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A Feedback Controlled Carburetion System Using Air Bleeds

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IF FEDERAL EMISSION STANDARDS FOR the early 1980's are to be achieved, carburetors must be developed or modified to deliver a more precisely controlled air-fuel ratio so that exhaust gases will be of uniform composition. Three-way and dual-bed catalytic converters are highly efficient in reducing emissions only if the air-fuel ratio is held constant. Figure 1 shows ideal efficiencies. Excessively rich or lean ratios decrease catalytic converter efficiency.

When Carter began development of a feedback or closed loop carburetion system, the approach chosen was to control air bleeds in the low and high speed carburetor fuel circuits. Other approaches are available and were considered. (1)*

This paper explains the reason for choosing the air metering method and the basic concepts of the control system. The preliminary prototype phase of the program was successful based on engineering tests and on system evaluation by various automotive manufacturers in July and August of 1976. Figure 2 shows a schematic of components.

If a carburetor could be calibrated to deliver a precise air-fuel ratio under all conditions for the duration of its functional life, there would not be a need for a feedback system. However, there are a number of conditions which cause undesirable variations in the air-fuel ratio delivered by a carburetor and which cannot be compensated for by the vehicle operator or by preadjustment.

Two objectives had to be met in order to meet the requirements of the catalytic converter. First, the carburetor had to be calibrated to provide a relatively constant air-fuel mixture. Second, an electro-mechanical system had to be developed to automatically compensate for internal and external variations in air-fuel ratio caused by changes in engine speed and load, barometric pressure, carburetor and air temperature, humidity and fuel composition and viscosity. (2) Variations are also introduced by inherent manufacturing tolerances of the engine and carburetor as well as wear on individual components.

*Numbers in parentheses designate References at end of paper.

ABSTRACT

A feedback controlled carburetion system has been developed that maintains a flow of exhaust gases of uniform composition. This is a requirement if three-way or dual bed catalytic converters are to be used in meeting projected emission standards. Exhaust gas uniformity depends upon delivery of a constant air-fuel ratio by the carburetor. Instead of metering fuel directly, Carter Carburetor finds that precise and responsive control of the air-fuel ratio is obtained by using variable air bleeds in the carburetor fuel circuits.

DESIGN CONCEPTS

The major factor leading to the selection of the variable air bleed control method was the development at Carter of carburetor altitude compensation using variable air bleeds. (3) This provided experience in controlling the air-fuel ratio by bleeding air into the main and idle fuel circuits as well as providing hardware for development work.

The variable air bleeds consist of tapered metering pins positioned in orifices by a linear solenoid. See Figure 3. This drive mechanism moves the pins in defined steps in response to signals from the electronic control unit. A sensor in the exhaust stream provides the input signal to the electronic control unit. This signal varies with air-fuel ratio. See Figure 6. The solenoid moves the pins until the exhaust sensor indicates that the desired air-fuel ratio has been reached. Thus, the pin movement adjusts the air-fuel ratio to compensate for changes detected in the exhaust gases.

This approach allows Carter carburetors, with minor changes, to be adapted for feedback control and allows the air metering unit to be mounted either integrally with the carburetor or remotely.

In place of the linear solenoid, other electro-mechanical drives such as a stepper-motor or a vacuum solenoid can be used to position the air metering pins, depending on the electronics/carburetor interface requirements.

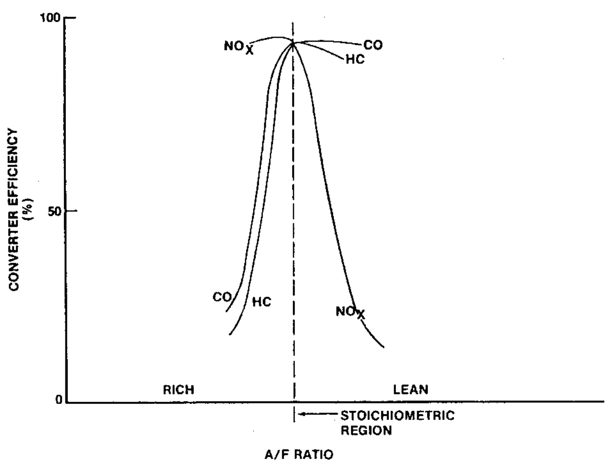

Fig. 1 - Ideal three-way catalytic converter efficiency

CARBURETOR OPERATION

As can be seen in Figure 4, the basic carburetor contains two fuel supply subsystems, the high-speed (main) circuit and the low-speed (idle) circuit. The high-speed circuit meters fuel with a tapered metering rod positioned in the jet by the throttle. Fuel is metered into the nozzle (main) well where air from the feedback controlled variable air bleed is introduced. Since this air is delivered above the fuel level, it reduces the vacuum signal on the fuel consequently reducing the amount of fuel delivered from the nozzle.

The idle circuit is needed at low air flows through the venturi because there is insufficient vacuum at the nozzle to draw fuel into the air stream. After leaving the main jet, fuel is supplied to the idle circuit by the low-speed jet. It is then mixed with air from the first idle bleed, accelerated through the channel restriction and mixed with additional air from the second idle bleed before being discharged from the idle ports below the throttle. Air from the variable air bleed is generally introduced between the first idle bleed and the channel restriction. This air reduces the vacuum signal on the low-speed jet and, consequently, the amount of fuel delivered to the idle circuit.

All power enrichment conditions override the feedback operation.

RANGE OF CONTROL

The basic purpose of feedback control is to provide a narrow air-fuel ratio band so that the catalytic converter will operate at maximum efficiency.

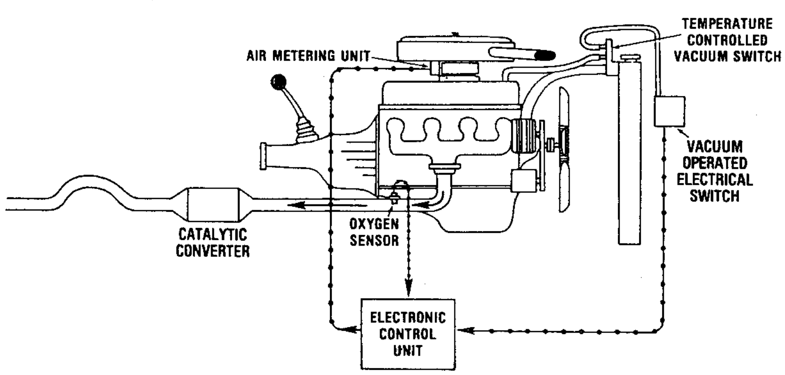

Fig. 2 - Feedback system

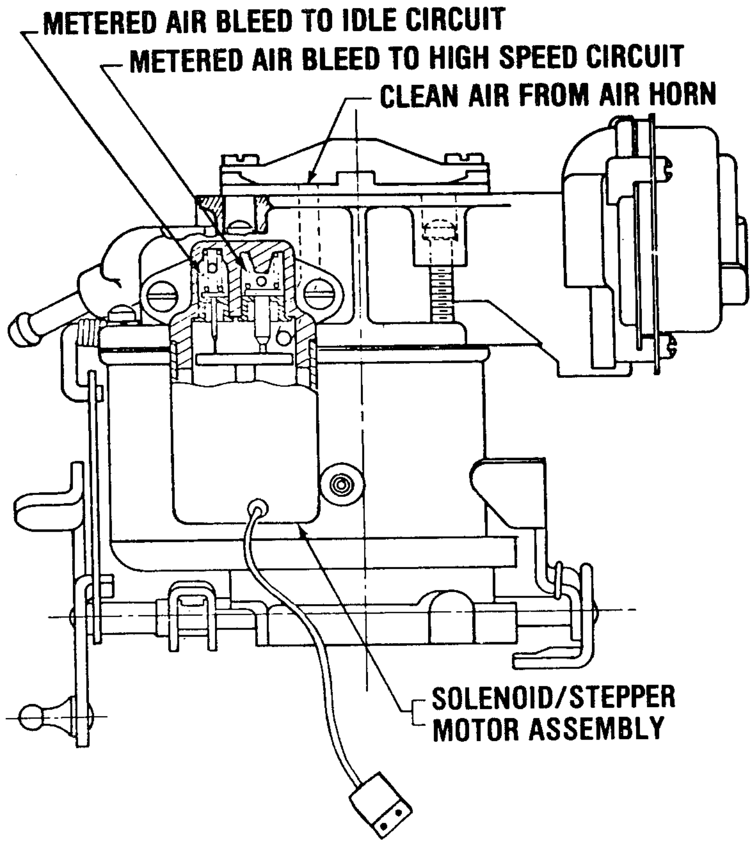

Fig. 3 - Air metering unit

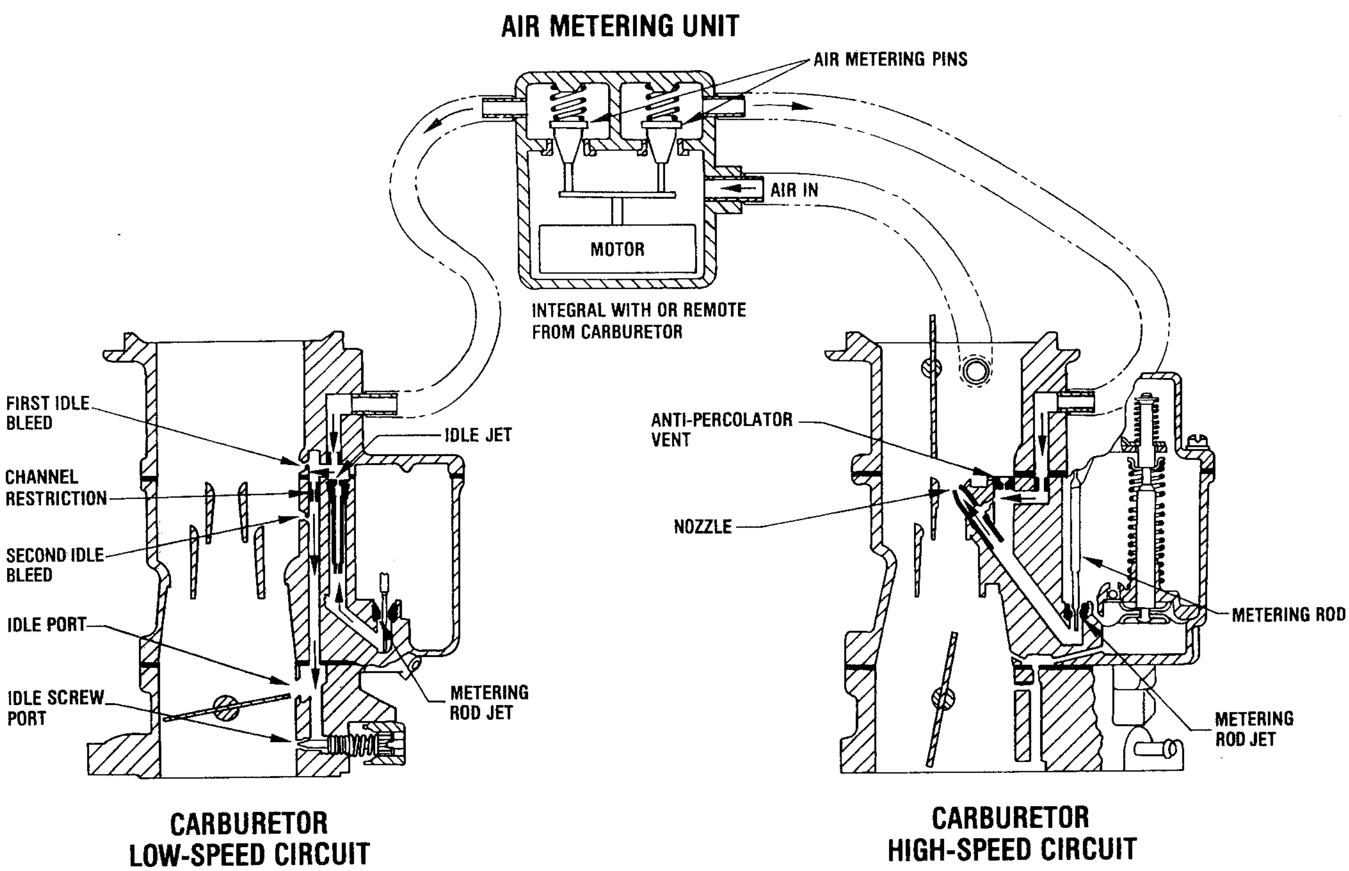

Fig. 4 - Carburetor fuel circuits

It was determined from experience and consultation with OEM customers that a feedback system might require a range of authority of approximately four air-fuel ratios. This range, in the present system, corresponds to control from two ratios leaner to two ratios richer than stoichiometry. This division is arbitrary and can be altered to any proportion desired.

Prior flow test work using carburetors with aneroid controlled altitude compensation shows that satisfactory control can be maintained to 7500 feet (2286m). Figure 5 (3). With feedback control it is expected that more precise compensation can be achieved at altitude.

COMPONENT DESCRIPTION

Oxygen Sensor - It is known that the partial pressure of oxygen in the exhaust reflects the air-fuel ratio with considerable accuracy. (4) Oxygen sensors are commercially available from several sources. Recent development work by manufacturers on the stabilized zirconia type has increased their usable life to a point where they are feasible for automotive use. (5) This type of sensor produces an output voltage that varies with the air-fuel ratio as shown in Figure 6. It is located in the exhaust pipe approximately six inches from the exhaust manifold flange. Care must be taken that maximum operating temperature does not exceed 900°C (1652°F) to prevent sensor damage.

Electronics - Figure 7 is a block diagram of the basic electronics. The sensor output signal is amplified by a buffer-amplifier and converted by logic circuitry into a digital count-up or count-down signal. Counting occurs at a rate determined by a clock oscillator and

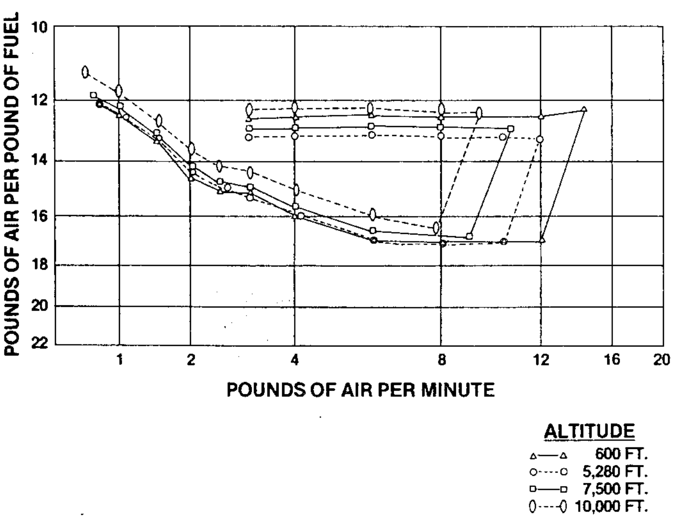

Fig. 5 - Flow curves of altitude compensated carburetor

can be set to match vehicle and catalytic converter characteristics.

The counter/memory circuitry simultaneously stores the current count and decodes it to supply a control signal to the output amplifier(s). The configuration of the amplifier(s) is determined by the type of mechanism selected to drive the metering pins.

When the circuitry detects wide-open throttle, cold starts or other predetermined conditions, it stops the counter. This, in effect, switches the feedback system to the open loop mode until operating conditions permit return to automatic (closed loop) control. During periods of open loop operation the solenoid retains the position it held just prior to entering the open loop mode.

A variable rate switch permits the system to effect a change in air-fuel ratio more quickly under certain conditions. For example, if it is determined empirically that a faster rate of air-fuel change is desirable during light-to-medium accelerations, the switch can be configured to close at the beginning of the acceleration. The amount of increase in clock oscillator frequency that occurs when the switch closes is adjustable, as is the duration of the frequency increase.

Because the actual characteristics of catalytic converters vary slightly from the ideal characteristics shown in Figure 2, it is sometimes necessary or desirable to maintain the carburetor air-fuel ratio at some ratio slightly removed from stoichiometry. A variable bias control contained in the closed loop electronics allows such variation. This control causes the air-fuel ratio excursions which might normally be distributed equally about stoichiometry to be shifted so that the time-average air-fuel ratio is different from stoichiometry. The amount and direction of shift may be selected as required.

Drive Mechanism - The device used at present to move the air metering pins is a linear solenoid that was developed for this application. This actuator has two coils which position the armature according to the voltage being applied by the electronic control unit to each coil.

The armature is attached to a disk upon which the low and high speed air metering pins rest. At zero voltage the armature is in the center or neutral position which is the basic stoichiometric sea level calibration. The metering pins are capable of moving ±0.100 inches (2.54mm) from this neutral position. The 0.200 inches (5.08mm) total travel represents a four air-fuel ratio change, e.g., 12.7 to 16.7 and is divided into 32 steps by the electronics. Thus, for each step correction of the electronics the solenoid moves 0.006 inches (0.15mm).

OPERATING CONDITIONS

Means are provided for the feedback system to automatically disengage (open loop mode) during cold starts and heavy accelerations. Feedback operation under these conditions would counteract the desirable operation of the carburetor.

Two conditions must be met before closed loop operation can begin or resume.

First, the oxygen sensor must be at operating temperature. This is determined by sending a signal to the oxygen sensor to measure its impedance. As sensor temperature increases, the impedance decreases until operating temperature is reached. This signals the electronic control unit that the sensor is prepared for closed loop operation.

The second condition necessary for closed loop functioning is the termination of choke operation. Choke termination is indicated by a specific engine coolant temperature. When the desired coolant temperature is reached, a switch is activated to indicate that choke enrichment is no longer necessary.

With both oxygen sensor and engine coolant at proper operating temperature, the electronic control unit initiates closed loop operation.

In case of a hot start, the system operates as it does for a cold start. Should either sensor or engine coolant temperature have dropped below the required levels, the system

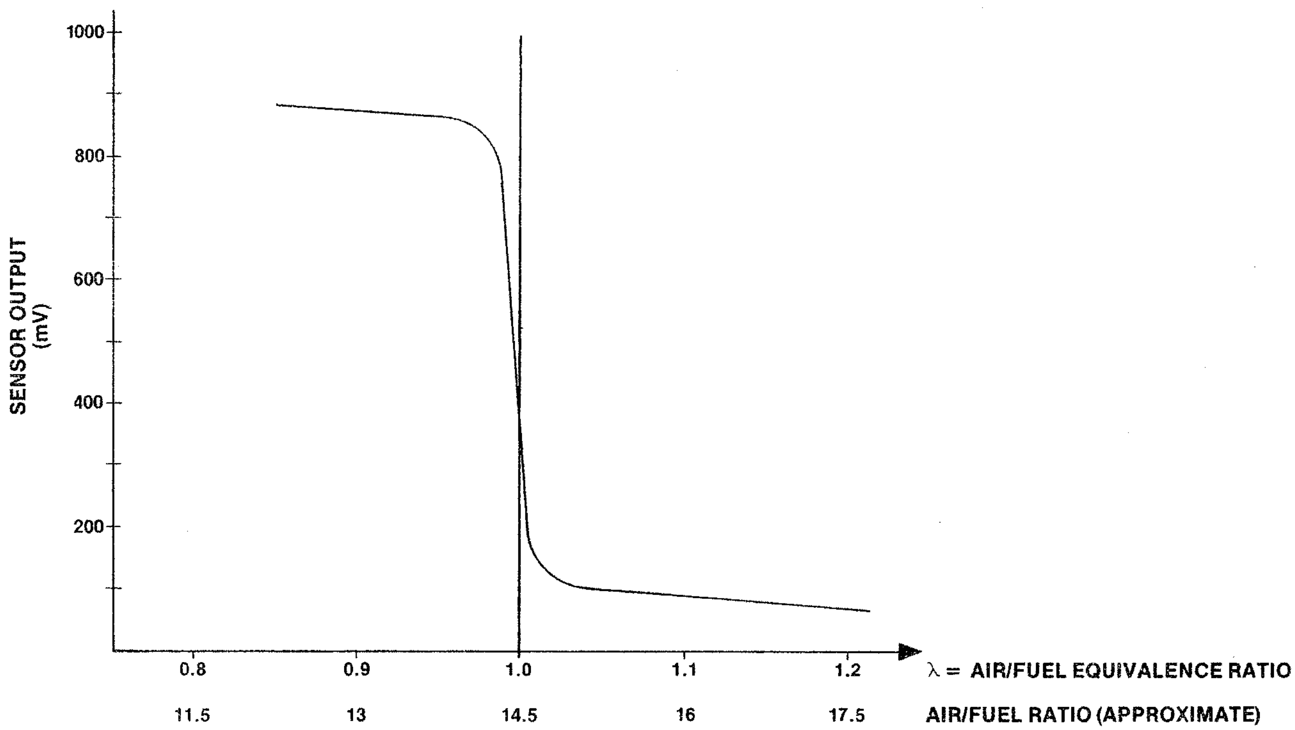

Fig. 6 - Oxygen sensor characteristics

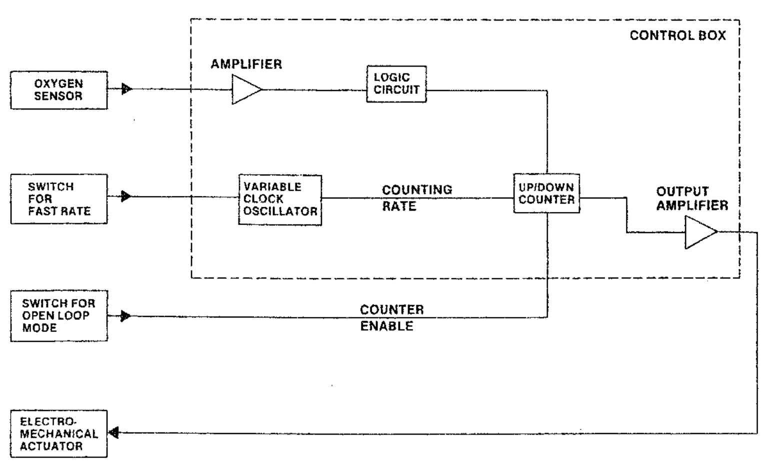

Fig. 7 - Control system block diagram

operates in the open loop mode until both reach their operating levels.

In the case of heavy acceleration or wide open throttle operation, which require power enrichment, the system switches into the open loop mode; this is accomplished by a diaphragm actuated electric switch connected to manifold vacuum. The switch is set to activate at the vacuum level required for power enrichment. When the vacuum rises above this level, the electronic control unit switches back into closed loop operation.

Idle, light-to-medium acceleration, cruise and deceleration modes are all under closed loop control at present.

The system is designed to ignore transient changes in the oxygen sensor output. An occasional misfire, for example, might produce a momentary indication from the oxygen sensor that the carburetor air-fuel ratio is incorrect. An attempt by the system to correct for this erroneous indication is not desirable. The system therefore ignores any indicated air-fuel ratio change which does not last longer than one clock period. See Figure 8 for graphic representation. The clock period is adjusted empirically for each type of vehicle on which the system is installed. Results obtained so far have indicated that a clock period of approximately 0.6 second is near optimum for the six and eight cylinder vehicles that were tested.

SYSTEM EVALUATION

By monitoring the movement of the air metering pins, it is possible to determine the frequency and magnitude of corrections required to maintain a constant air-fuel ratio. The fewer and smaller the corrections, the more precise is the basic carburetor calibration. The instrument used to determine the position of the linear solenoid and, thus, the movement of the metering pins, is a LVDT (Linear Variable Differential Transformer) which is attached to the bottom of the solenoid. Output of the LVDT can be monitored on a meter or recorded on a strip chart as shown in Figures 10 and 11.

At the time this paper was written, metering pin travel did not exceed 0.040 inches (1.02mm) during a 1975 EPA emission test. This represents approximately 0.7 air-fuel ratio.

Figure 9 shows a typical feedgas carbon monoxide trace produced by an engine equipped with a carburetor that was calibrated to stoichiometry. The feedback electronics were disabled during this test.

Figure 10 shows the carbon monoxide trace with the feedback electronics activated. As can be seen, the carbon monoxide is more controlled than in Figure 9.

Figure 11 shows the carbon monoxide trace after maladjustment of the carburetor. The feedback system is activated and the metering pin activity is considerably greater than in Figure 10. The carbon monoxide trace is not as controlled as in Figure 10, but is better than that in Figure 9. Traces were obtained by using a Beckman IR315A nondispersive infrared CO analyzer.

SUMMARY

A practical carburetor feedback system which meters air to control fuel flow has been developed to provide an essentially constant air-fuel ratio. This is a requirement for efficient uses of three-way and dual bed catalytic converters if automobiles are to meet projected emission standards. It has been found that: 1) Air bleed control can be integrated with present Carter carburetors with minor hardware modifications, 2) The system is insensitive to transient air-fuel ratio changes indicated by the oxygen sensor, 3) The system can be tailored to various types of catalytic converters and vehicle combinations, 4) The system provides a more constant air-fuel ratio than is presently obtainable

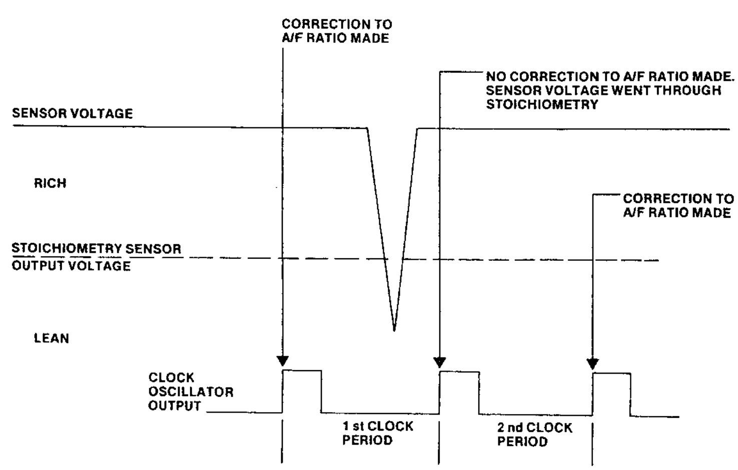

Fig. 8 - System response to O_2 sensor output

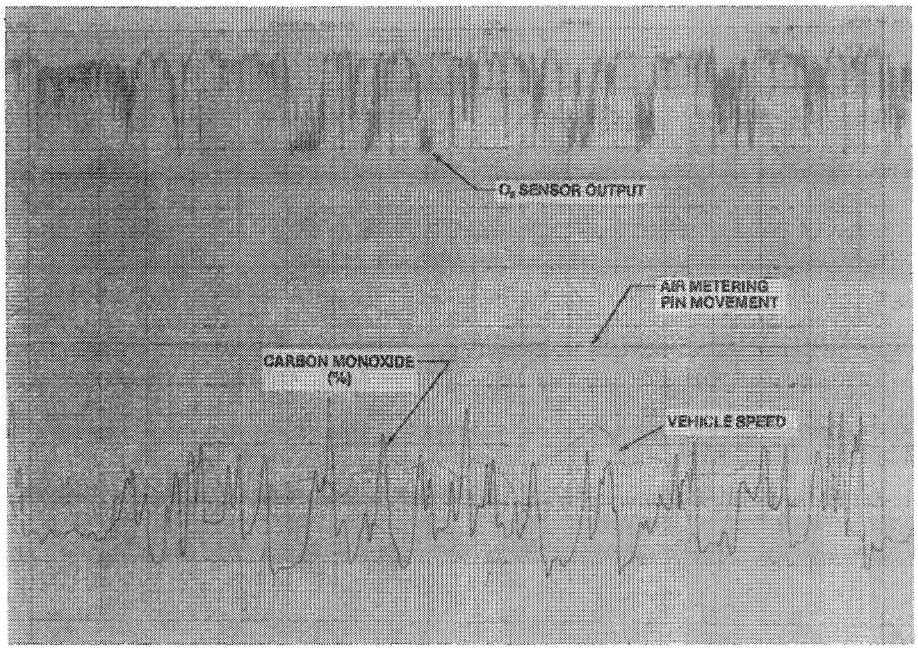

Fig. 9 - Base calibration

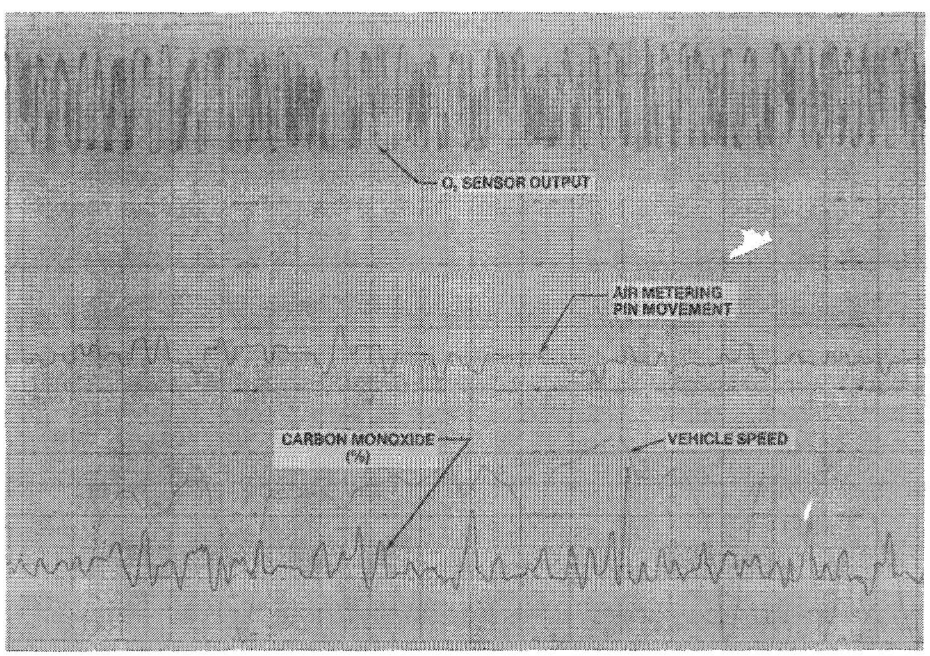

Fig. 10 - Base calibration with feedback

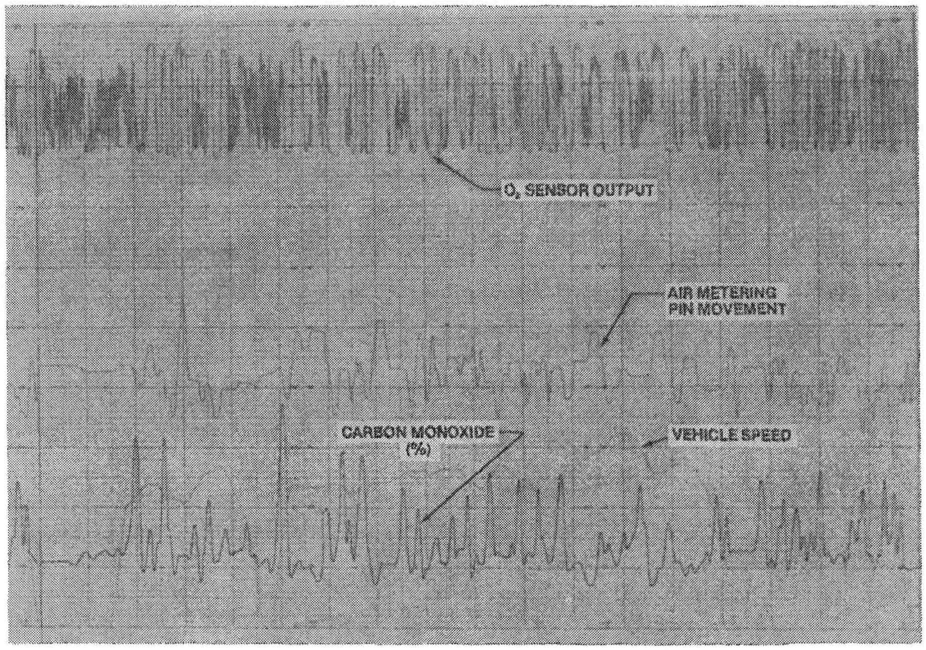

Fig. 11 - Maladjusted carburetor with feedback

with carburetors alone by compensating for internal and external effects.

ACKNOWLEDGEMENTS

The authors wish to thank the people at Carter Carburetor who contributed to this work, in particular, Thomas Byrnes, Jr., Pete Hoekstra, and Mike Sloboda. Also, that of Allen W. Lindberg, P.E., of St. Louis, Missouri.

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