Dec. 9, 1969 E. H. CASEY ET AL 3,482,558

FUEL INJECTION SYSTEM

Filed Jan. 12, 1968 2 Sheets-Sheet 1

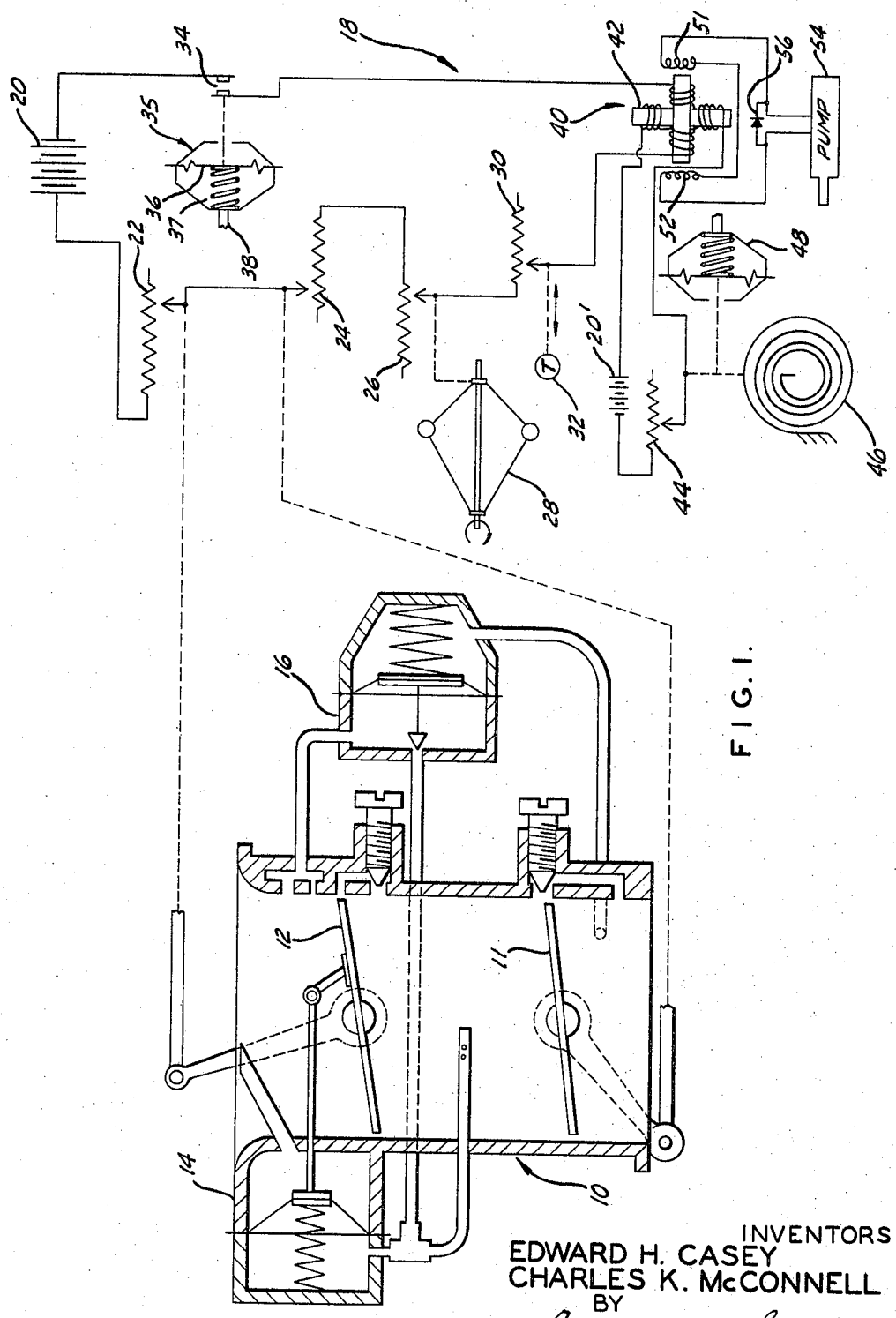


FIG. 1.

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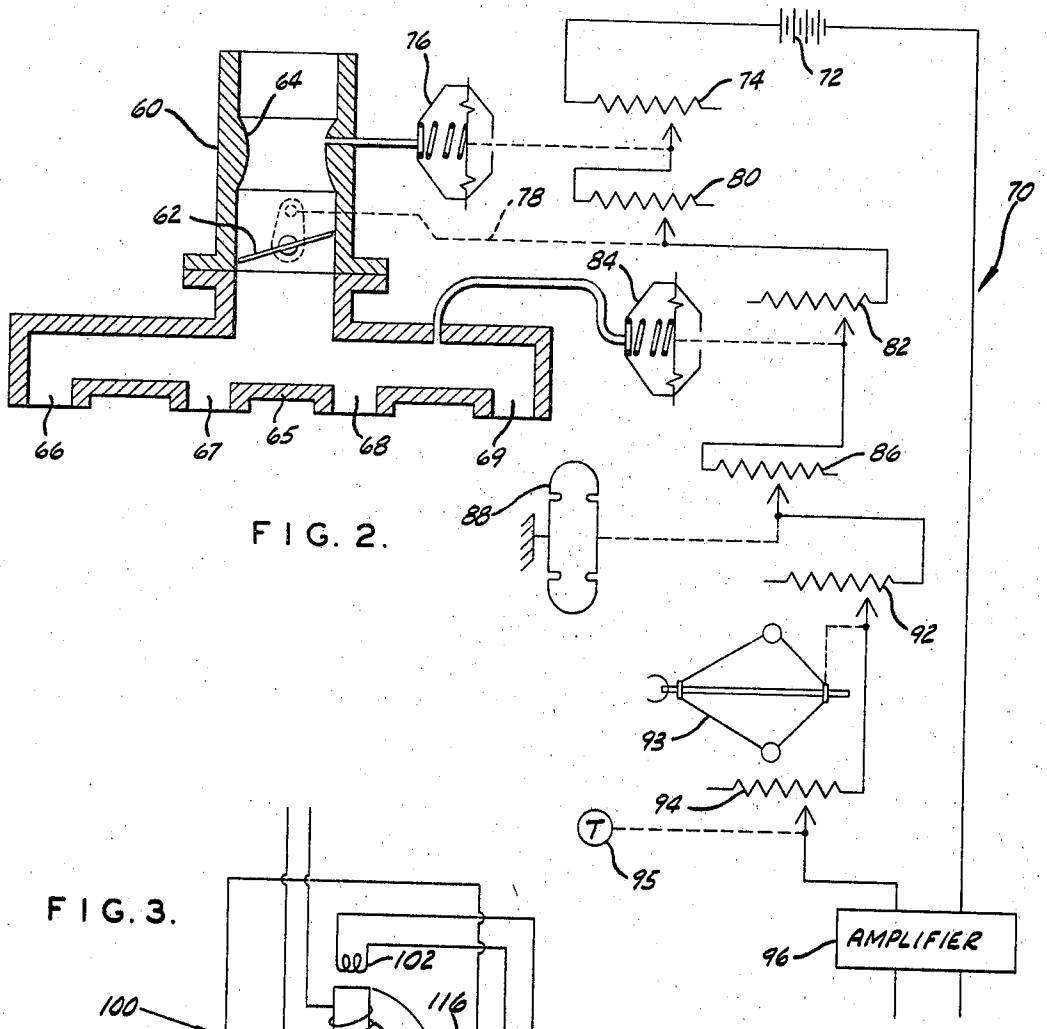
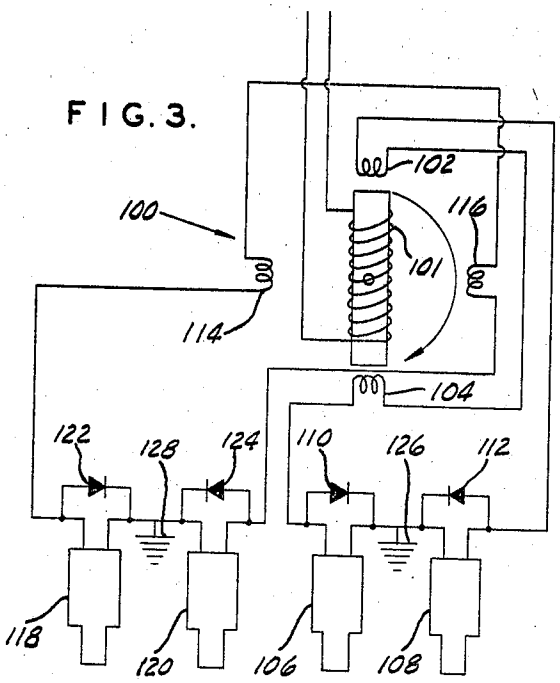


FIG. 2.

FIG. 3.



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FUEL INJECTION SYSTEM

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U.S. Cl. 123—139 8 Claims

ABSTRACT OF THE DISCLOSURE

This invention is a fuel injection system for an internal combustion engine including an electric fuel pump, preferably a piezoelectric pump, connected to each cylinder. The pumps are metered and timed by circuits responsive to the varying automotive requirements, so that each cylinder receives a charge of fuel of the right amount at the right time in its cycle.

Background of the invention

It has long been known that a fuel injection system can be used instead of a carburetor for feeding gasoline to an internal combustion engine. Some fuel injection systems heretofore proposed have included a metering valve for each cylinder, the valves being connected to a fuel pump supplying fuel at a constant pressure. Such a system requires not only a constant fuel pressure over widely varying conditions, but also very fast acting valves which are capable of being accurately metered over long periods to pass a variable precise fraction of a drop of fuel over a wide range of operating conditions. Another type of fuel injection system uses continuously operating metering valves, which require extremely fine adjustment. It is difficult and expensive to provide equipment meeting these requirements. The present system circumvents many of the prior art difficulties by avoiding the use of metering valves altogether.

Summary of the invention

The fuel injection system of the present invention includes a plurality of electrically controllable pumps, such as piezoelectric crystal pumps or the like, each separately connected between one cylinder of the automobile engine and the fuel line to the gasoline tank. The fuel pumps are connected to an electrical control circuit which is responsive to all required automotive operating conditions to produce timed metered charges of fuel of the right quantity. An air horn including a throttle valve is connected to the intake manifold. Connections are provided from the throttle valve to the pump control circuit to help to attain a fuel to air ratio which will satisfy the varying operating conditions. The circuit for energizing the pumps includes a timing device operated by the engine which causes the pumps to be pulsed sequentially. The pulses are varied in magnitude in accordance with engine operating conditions, and the pumps produce fluid pulses of a magnitude corresponding to the variable magnitude of the electrical pulses.

Description of the invention

The invention will be fully understood from the following description and the drawing, in which:

FIGURE 1 is a schematic diagram of one embodiment of the invention.

FIGURE 2 is a partial schematic diagram of another embodiment of the invention.

FIGURE 3 is a circuit diagram of the connections of an alternator to the electrical pumps.

The embodiment of the invention shown in FIGURE 1 includes an air horn **10**, the elements of which are shown and described in Patent 2,904,026. Air horn **10** includes a throttle valve **11** adapted to be operated by the usual throttle pedal, and an air valve **12** adapted to be actuated by servo-motor **14**. The action of servo-motor **14** is modified by pressure comparator **16** in response to the position of throttle valve **11**, as more fully explained in the above mentioned patent. Air flows downwardly through air horn **10** to the intake manifold of the engine for conducting air to each cylinder. Valves **11** and **12** meter the air supplied to the engine.

The fuel metering circuit may obviously take many forms and provide control in accordance with the engine operating variables, and therefore the circuits shown herein are to be considered only as illustrative of circuits which may be used. In FIGURE 1 the circuit **18** includes a voltage source **20** connected in series with a plurality of rheostats or variable resistors. Resistor **22** is connected to air valve **12** so that its effective resistance decreases as the valve opens. The resistance of resistor **24** decreases as throttle valve **11** opens. Rheostat **26** is arranged so that its resistance in the circuit increases as the engine speed increases. For this purpose, resistor **26** is connected to a governor **28** adapted to be driven by the engine crankshaft. For temperature compensation rheostat **30** is connected to an actuating temperature sensor **32** responsive to engine temperature. Sensor **32** may be arranged to sense the temperature of the engine coolant, or the ambient temperature under the hood of the car. Circuit **18** is also provided with switch **34** adapted to be operated by vacuum motor **35**, having a diaphragm **36**, a spring **37** and a conduit **38** communicating with the manifold. During deceleration the manifold vacuum causes motor **35** to open switch **34** and thereby shut off the supply of fuel, as will be further explained below. Circuit **18** is connected to a rotor winding **41** of an alternator **40**.

For cold starting of the engine an additional winding **42** is provided on the rotor of the alternator. Winding **42** is shown at right angles to winding **41** for convenience of illustration, and in practice may be placed at a much smaller angle, such as 45 degrees. Winding **42** is connected to a circuit including rheostat **44** and voltage source **20'**, which may be the same or similar to voltage source **20**. Rheostat **44** is varied by thermostat **46** so that when the engine is cold the circuit resistance is minimum and increases rapidly to a high value or infinity as a prescribed temperature is reached. Rheostat **44** is also controlled by vacuum motor **48**, which senses manifold pressure and increases the resistance of rheostat **44** as the engine begins to run and approaches idling speed. Thus the cold starting circuit **20'**, **42–48** provides an increase of fuel during cranking, and then decreases the supply of fuel to avoid racing the engine.

Alternator **40** includes, in addition to rotor windings **41, 42**, stator windings **51, 52**. The stator windings are connected in series to a plurality of suitable electrical pumps **54** having an output corresponding to the magnitude of the voltage or current supplied thereto by the alternator. The pumps used herein are preferably of the piezoelectric type, one suitable form of which is shown in Patent 3,149,162, although it will be obvious that other pumps such as the magnetostrictive type shown in Patent 2,317,166 may be used or adapted to the invention. Although only one set of windings **51, 52** is shown, the alternator is provided with a set of these windings for each pump, and the windings are spaced angularly about the rotor so that each injector pump will be impulsed in turn. Each pump may be shunted by a diode rectifier **56**, the purpose of which will be more fully described below. The alternator is preferably driven by the engine at one half engine speed, and assuming a conventional four cycle

engine, each pump will be impulsed once during each revolution of the alternator.

The operation of the system shown in FIGURE 1 may be summarized as follows. The fuel injection system, which replaces the conventional automobile engine carburetor, includes an air horn **10** having a throttle valve **11** and an air valve **12**, corresponding to the choke valve of a carburetor. Air valve **12** is operated by servo-motor **14** in response to the relative pressures upstream and downstream of the air valve. Since the air horn per se is not the present invention, not all details thereof are shown, but it will be understood that it may include other features shown in Patent 2,904,026. The positions of valves **11** and **12** determine the settings of rheostats **24** and **22** so that as the valves open to increase the air flow, the current in circuit **18** is increased to increase the supply of fuel to the engine, so as to maintain a desirable air to fuel ratio. The increased fuel and air supply tends to increase the speed of the engine and, consequently, the speed of the alternator. Since the voltage generated by the alternator is proportional to its speed, a higher voltage will be supplied to the pumps at higher engine speeds, tending to cause still greater fuel suply. This regenerative effect is counteracted by rheostat **26**, which by way of a suitable taper of the resistor controls the circuit as a function of engine speed and which through the same taper can alter relative fuel air ratios particularly through low part throttle ranges where somewhat richer mixture may be required. It may also be noted that the duration of the output pulses of the alternator becomes shorter as its speed increases, so that the increase in voltage of the pulses with increasing speed can be moderated by designing the output circuits of the alternator to have a time constant which is long relative to the duration of the pulses. It will be evident, also, that if desired the output voltage of the alternator could be adjusted in response to engine speed.

During deceleration, if valve **11** closes or nearly closes, it is desirable to shut off the fuel supply quickly. For this purpose switch **34** is provided. Closure of valve **11** causes the manifold vacuum to rise suddenly to a high value and operate vacuum motor **35** to open switch **34**. During deceleration rheostats **22** and **24** will reduce the supply of fuel, but during a transient period at least, the air-fuel mixture may become so lean that it would not burn. This would result in a high hydrocarbon emission. The fuel cut-off provided by switch **34** prevents such emission.

During cold engine starting both windings **41** and **42** of the alternator are energized, so that each pump **54** receives two pulses during each cycle of the alternator. The pumps may be placed in the air induction system close to the intake valves, or they may be placed in the cylinder head of each cylinder. If placed in the air induction system the pumps are pulsed shortly before or during the intake stroke of their respective pistons, but if placed on the cylinder heads they may be pulsed during the intake stroke and the early part, preferably, of the compression stroke of the respective pistons. Double pulsing of the pumps permits the required large fuel supply for cold engine starting without increasing the capacity of the pumps. During normal running of the engine only winding **41** of the alternator is energized and the pumps are operated only once during each alternator cycle.

The system of FIGURE 2 includes a modified air horn **60** having a throttle valve **62** and a venturi section **64**. The air horn is connected to an intake manifold **65**, shown schematically, having inlets **66–69** to the engine cylinders. The control circuit **70** is similar to circuit **18** of FIGURE 1. A voltage source **72** is in series with a plurality of rheostats. Rheostat **74** is operated by vacuum motor **76**, which responds to the pressure at the throat of venturi **64**, and causes the resistance to decrease with increased air flow in the horn. Throttle valve **62** is connected by linkage **78** to rheostat **80** to decrease the resistance with increasing opening of the throttle. Another rheostat **82** is operated by vacuum motor **84** to response to manifold pressure to increase the resistance with increasing vacuum. This control is helpful during acceleration, when the increased air flow may not reach the cylinders as soon as the increased fuel flow, resulting in a rich mixture. Rheostat **82** corrects this tendency by retarding the fuel increase in dependence on the air flow in the manifold.

Rheostat **86** is operated by a pressure sensor **88**, such as an aneroid barometer, for varying the fuel supply with altitude. Elements **92** to **95** are similar to elements **26–32** of FIGURE 1. Circuit **70** is connected to power amplifier **96**. The output of the amplifier may be supplied to an alternator, being impressed on the winding **41** thereof as shown in FIGURE 1, or supplied to an alternative circuit for energizing the electrical pumps. It is believed the operation of the circuit of FIGURE 2 will be understood from the foregoing description. It is apparent that, for simplicity, a four cylinder engine has been assumed in FIGURE 2, and the injector pumps, not shown, may be placed in or near each of the manifold inlets **66–69**.

FIGURE 3 shows an advantageous circuit for connecting the output of an alternator to four injector pumps. Alternator **100** has a rotor winding **101** and a cold starting winding (not shown) similar to winding **42**, and is provided with four output windings spaced 90 degrees apart. Opposite windings **102**, **104** are connected in series with piezoelectric pumps **106**, **108**, which are shunted by oppositely poled high voltage rectifiers **110**, **112**. Windings **114**, **116** are similarly connected to pumps **118**, **120** and rectifiers **122**, **124**. The housings of the pumps may be grounded at points **126**, **128**. As rotor **101** sweeps past windings **102**, **104** a pulse is impressed, say, on pump **106** while pump **108** is by-passed by rectifier **112**. Pump **108** is energized and pump **106** is by-passed one half cycle later. Pumps **118** and **120** are energized similarly in alternation. Thus the energization of the pumps is accomplished with an economy of circuitry.

We claim:

1. A fuel injection system for an automobile engine having a plurality of cylinders; a separate electric fuel pump positioned adjacent to each cylinder; a source of fuel connected to said pumps; an air flow metering means connected to said cylinders including a throttle valve; an electric circuit for supplying electrical pulses to said pumps sequentially in synchronism with the engine, said circuit having variable means responsive to said air flow metering means, and to a plurality of engine operating conditions for controlling the magnitude of said electrical pulses; means for supplying additional electrical pulses to said pumps in response to a cold engine condition for facilitating starting of the engine; and means for terminating the supply of said additional pulses in response to operation of the engine, whereby said pumps produce discrete fluid pulses having a magnitude corresponding to that of said electrical pulses.

2. A system according to claim **1**, including an engine driven alternator having rotor winding means in series with said variable means of said circuit and a plurality of stator windings, said stator windings being displaced angularly from one another for producing pulses sequentially, pairs of said stator windings being spaced diametrically opposite each other and connected in series across a pair of said pumps, and a rectifier connected across each pump, the rectifier across each pair of pumps being oppositely poled.

3. A system according to claim **2**, wherein said alternator includes an additional rotor winding, means for supplying current to said additional rotor winding in response to a cold engine condition for facilitating starting the engine, and means for terminating said current in response to operation of the engine.

4. A system according to claim **1**, including an engine driven alternator having rotor winding means including a winding in series with said variable means of said circuit and having a plurality of stator windings, said stator

windings being displaced angularly from one another and selectively connected to said pumps, and means connected to said rotor winding means for supplying additional electrical pulses to said pumps in response to a cold engine condition for increasing the supply of fuel for engine starting, and means for terminating said additional electrical pulses in response to operation of the engine.

5. A system according to claim 4, including means for de-energizing the alternator in response to a closing movement of the throttle to accomplish a deceleration of the engine, whereby the supply of fuel is cut off during deceleration.

6. A system according to claim 5, wherein said means for de-energizing the alternator includes a switch in said circuit, and means for opening said switch in response to a predetermined pressure drop in the intake manifold.

7. A system according to claim 1, said system having pedal means for opening and closing the throttle valve to accelerate and decelerate the engine, and means for interrupting the energization of said fuel pumps in response to a closing of the throttle valve to decelerate the engine.

8. A fuel injection system for an automobile engine having a plurality of cylinders, comprising a separate fuel injector positioned adjacent to each cylinder; a source of fuel connected to said injectors; an air flow metering means connected to said cylinders, including at least a throttle valve; an electric circuit for supplying electrical pulses to said injectors in synchronism with the engine, said circuit having variable means responsive to said air flow metering means and to a plurality of engine operating conditions

for varying the voltage of said electrical pulses, characterized in that each of said fuel injectors is a pump having an electrostrictive actuator; and said electric circuit includes an engine-driven alternator having rotor winding means, including a winding in series with said variable means of said circuit, and having a plurality of stator windings connected to said pumps; and means connected to said rotor winding means for supplying additional electrical pulses to said pumps in response to a cold engine condition for increasing the supply of fuel for engine starting; and means for terminating said additional electrical pulses in response to operation of the engine.

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U.S. Cl. X.R.

103—1; 123—32, 119

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,482,558 **Dated** December 9, 1969

Inventor(s) Edward H. Casey and Charles K. McConnell

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 2 and column 3, line 13, change Patent "2,904,026" to read ---2,876,758---

SIGNED AND
SEALED
NOV 17 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
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WILLIAM E. SCHUYLER, JR.
Commissioner of Patents