ELECTROJECTOR
Bendix Electronic Fuel Injection System

By

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We of the Bendix Aviation Corp. have for some time been trying to devise a fuel injection system that would be adaptable to passenger car installations. To promote ready acceptance, the system should be adaptable to existing engines with a minimum amount of modifications; its silhouette should contribute to the lower hood line trends; and it should be priced so that eventually it could be used in the high volume field.

Approximately four years ago, we initiated work on a system using a solenoid controlled valve in conjunction with an engine driven commutator with segments shaped to vary the solenoid energizing time in relation to engine characteristics. A sample was fabricated and tested, but the preliminary results indicated the impracticability of mechanically modulating the operation of the solenoid valves. However, from this first development, a second system was devised which utilized an electronic control or brain box to modulate the operation of the solenoid injection valves. The test results with this electronically controlled fuel injection system were very encouraging. In conformance to the Corporation's policy of combining the specialized engineering talent of various Divisions, and to develop the system's approach to the problem, the Research, Radio, Friez, and Scintilla Divisions were contacted to assist and counsel us in this program.

The Bendix Electrojector is a new and novel approach to the fuel injection problem for passenger car installations. As indicated in its name, it is electronically controlled and electrically actuated. It has timed intake port injection and a low pressure, 20 p.s.i. common rail fuel system and employs controls that are responsive to intake manifold pressure, engine speed, air pressure, and temperature.

As in any fuel system, whether it uses a carburetor or fuel injection, the metering system must meet certain engine requirements: (1) optimum air to fuel ratio under varying loads and speeds for maximum economy; (2) starting enrichment which tapers off during warmup for good cold weather operation; (3) idling enrichment to compensate for exhaust gas dilution; (4) full throttle or load enrichment for maximum power; (5) acceleration enrichment to avoid momentary lean-out during that transient period; and (6) a fast idle during the warmup period to prevent engine stalling because of the added friction load during this period. In addition to these basic requirements, it is also highly desirable to cut off the fuel flow to the engine during deceleration to reduce the smog problem and to include automatic altitude compensation to expand the optimum operating range of the vehicle.

The following outline and schematics show how the Bendix Electrojector system accomplishes these objectives.

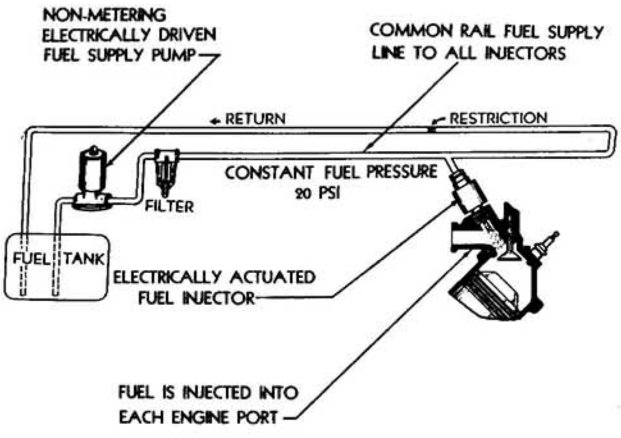

FIG. 1 THE FUEL SUPPLY SYSTEM

Figure #1 indicates the basic fuel supply system in which fuel is drawn from the fuel supply tank by an electrically driven, non-metering, fuel supply pump that maintains the line pressure to the fuel

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injector valve, of which there is one for each cylinder of the engine, at 20 lbs. plus or minus ½ lb. per square inch. Between the fuel pump and the injector is a fuel filter. In the Electrojector system, it is not necessary to filter the fuel finer than twenty microns particle size as the system does not have close fitting mechanically operating units. Experience to date has indicated that the best results are obtained when the fuel is directed at the head of the intake valve so that a minimum amount of wall wetness results. A fuel return line is incorporated in the system to continually purge any air or fuel vapor from the fuel supply system. To date, we have not experienced any engine malfunctioning due to air or fuel vapor in the lines even though the system has been subjected to high underhood temperatures and empty fuel lines during a shutdown period.

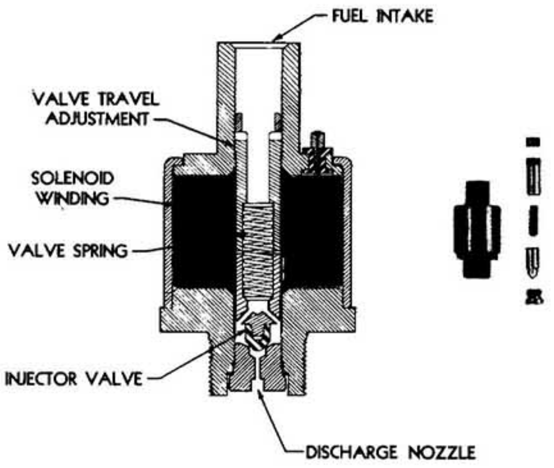


FIG. 2 THE FUEL INJECTOR

A more detailed picture of the solenoid fuel injector valve is shown in Figure #2. Fuel enters at the top of the unit and passes through the center core of the valve, discharging through the nozzle at the lower end when the injector valve is off its seat or open. Considerable experimental work and testing was done on this valve and solenoid assembly in order to realize a unit that could operate at high speed, maintain calibration, require low power for operation, and be manufactured at a reasonable price. This, like other units in the system, is new, when compared to carburetor experience, and is continually undergoing changes for improvement in operation and ease of manufacturing.

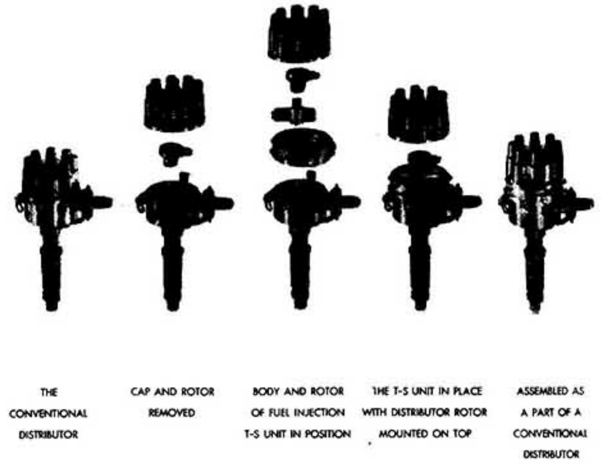


FIG. 3 TRIGGERING SELECTOR UNIT

The Bendix Electrojector is a timed fuel injection system and Figure #3 indicates the method by which this is accomplished. To a standard engine distributor, a fuel injection triggering selector unit and rotor are added. They are inserted as a sandwich between the base of the distributor and the standard ignition distributor cap. In the triggering selector unit, there is a set of breaker points and a distributing commutator with a section of the commutator for each solenoid injection valve.

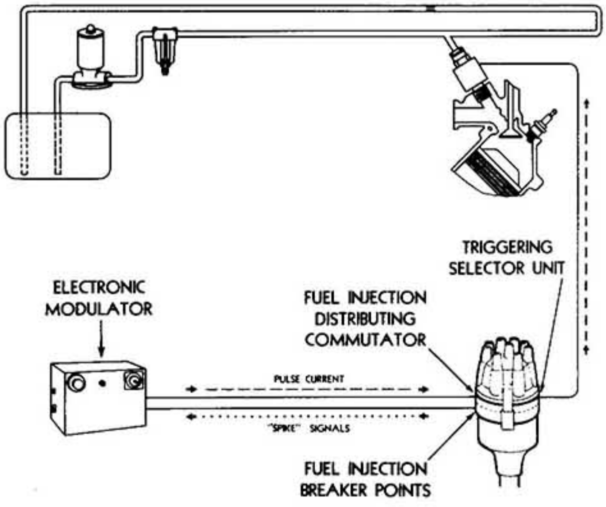


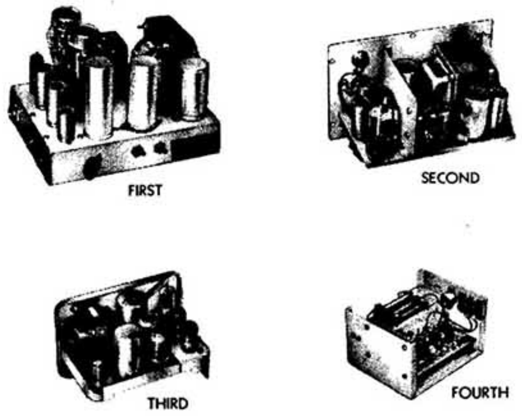
FIG. 4 THE INJECTION TIMING AND INJECTOR ACTUATING ELEMENTS

The breaker points are actuated by the same cam that operates the regular engine ignition points. Thus, for each two revolutions of the engine, the fuel injector breaker points have made and broken contact the same number of times as there are cylinders in the engine. Each time the fuel injector breaker points make contact, a triggering impulse is transmitted to the electronic modulator box. After which, the modified signal is returned to the selector portion of the assembly and the impulse is distributed to the correct fuel injector valve. Figure #4 illustrates how the electronic modulator control and triggering selector units are arranged in the system. Through the triggering selector unit, engine speed and fuel injection timing are sensed and the electrical impulse is correctly distributed to the individual fuel injectors. Because the commutator segments neither make nor break the electrical circuit in the system and the electrical energy transmitted by the breaker points is low, very acceptable operating life is expected from this unit. This simple distributor modification is the only change necessary in the engine drive system to adapt it to the Bendix Electrojector system.

A separate triggering selector unit can be installed and driven by a flexible shaft from the standard distributor drive in installations where distributor height, configuration or function prevent the use of the above sandwich type unit.

The first function of the electronic modulator control or brain box is to transform the spike signals received from the triggering selector unit into an electrical pulse of a given standard width. Simultaneously, signals indicating engine operating conditions are also being received by the electronic modulator control from sensing units located on various parts of the engine. By integrating these external sensing signals into the standard pulse width circuit of the electronic control system, the standard pulse width is modified to reflect engine conditions. This modified electrical pulse is then transmitted to the selector portion of the triggering selector unit which in turn distributes or directs the pulse to the correct fuel injector.

Originally, vacuum tubes were used in the electronic modulator control, which necessitated a short warmup time for the vacuum tubes before the system could be put into operation and required a relatively high current draw from the standard car battery. To improve the operating characteristics of the unit and to increase service life, the control was transistorized. Figure #5 shows how the size of the modulator box was reduced as the development program progressed; and Figure #6 shows one of our more recent units. In this unit, the waiting period has been eliminated and the maximum average current draw reduced to 3½ amperes.


FIRST

SECOND

THIRD

FOURTH

FIG. 5 DEVELOPMENT PHASES OF THE ELECTRONIC MODULATOR

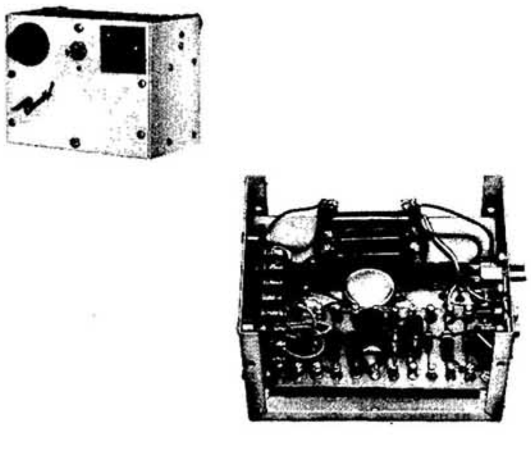


FIG. 6 THE ELECTRONIC MODULATOR

Standard type, but larger, throttle valves are used to control the air flow to the engine. Attached to the throttle body is an intake manifold pressure sensor that transmits a signal to the electronic modulator control box indicating the relative density of the air charge entering the engine.

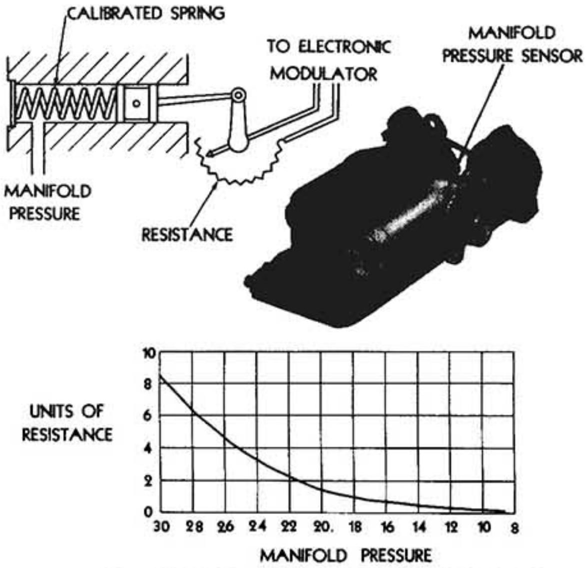


FIG. 7 INTAKE MANIFOLD PRESSURE SENSOR

Figure #7 schematically indicates the operation of the intake manifold pressure sensor and shows a photograph of a throttle body. The actual resistance characteristic will vary for different makes and models of engines.

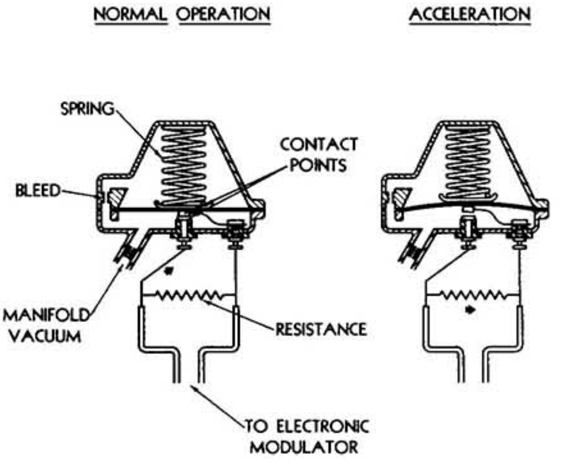


FIG. 8 ACCELERATION ENRICHMENT

Basically, in this and all of the other external sensing units, introduce added resistances into the fundamental circuit to modulate the pulse width of the electrical impulse that is transmitted to the solenoid injector valve. As the sensing circuits' resistances increase, the pulse widths increase and the length of the time that the injector valve is held off the seat likewise increases, which results in additional fuel flow.

Experience has indicated that, when an engine is accelerated, it is necessary to supply a small extra quantity of fuel to the engine in order to obtain smooth engine operation during this transient period. Figure #8 illustrates one method of accomplishing this temporary enrichment through a manifold vacuum change sensing device. In operation, a rapid change in manifold vacuum will cause the points to separate and introduce an additional resistance in the control system thus increasing the operating pulse width of the electrical signal for the length of time necessary to equalize the pressure in the chambers on both sides of the diaphragm in the unit. The added pulse width will increase the fuel flow from each injector inasmuch as the injectors will be energized for a longer period of time during this transient period. We are also considering alternate methods such as mechanical operation through the accelerator or throttle linkage.

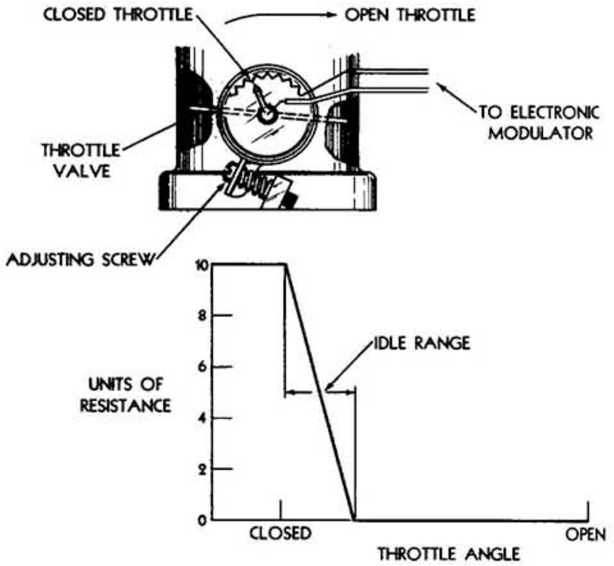


FIG. 9 IDLE ENRICHMENT

Smooth idling is important in any car operation and in order to meet the slight variations in fuel requirements between engines of the same make and model, a separate idle enrichment control, shown in Figure #9, is incorporated in the Bendix Electrojector system. A rheostat is connected to the throttle shaft to interject a variable resistance in the control circuit when the throttle is in the idle position. The idle adjustment is obtained by adjusting this resistance instead of the conventional idle mixture adjustment needle.

We have now conveyed signals to the electronic modulator depicting the speed of the engine and intake manifold pressure as well as its accelerating and idle requirements. The electronic modulator integrates these various signals and transmits them through the distributing commutator system to the correct solenoid injector valve and causes them to deliver fuel to the engine in the proper quantities. This, however, is not sufficient to satisfy all conditions of operation. During cold weather operation, it is necessary to supply additional fuel for starting and to diminish this enrichment as the engine warms up.

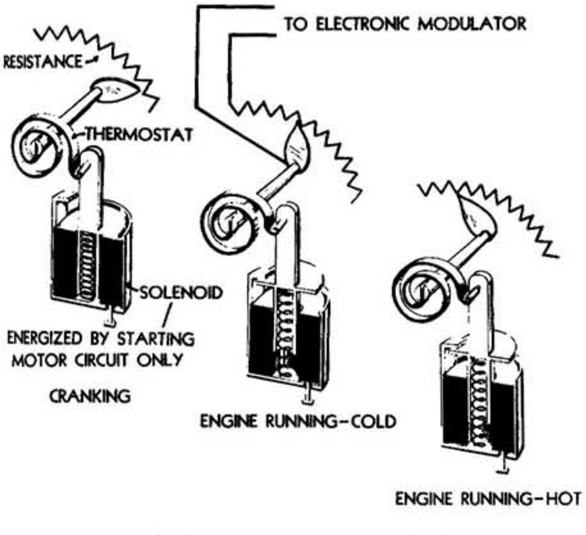


FIG. 10 STARTING ENRICHMENT

Figure #10 indicates how this can be accomplished in the Bendix Electrojector system. Cold tests have indicated that it is necessary to supply more fuel to the engine during the cranking period per engine cycle than is necessary to operate it after the start and that the quantity of fuel required will vary with the engine temperature. To accomplish this end result, a thermostat positions a variable resistance such as a rheostat in the control system that will increase the resistance as the temperature diminishes thus increasing the pulse width with decreasing temperatures. To obtain the added fuel flow during the cranking period, an electric solenoid operating through the thermostat repositions the rheostat to a higher resistance position during the cranking period. Since the thermostat reflects engine temperature, the amount of enrichment decreases as the engine warms up. This signal, like the others, is transmitted to the electronic modulator box for integration with the other signals.

A conventional fast idle cam and thermostat mechanism provide the necessary fast idle speeds during the warmup period.

An additional refinement in temperature control can be obtained by inserting a thermistor that senses the actual air temperature being supplied to the engine during normal temperature operation in the air intake passage. This signal, in the form of resistance, is transmitted back to the electronic modulator control unit which in turn modifies the pulse width, and thus fuel delivery to the engine, in relationship to the actual air temperature being supplied to the engine.

In recent years, smog control has become more and more of a problem. To reduce this annoyance, it has been found advantageous to cut off the fuel flow to the engine during deceleration when the manifold vacuum is abnormally high. Since, as indicated previously, fuel flow modulation is par-

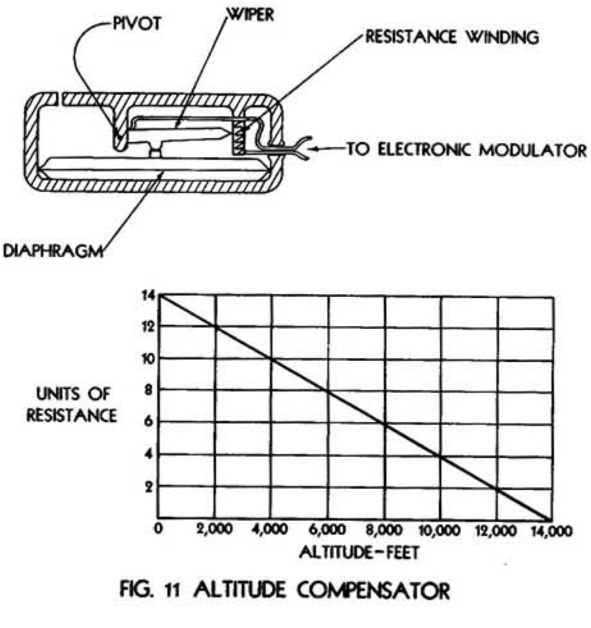
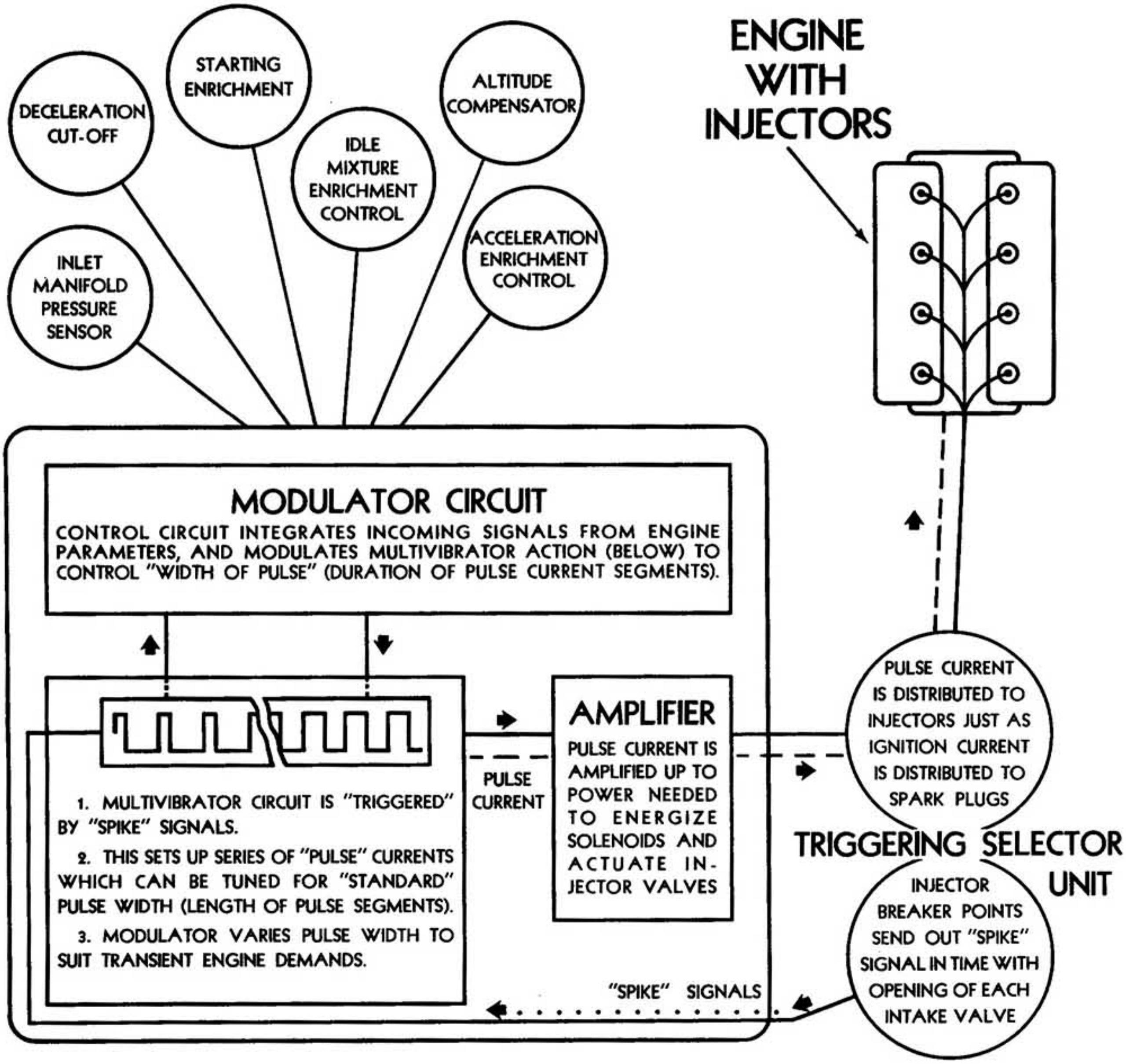


FIG. 11 ALTITUDE COMPENSATOR

tially controlled by manifold vacuum, fuel cutoff is attained when the manifold vacuum exceeds a predetermined value. With the fuel injectors located adjacent to the intake valves, there is very little, if any fuel carryover from the manifold and thus a clean cutoff is effected.

While altitude control and compensation are commonplace in aircraft units, it is commercially non-existent in present passenger car installations. By the addition of an automatic altitude compensator sensing unit attached to the electronic modulator box, it is possible, with the Bendix Electrojector unit, to obtain automatic altitude compensation. Figure #11 schematically illustrates a configuration of such an altitude compensator which includes a small aneroid with a variable resistance unit, that transmits its signal to the modulating unit. Hence, we now have modulating and sensing means for controlling the fuel flow to an engine under all engine operation conditions.



CONTROL CIRCUIT INTEGRATES INCOMING SIGNALS FROM ENGINE PARAMETERS, AND MODULATES MULTIVIBRATOR ACTION (BELOW) TO CONTROL "WIDTH OF PULSE" (DURATION OF PULSE CURRENT SEGMENTS).

1. MULTIVIBRATOR CIRCUIT IS "TRIGGERED" BY "SPIKE" SIGNALS.

2. THIS SETS UP SERIES OF "PULSE" CURRENTS WHICH CAN BE TUNED FOR "STANDARD" PULSE WIDTH (LENGTH OF PULSE SEGMENTS).

3. MODULATOR VARIES PULSE WIDTH TO SUIT TRANSIENT ENGINE DEMANDS.

PULSE CURRENT IS AMPLIFIED UP TO POWER NEEDED TO ENERGIZE SOLENOIDS AND ACTUATE INJECTOR VALVES

PULSE CURRENT IS DISTRIBUTED TO INJECTORS JUST AS IGNITION CURRENT IS DISTRIBUTED TO SPARK PLUGS

INJECTOR BREAKER POINTS SEND OUT "SPIKE" SIGNAL IN TIME WITH OPENING OF EACH INTAKE VALVE

FIG. 12 ENGINE PARAMETERS AND DEMANDS

To summarize this control system, Figure #12 schematically indicates the various items and sensing units. Now, to review the cycle of operation: as the engine rotates, the injector breaker points send out spike signals in time with the opening of each intake valve to the electronic modulator unit. The multi-vibrator circuit in the electronic control box is triggered by the spike signals and this sets up a series of pulse currents tuned to a standard pulse width. The standard pulse segments are then subject to modification by the various modulating or sensing circuits: the inlet manifold pressure sensor, deceleration cutoff sensor, starting enrichment control, idle mixture enrichment control, altitude compensator, and acceleration enrichment control. This modified impulse is then transferred to an amplifier where the pulse current is amplified to the power needed to energize and to actuate the solenoid injector valves. This amplified electrical pulse is then directed to the selector where it is distributed to the proper fuel injectors just as an ignition current is distributed to the various spark plugs. The injectors then react to the power impulse causing the valve to lift from its seat and permit the required fuel to flow to the cylinder.

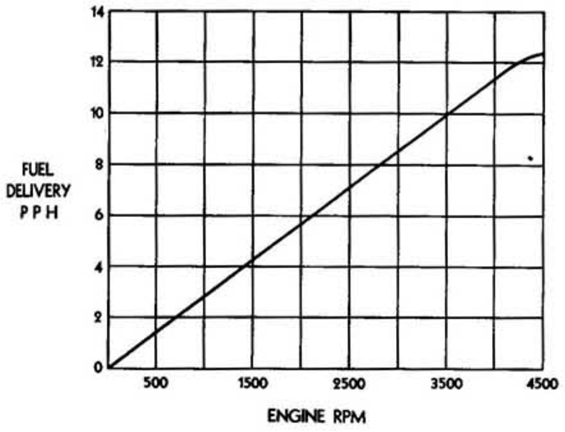


FIG. 13 FUEL DELIVERY PER INJECTOR AT CONSTANT PULSE WIDTH

The Bendix Electrojector system maintains a constant pulse width during full throttle operation and this results in a fuel delivery that is proportional to engine speed through the major portion of the speed range, as indicated in Figure #13. At engine speeds above approximately 4,000 r.p.m., there is a slight fall off in the fuel delivery curve. Fortunately, a similar trend is noticed in engine air consumption.

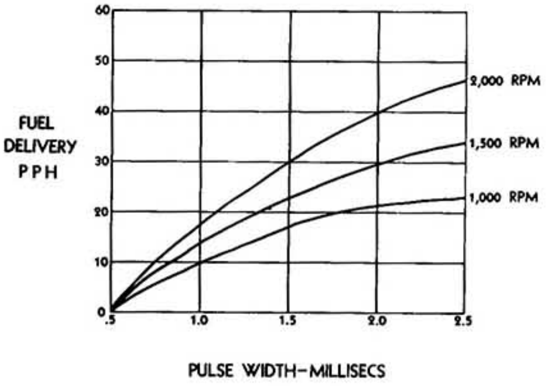


FIG. 14 FUEL DELIVERY INCREASING WITH PULSE WIDTH PER INJECTOR VALVE

When the pulse width is varied, fuel delivery over the speed range will increase with increasing pulse widths. However, fuel delivery is not directly proportional to the pulse widths, but assumes a characteristic curve as indicated in Figure #14. The actual shape of the fuel curve with varying pulse widths and at constant engine speed is a summation of the various electrical, flow, and motion characteristics of the units in the system.

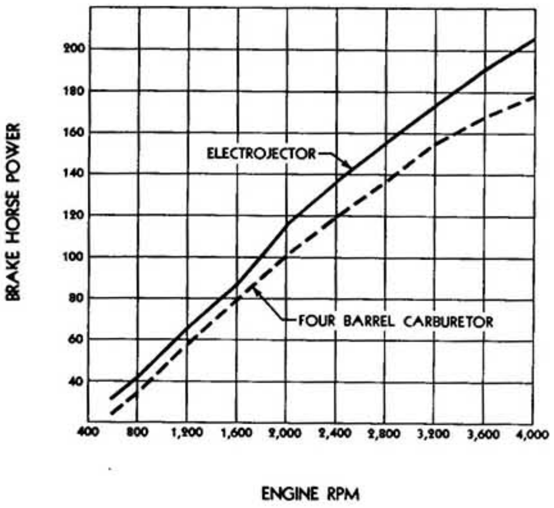


FIG. 15 TYPICAL TEST RESULTS

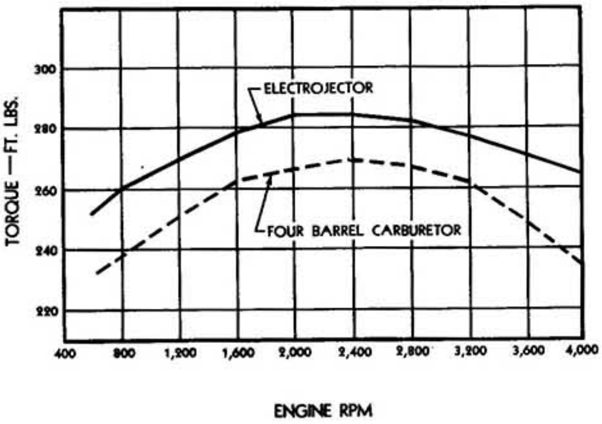


FIG. 16 TYPICAL TEST RESULTS

With either direct or port fuel injection, increased engine torque and horsepower are obtainable through the use of larger intake manifolds engineered for maximum air delivery and the elimination of intake manifold heat. Figure #15 is a typical horsepower comparison test between a standard 4-barrel carbureted installation and the same engine equipped with a Bendix Electrojector fuel injection system; Figure #16 indicates the torque results.

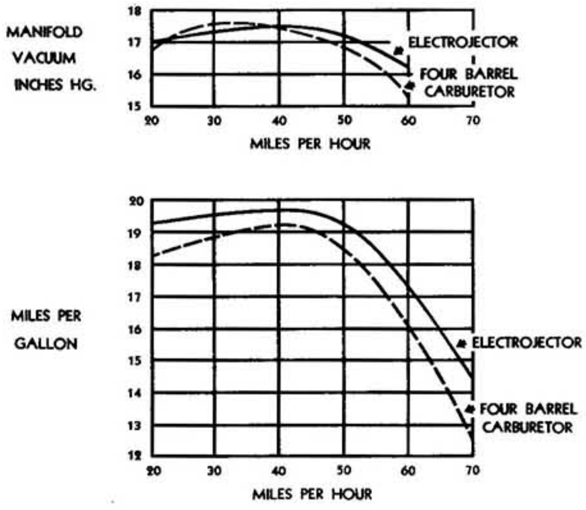


FIG. 17 ROAD ECONOMY TESTS

In our preliminary experimental road economy test with the Bendix Electrojector fuel injection system, we have obtained results indicating better part throttle road economy as shown in Figure #17. (We have also had test results on other installations that were not as satisfactory.) Results as shown in Figure #17 do however indicate a potential improvement in part throttle economy. For optimum results, the fuel injectors, manifold, and engine must all be compatible with each other. What the ultimate gains and improvements in part throttle economy will be is partially dependent upon how well the fuel injection concept can be integrated into this overall engine design.

With respect to cold weather operation, we have had some very encouraging cold start and warmup test results. Since the fuel is injected adjacent to the intake valve, the starts have been very good and the length of time required to supply added fuel during the warmup period was very materially reduced. This characteristic of the fuel injection system should improve the overall tank economy during short run operations in cold weather.

A complete installation is shown in Figure #18.

When comparing the Electrojector system with other fuel injection systems, it has these advantages:

Elimination of the expense and complication of a high-pressure metering type pump.
Fewer moving parts.
No special pump-drive from engine.
No critical filtering requirement.
No surge or inertia effects as in a pulsating, high pressure fuel line.
No vaporlock.
Self-priming.

PLUS Easier adaptation and assembly line installation.

Quieter operation.
Low electrical requirements.
No ultra-precision machining standards.

When comparing fuel injection against carburetor, the Electrojector system has these advantagès

- Increased power.
- Higher torque.
- Quicker cold starting and warmup.
- Wider latitude in fuel.
- More room under hood.
- Idle cutoff.
- Ambient air compensation.
- Altitude compensation.
- Faster, livelier response to throttle, and better all around performance.
- Lower hood line possible.
- Higher volumetric efficiency — intake manifold can be designed entirely for air.
- Flow efficiency without compromise for distribution to maintain gas velocity at low speeds.
- No cold muffler on dual exhaust systems.
- No need for manifold heat — cooler inlet adds to volumetric efficiency and power.
- Lower intake temperature allows earlier spark, and higher compression without detonation adding to power.
- No throttle valve icing.
- No cornering or hill-angle effects.

In conclusion, we are conscious that this is a new concept in fuel metering and poses new and different problems. We and our associates are energetically conducting test programs to add to our knowledge of the system as time and equipment are available.

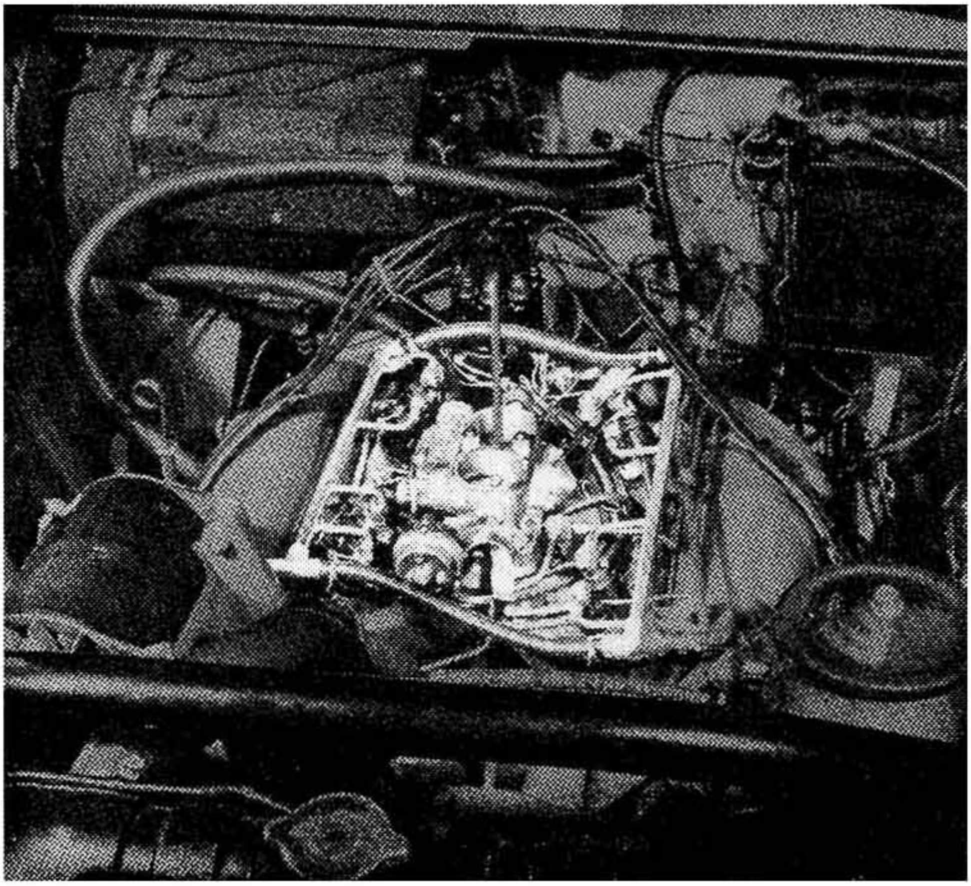


FIG. 18 ELECTROJECTOR CAR INSTALLATION