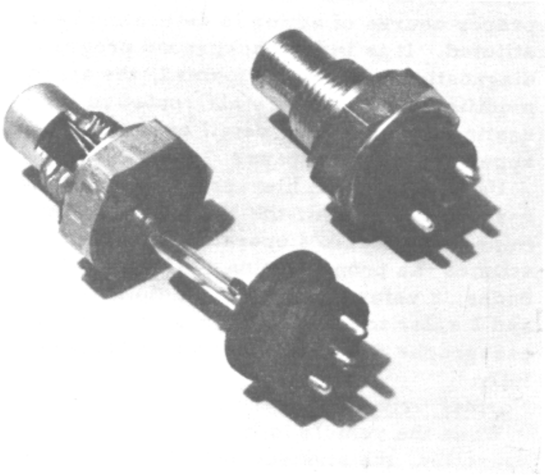

Fig. 6 Temperature Switch With Cutaway View

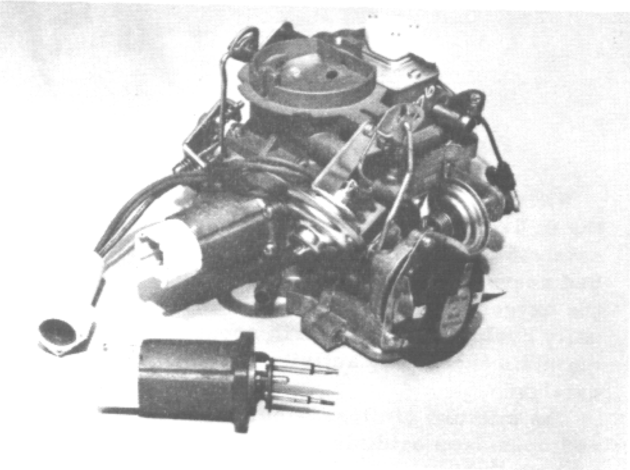

Fig. 8 Stepper Motor, WOT Switch
And Carburetor Assembly

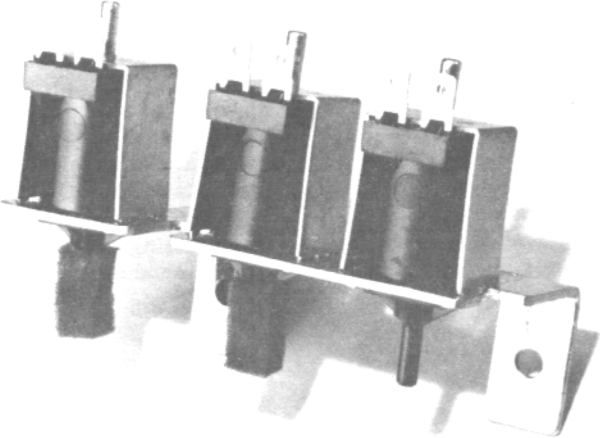

Fig. 10 Vacuum Switch Solenoids

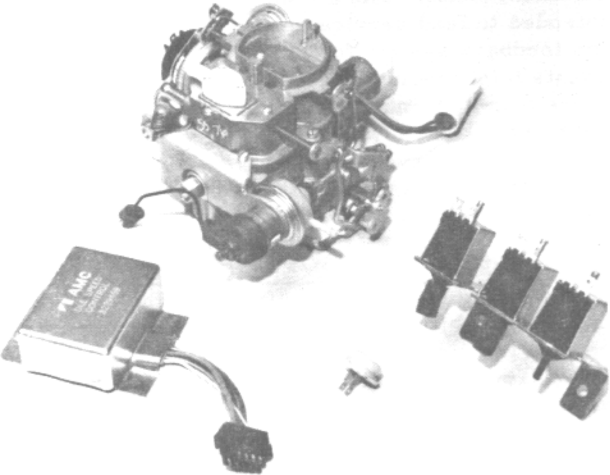

Fig. 11 Idle Speed System Components

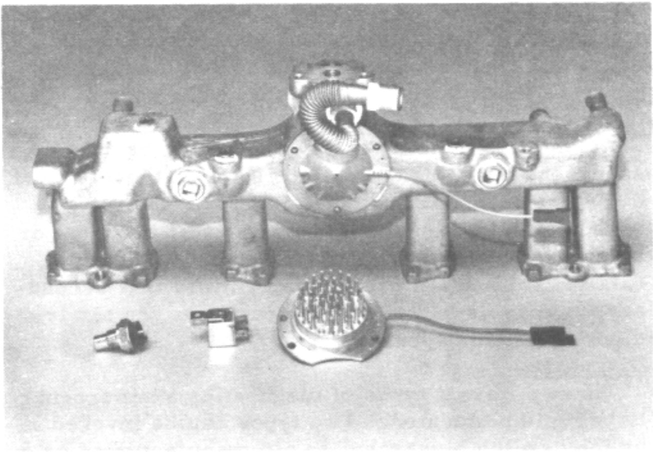

Fig. 12 Early Fuel Evaporation (EFE) System

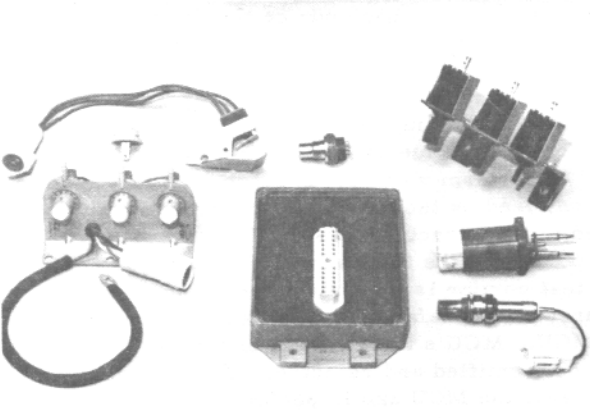

Fig. 13 1981 Fuel Feedback (FFB) System