US005813374A

United States Patent [19]

Chasteen

[11] Patent Number: 5,813,374

[45] Date of Patent: Sep. 29, 1998

[54] **TWO-CYCLE ENGINE WITH ELECTRONIC FUEL INJECTION**

[75] Inventor: **Ronald E. Chasteen**, Colorado Springs, Colo.

[73] Assignee: **Injection Research Specialists, Inc.**, Colorado Springs, Colo.

[21] Appl. No.: **341,193**

[22] Filed: **Dec. 5, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 836,795, Feb. 18, 1992, Pat. No. Re. 34,803, which is a continuation of Ser. No. 119,626, Nov. 12, 1987, abandoned.

[51] **Int. Cl.**[6] **F02B 33/04**

[52] **U.S. Cl.** ..... **123/73 C**

[58] **Field of Search** ..... 123/73 C, 478, 123/480, 486, 491, 73 A, 65 BA, 383, 502, 632, 644, 531; 364/550, 557, 551–1, 510, 431.05, 431.06; 236/DIG. 8

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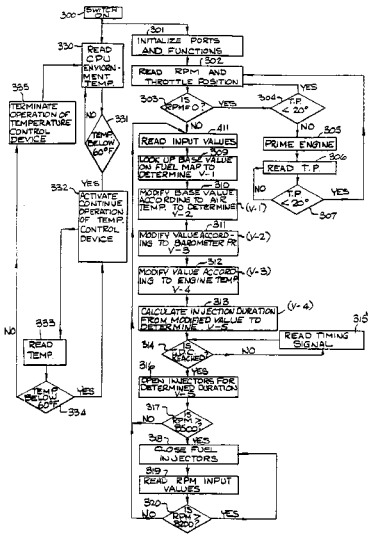
Primary Examiner—Raymond A. Nelli

Attorney, Agent, or Firm—St. Onge Steward Johnston & Reens LLC

[57] **ABSTRACT**

A fuel injection system for a two-stroke cycle engine comprising an air manifold; a throttle valve; a fuel injector; a fuel supply system including a fuel pump; a battery voltage sensor; an air temperature sensor; an engine speed sensor; a timing sensor; a barometric pressure sensor; a throttle position sensor; a first data processor for receiving and processing sensing signals for determining fuel injector duration and timing and fuel pump operating speed; a first data processor temperature sensor for sensing the relative temperature of certain electronic components in the first data processor; a heater operatively associated with the first data processor electronic components for selectively heating the electronic components; and a second data processor operable independently of the first data processor for receiving an electronic component temperature sensing signal and for generating a control signal to the heater responsive thereto for heating the components when the temperature thereof is below a predetermined minimum value.

6 Claims, 5 Drawing Sheets



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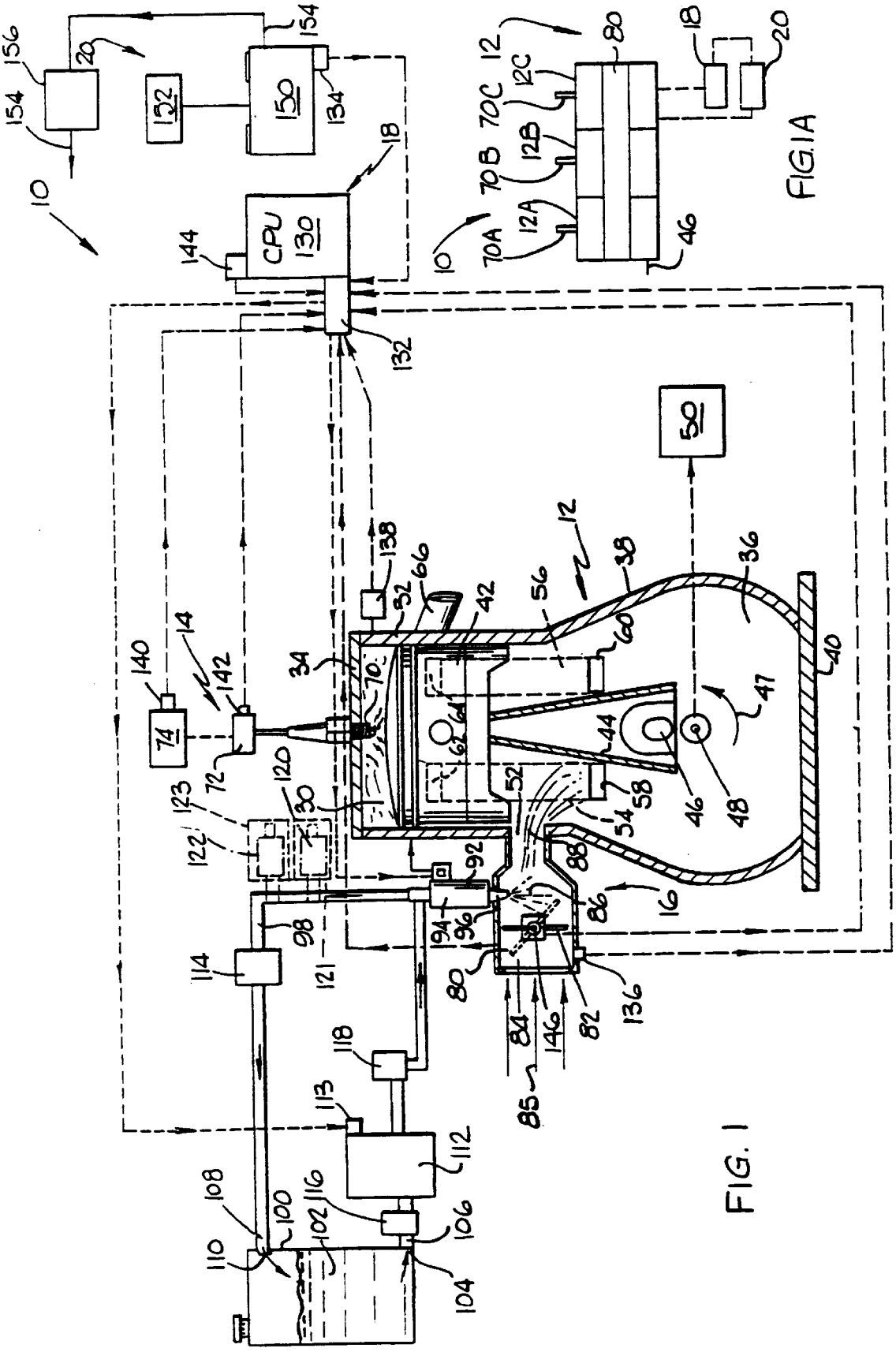

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113
112
85
108
100
102
116
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12
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18
20
12C
70C
12B
70B
12A
70A
46

FIG. 1A

FIG. 1

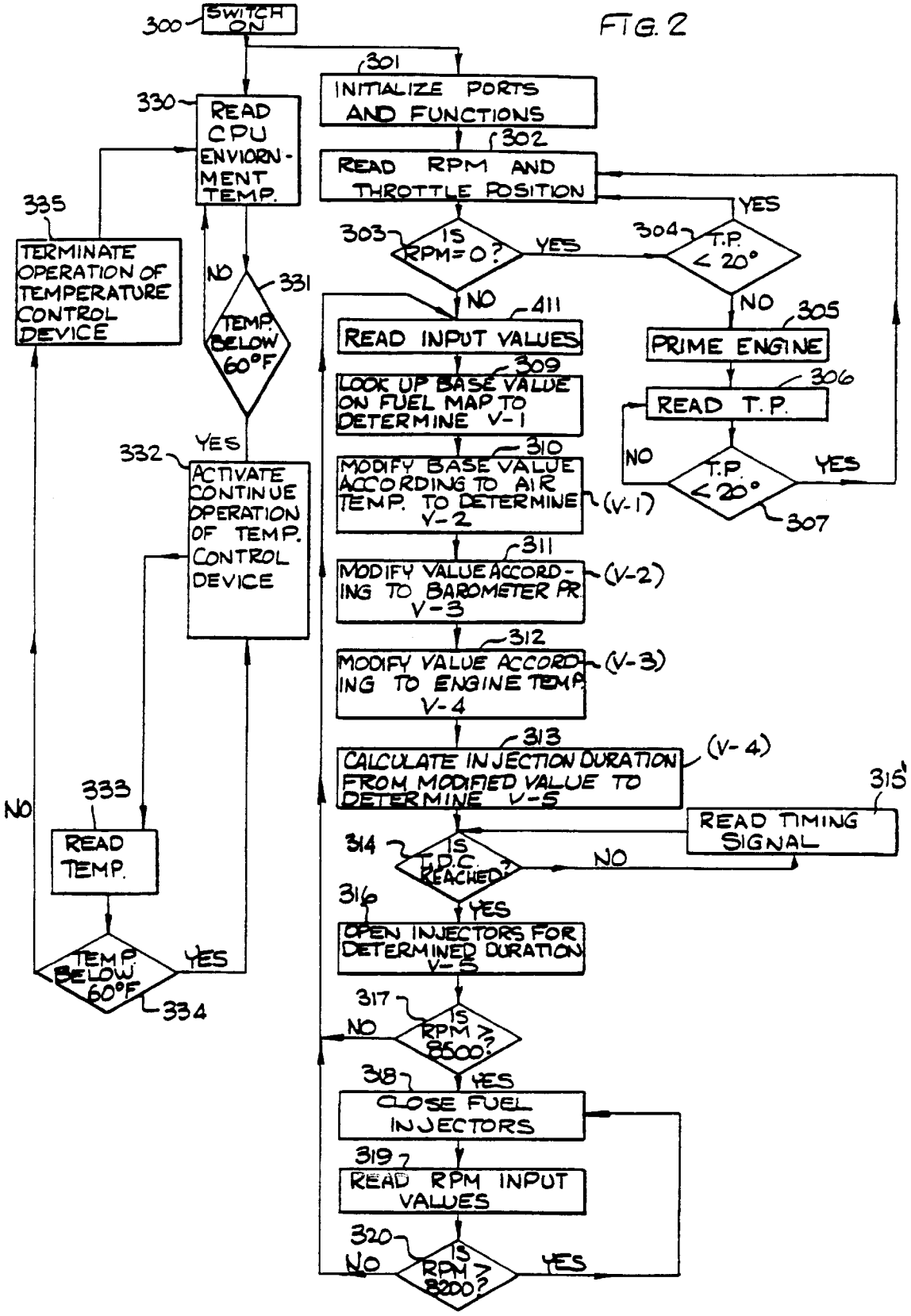
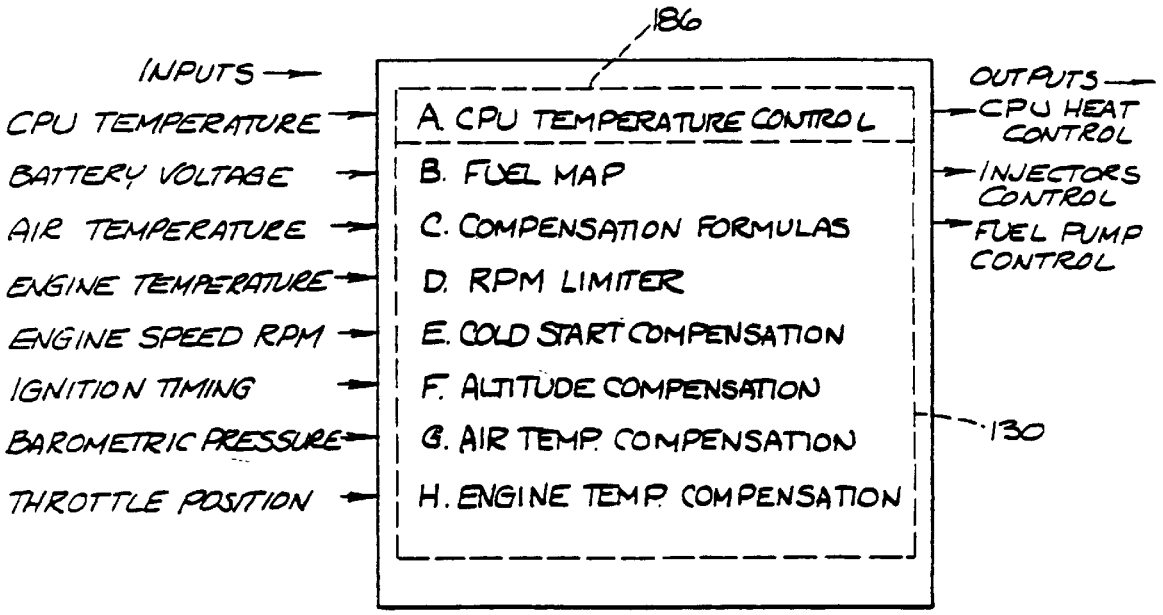

300
SWITCH ON
301
INITIALIZE PORTS AND FUNCTIONS
302
READ RPM AND THROTTLE POSITION
303
IS RPM=0?
YES
304
T.P. < 20°
YES
NO
411
READ INPUT VALUES
309
LOOK UP BASE VALUE ON FUEL MAP TO DETERMINE V-1
310
MODIFY BASE VALUE ACCORDING TO AIR TEMP. TO DETERMINE V-2
(V-1)
311
MODIFY VALUE ACCORDING TO BAROMETER PR V-3
(V-2)
312
MODIFY VALUE ACCORDING TO ENGINE TEMP V-4
(V-3)
313
CALCULATE INJECTION DURATION FROM MODIFIED VALUE TO DETERMINE V-5
(V-4)
314
IS T.D.C. REACHED?
NO
YES
315
READ TIMING SIGNAL
316
OPEN INJECTORS FOR DETERMINED DURATION V-5
317
IS RPM > 8500?
NO
YES
318
CLOSE FUEL INJECTORS
319
READ RPM INPUT VALUES
320
IS RPM > 8200?
NO
YES
NO
305
PRIME ENGINE
306
READ T.P.
T.P. < 20°
NO
YES
307
330
READ CPU ENVIORNMENT TEMP.
331
TEMP. BELOW 60°F
NO
YES
332
ACTIVATE CONTINUE OPERATION OF TEMP. CONTROL DEVICE
335
TERMINATE OPERATION OF TEMPERATURE CONTROL DEVICE
333
READ TEMP.
TEMP BELOW 60°F
YES
334
NO

FIG. 2

FIG. 3


186
INPUTS
CPU TEMPERATURE
BATTERY VOLTAGE
AIR TEMPERATURE
ENGINE TEMPERATURE
ENGINE SPEED RPM
IGNITION TIMING
BAROMETRIC PRESSURE
THROTTLE POSITION
A. CPU TEMPERATURE CONTROL
B. FUEL MAP
C. COMPENSATION FORMULAS
D. RPM LIMITER
E. COLD START COMPENSATION
F. ALTITUDE COMPENSATION
G. AIR TEMP. COMPENSATION
H. ENGINE TEMP. COMPENSATION
OUTPUTS
CPU HEAT CONTROL
INJECTORS CONTROL
FUEL PUMP CONTROL
130

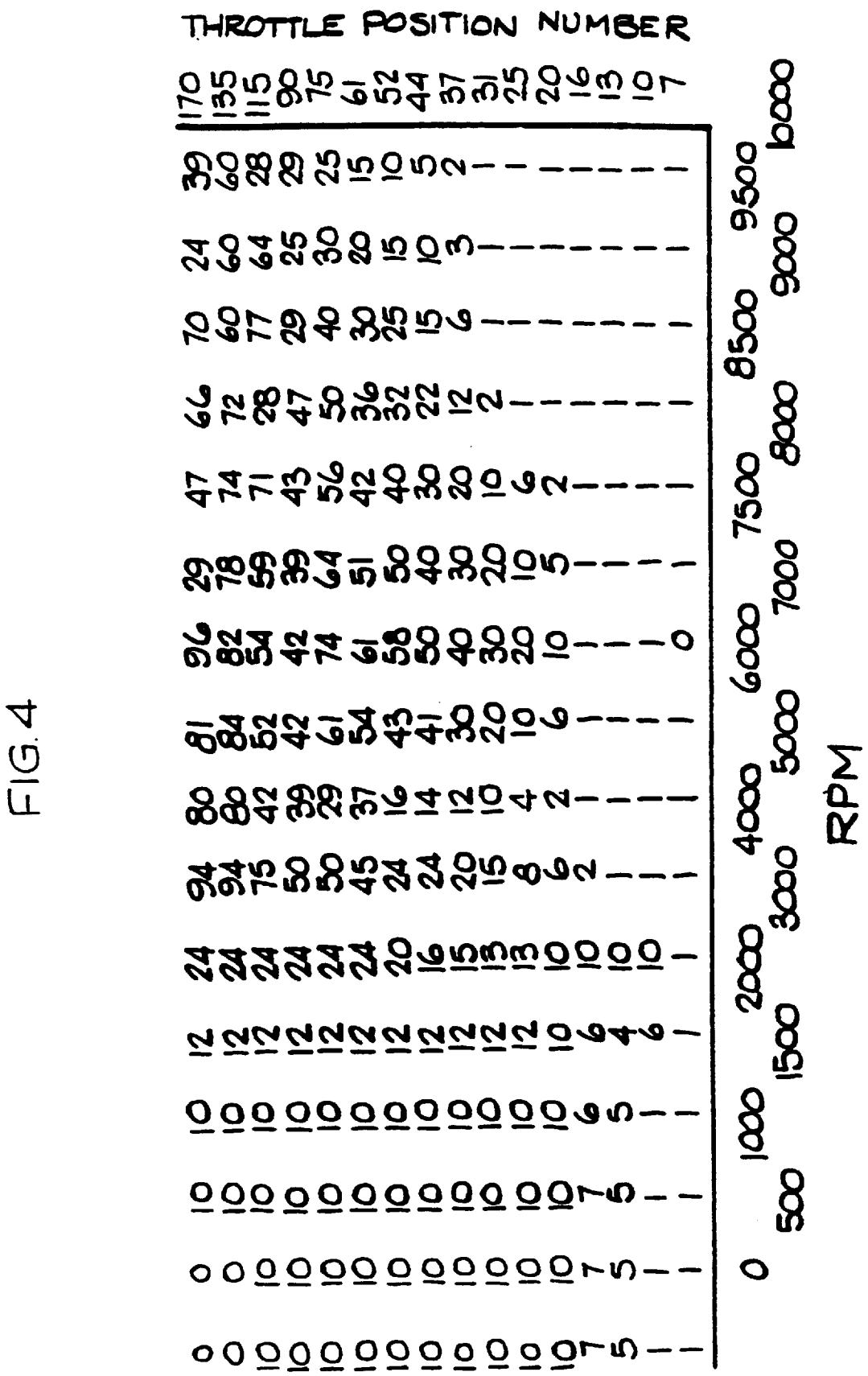
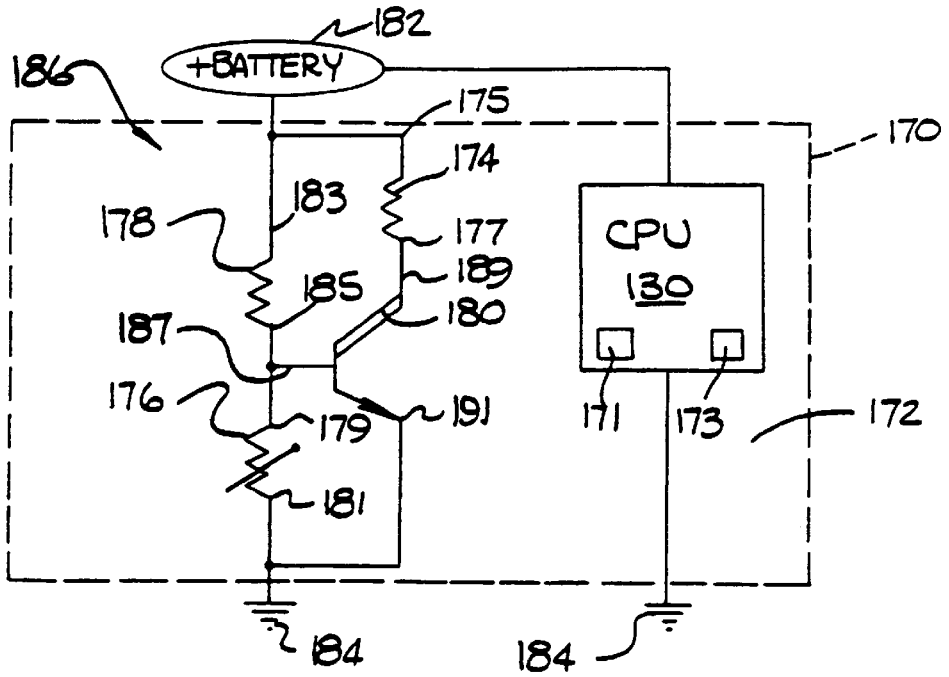

THROTTLE POSITION NUMBER
170 135 115 90 75 61 52 44 37 31 25 20 16 13 10 7
0 500 1000 1500 2000 3000 4000 5000 6000 7000 7500 8000 8500 9000 9500 10000
RPM

FIG. 4

FIG. 5


182
+BATTERY
186
175
170
174
183
178
177
CPU
130
189
185
180
187
176
191
171
173
172
179
181
184
184

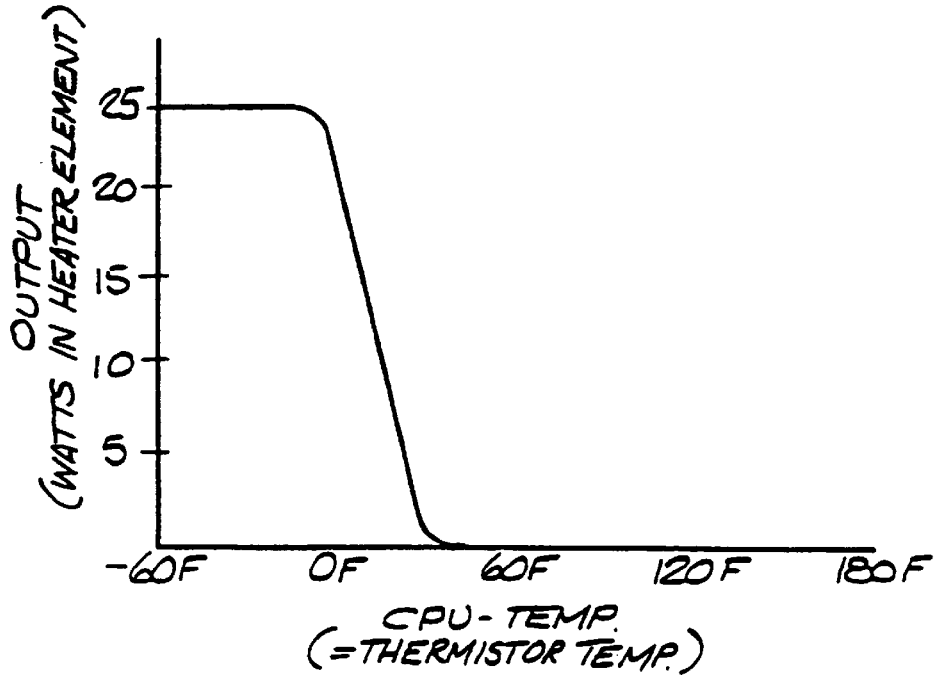

OUTPUT
(WATTS IN HEATER ELEMENT)
25
20
15
10
5
-60F
0F
60F
120F
180F
CPU-TEMP.
(=THERMISTOR TEMP.)

FIG. 6

TWO-CYCLE ENGINE WITH ELECTRONIC FUEL INJECTION

This application is a continuation of application Ser. No. 07/836,795, filed Feb. 18, 1992, now U.S. Pat. No. Re. 34,803, which is a continuation of U.S. patent application Ser. No. 119,626, filed Nov. 12, 1987, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates generally to two-stroke operating cycle engines and, more particularly, to a two-stroke engine fuel injection system and control system therefor which are adapted for extreme weather conditions.

Two-stroke operating cycle engines (two-cycle engines), although less fuel-efficient than four-stroke operating cycle engines (four-cycle engines), are capable of developing greater horsepower and torque than a comparably-sized four-cycle engine. This feature has led to the use of two-cycle engines in many environments in which operating efficiency is secondary to torque and weight considerations.

Electronically-controlled fuel injection is widely used in four-cycle engines. In electronic fuel injection used in four-cycle engines, sensor readings associated with various engine operating parameters are used to calculate an optimum fuel/air mixture for the engine. Fuel is then injected directly into the engine's cylinders in the proper amount based upon this electronically determined fuel/air mixture. In some four-cycle engine fuel injection systems, the fuel is injected into an air plenum upstream of the cylinder and is subsequently allowed to enter the cylinder with the plenum air through operation of an intake valve. Electronic fuel injection systems have replaced conventional carburetors in many four-cycle engines, especially in the automotive industry. However, fuel injection is not in general use with two-cycle engines and has not heretofore been used with small-displacement two-cycle engines which are used under severe cold weather conditions, for a number of reasons. Small two-cycle engines are used in association with equipment that is relatively inexpensive as compared to automobiles and other machines with which electronic fuel injection has been widely used in the past. In relatively large, expensive machinery, the cost associated with modifying basic engine components to enable internal mounting of various engine parameter sensors may be justified by increased fuel savings and engine performance and may amount to a relatively small portion of the purchase price of such an automobile, etc. In smaller engine environments, the cost of internal engine modification to existing engine assemblies would, in most cases, far outweigh any fuel savings which might be achieved by an electronic fuel injection unit and would represent a substantial increase in the cost of the associated small the two-cycle engine.

Fuel injection systems without electronic controls have been used on two-cycle engines, but have not been satisfactory on small-displacement, small-mass two-cycle engines. The reason that fuel injection without electronic control has not been used successfully in small two-cycle engines is that such engines lack flywheels and other high-mass rotating components which tend to stabilize engine operation. Dueto this lack of a large rotating mass in such engines, even a short duration mismatch between the rate at which fuel is actually delivered to the engine and the optimum engine fuel rate requirements will cause engine sputter or rapid deceleration and stalling. Small, two-cycle engines are especially subject to malfunction under variable operating conditions such as changes in sea level, with

associated barometric changes and changes in ambient air temperature. Many machines such as snowmobiles, snowblowers, dirt bikes, etc., are operated in such widely variable operating conditions. In view of the costs associated with engine modification for sensors' need for electronic control of fuel injectors and in view of the fact that the engine parameters which are critical to control of fuel injectors for two-cycle engines were not, prior to the present invention, understood in the art, a successful electronically-controlled fuel injection system for small, two-cycle engines which are subject to extremes in operating conditions has not been developed in the prior art.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide an electronic fuel injection system for a two-cycle engine which requires no internal modification to the basic engine assembly.

It is another object of the present invention to provide an electronic fuel injection control system which may be readily adapted for use with any conventional two-stroke cycle engine assembly.

It is another object of the present invention to provide a relatively small two-stroke cycle engine with electronic fuel injection which is capable of operation under variable and extreme conditions of air temperature and under widely varying barometric pressure conditions.

It is another object of the present invention to provide a fuel injection system for a two-cycle engine in which fuel injection takes place in an air manifold.

It is another object of the present invention to provide a fuel injection and control system for a two-cycle engine in which all fuel injectors simultaneously inject fuel into portions of an air manifold which are associated with individual cylinder/crankcases.

It is another object of the present invention to provide a control system for a electronic fuel injection system which utilizes relatively inexpensive electronic components and which is not subject to electronic component malfunction associated with low-temperature operation.

It is another object of the present invention to provide an electronic fuel injection system for a two-cycle engine which includes an electronically-stored fuel map indicative of the optimum fuel requirements for the engine under standard operating conditions over variable engine speed conditions and variable throttle conditions.

It is another object of the present invention to provide an electronic fuel injection system which provides a selected set of operating condition sensor inputs which do not require internal engine unit modifications and which provide optimized engine performance.

SUMMARY OF THE INVENTION

The present invention is directed to an electronic fuel injection system for a small two-cycle engine. One aspect of the invention is a temperature control assembly which is operably associated with an electronic central processing unit of the type having electronic components which are subject to malfunction under low temperature conditions. The electronic components of the heating assembly are not subject to malfunction under low temperature conditions and are designed to produce a heating response which is inversely proportional to temperature below a predetermined threshold temperature. The heating assembly is preferably mounted within a relatively small enclosure which

also houses the electronic control system central processing unit. The heating assembly senses the temperature within the relatively small enclosure and rapidly heats electronic components within the relatively small enclosure to a predetermined temperature in response to sensing an environmental temperature within the enclosure which is below the predetermined temperature. The heating system may be actuated at the same time the electronic control system is actuated such as by the turning of the ignition switch of an associated machine, such as a snowmobile, etc.

Another feature of the present invention is th provision of an electronically-controlled fuel injection system which has a plurality of sensor inputs which are limited to the sensor inputs which are critical to the operation of a two-cycle engine and which may be mounted externally of a main engine assembly comprising a cylinder crankcase, piston, and crankshaft exclusive of the carburetion/fuel injection system therefor. The electronically-controlled fuel injection system of the present invention may thus be used without modification of existing two-cycle engine assemblies and is controlled by a CPU which may include a programmable memory device such as an EPROM which may be selectively programmed for any particular engine assembly with which the electronic fuel injection system is to be used. Another feature of the invention is the injection of fuel from a fuel injector into a portion of an air manifold which is in direct fluid communication with the crankcase portion of each individual cylinder/crankcase assembly. This injection of fuel into a manifold upstream of a crankcase provides mixing of a precise amount of fuel and air prior to entry of fuel into the crankcase and also enables all fuel injectors to be opened and closed simultaneously, rather than being timed to the operation of each associated piston.

Thus, the present invention may comprise a control system for controlling the operation of a machine designed to be operated in a relatively broad air temperature, comprising: (a) at least one performance variable sensing means for sensing the present state of a preselected variable associated with machine performance and for generating a performance variable sensing signal indicative of said present state of said preselected performance variable; (b) a first data processing means for receiving and processing said performance variable sensing signal and for generating a control signal based upon the processing of said sensing signal for controlling at least one operating parameter of said machine; said data processing means comprising at least one temperature-sensitive electronic circuit component which is subject to malfunction below a predetermined malfunction temperature which is within said relatively broad operating temperature range of said machine; (c) component environment temperature sensing means for sensing the temperature within the immediate operating environment of said temperature-sensitive electronic circuit component and for generating a temperature signal representative of the sensed temperature; (d) a second data processing means which operates independently of said first data processing means and which is not subject to temperature-related malfunction within said operating temperature range of said machine for processing said signal from said component environment temperature sensing means and generating a heating control signal responsive thereto when the temperature in said electronic circuit environment is sensed to be below said predetermined malfunction temperature; (e) heating means responsive to said heating control signal for heating said temperature sensitive electronic component environment in response to said control signal; (f) power supply means for providing electric energy for operating said control system; (g) switch means for selectively operably electrically connecting or disconnecting said energy supply means and electrically operated components of said control system.

The present invention may also comprise a fuel injection system for a two-stroke cycle engine of the type comprising at least one cylinder, a crankcase associated with said cylinder, a piston reciprocally mounted in said cylinder and crankcase; a reciprocally openable and closable crankcase inlet for enabling combustible fluid to be drawn into the crankcase, a reciprocally openable and closable transfer port for transferring combustible fluid compressed in said crankcase to said cylinder, an ignition system for igniting compressed combustible fluid in said cylinder, a reciprocally openable and closable exhaust port in said cylinder for enabling exhaust of burned combustible fluid from said cylinder, a crankshaft connected to said piston for transferring mechanical energy from said piston to a drive unit, and an electrical energy supply source including a battery for operating the ignition system and other electrical components, comprising: (a) air manifold means operably associated with said crankcase inlet; (b) throttle valve means operably positioned in said air manifold means for controlling airflow into said crankcase inlet, said throttle valve means dividing said manifold means into an upstream portion positioned remote from said crankcase inlet and a downstream portion positioned contiguously with said crankcase inlet; (c) fuel injection means for injecting a fine spray of fuel into said downstream portion of said manifold means whereby a mixture of air and fuel is provided in said downstream portion of said manifold means which is subsequently drawn into said crankcase through said crankcase inlet; (d) fuel supply means for supplying fuel to said fuel injection means comprising: (i) fuel reservoir means for holding a volume of fuel therein and having a reservoir inlet and a reservoir outlet; (ii) fuel circulation conduit means for transferring fuel from said fuel reservoir to said fuel injection means comprising a first end inlet in fluid communication with said fuel reservoir outlet, a second end outlet in fluid communication with said fuel reservoir inlet and an intermediately positioned fuel injection outlet positioned in fluid communication with said fuel injection means; (iii) fuel pump means operatively associated with circulation conduit means at a position thereon between said conduit means first end inlet and said conduit means fuel injector outlet for pumping fuel through said circulating conduit; (iv) pressure limiting regulator means operatively associated with said circulation conduit means at a position thereon between said conduit means fuel injector outlet and said conduit means second end outlet for preventing pressure in said conduit means from exceeding a predetermined maximum pressure; (e) battery voltage sensing means for sensing battery voltage and for providing a battery voltage sensing signal representative thereof; (f) air temperature sensing means for sensing the temperature of air in said upstream portion of said manifold means and for providing an air temperature signal representative thereof; (g) engine speed sensing means for sensing the speed of revolution of said engine and for providing an engine speed signal representative thereof; (h) timing sensing means for sensing each occurrence of a predetermined cyclically repeating state of said engine and for providing a timing signal indicative thereof; (i) barometric pressure sensing means for sensing atmospheric air pressure and for generating a barometric pressure sensing signal representative thereof; (j) throttle position sensing means for sensing the relative amount of opening of said throttle valve means and for generating a throttle position signal representative thereof; (k) first data processing means

for receiving and processing said sensing signals comprising: (i) means for processing said engine speed sensing signal and said throttle position sensing signal and for generating a priming control signal to said fuel injection means for selectively injecting or not injecting fuel into said manifold means based on said engine speed signal and said throttle position signal; (ii) means for receiving and processing said engine speed signal and throttle position signal for determining a base fuel injection value; (iii) means for receiving and processing said air temperature signal and calculating an air temperature modification value of said base fuel injection value; (iv) means for receiving and processing said barometric pressure sensing signal for calculating a barometric pressure modification value of said base fuel injection value; (v) means for receiving and processing said engine temperature signal for calculating an engine temperature modification value of said base fuel injection value; (vi) means for determining a total fuel injection value representative of the total fuel amount which is to be injected by said fuel injection means during a single two-stroke operating cycle of said piston from said base fuel injection value, said air temperature modification value, said barometric pressure modification value, and said engine temperature modification value; (vii) means for determining an injector open duration interval based on said total fuel injection value and a known fuel output rate capacity of said fuel injection means; (viii) means for generating a control signal for opening said injection means for said determined injector duration open interval at a predetermined point in time determined from said timing sensing signal; (ix) means for receiving and processing said engine speed signal for overridingly terminating fuel injection means operation in response to an engine speed sensing signal indicative of a predetermined maximum speed and for restoring fuel injection means operation in response to an engine speed sensing signal indicative of a predetermined restore operation speed lower than said predetermined maximum speed; (x) means for receiving and processing said engine speed sensing signal and for generating a pump control signal in response thereto for maintaining said pump at an optimum operating speed for providing said predetermined maximum operating pressure in said fuel circulation conduit means at said pump; (l) first data processing means temperature sensing means for sensing the relative temperature of certain electronic components in said first data processing means and providing a component temperature sensing signal indicative thereof; (m) heating means operative associated with said first data processing means electronic components for selectively heating said electronic components; (n) second data processing means operable independently of said first data processing means for receiving said electronic component temperature sensing signal and for generating a control signal to said heating means responsive to said component temperature sensing signal for heating said components when the temperature thereof is below a predetermined minimum value.

BRIEF DESCRIPTION OF THE DRAWING

An illustrative and presently preferred embodiment of the invention is shown in the accompanying drawing in which:

FIG. **1** is a schematic illustration of a two-stroke cycle engine with electronically-controlled fuel injection.

FIG. **1A** is a schematic illustration of the engine of FIG. **1** showing additional cylinder portions thereof.

FIG. **2** is a flow chart illustrating operations of the electronic control unit of the present invention including the operation of the central processing unit and also the operation of a central processing unit temperature control assembly.

FIG. **3** is a diagram illustrating sensor inputs and control signal outputs and basic functions performed by an electronic control unit.

FIG. **4** is a typical engine fuel map expressed in rectangular coordinates.

FIG. **5** is a schematic illustration of an electronic control unit for a fuel injection system.

FIG. **6** is a graph of heater output as a function of CPU temperature for a typical CPU temperature control assembly of the type illustrated in FIG. **5**.

DETAILED DESCRIPTION OF THE INVENTION

A two-stroke engine unit **10** of the present invention is shown schematically in FIG. **1**. In general, the two-stroke cycle engine unit **10** comprises an engine assembly **12**, an ignition assembly **14**, a fuel/air input assembly **16**, an electronic control assembly **18** and an electrical power supply assembly **20**.

ENGINE ASSEMBLY

The engine assembly **12** illustrated in FIG. **1** is of a type which is conventional and well known in the art. The engine assembly comprises a cylinder cavity **30** which is generally referred to in the art simply as a cylinder. The cylinder cavity is defined by a cylindrical sidewall **32** and a circular top well **34** which is fixedly attached to the sidewall **32**. The engine assembly also comprises a generally pear-shaped crankcase cavity **36** which is generally referred to in the art simply as a crankcase. The crankcase cavity is defined by a crankcase sidewall **38** which is fixedly connected at the upper portion thereof to a lower portion of cylindrical sidewall **32**. The crankcase wall is fixedly connected at a lower portion thereof to a base plate **40**. The cylindrical cavity **30** and crankcase cavity **36** thus provide the upper and lower portions of a continuous total engine cavity. A cylindrical piston **42** is slidingly mounted in cylindrical cavity **30** and is pivotally attached to a connecting rod **44** which is, in turn, pivotally attached to a portion of crankshaft **46** which rotates, as indicated at **47**, about a crankshaft central axis of rotation **48**. The reciprocal motion of piston **42** within cylinder **30** is transferred by connecting rod **44** and crankshaft **46** to a conventional drive assembly **50** of an associated machine such as, for example, a snowmobile **12**.

A fuel/air mixture which is sometimes referred to herein as combustion fluid or combustion material is drawn into the crankcase **36** through a combustion fluid inlet **52** sometimes referred to herein as an intake port **52**. The intake port **52** is positioned at an upper portion of crankcase **36** and is cyclically opened and closed by reciprocation of piston **42**. Transfer passages **54**, **56**, etc., having crankshaft transfer passage openings **58**, **60**, etc., and cylinder transfer port openings **62**, **64**, etc., enable transfer of compressed combustion fluid within the crankcase **36** to the cylinder **30**. The cylinder transfer passage openings **62**, **64**, etc., are cyclically opened and closed through reciprocal motion of piston **42**. A cylinder exhaust gas outlet **66** sometimes referred to herein as exhaust port **66** is provided in the cylinder sidewall **32** to discharge burned combustion fluid from cylinder **30**. Exhaust port **66** is also cyclically opened and closed by reciprocation of piston **42**. The engine assembly may comprise a plurality of cylinder/crankcase/piston assemblies

identical to those described above which are operable connected to common crankshaft **46**.

The mechanical operation of the two-cycle engine assembly, in general, is as follows. During upward motion of piston **42**, crankcase intake port **52** is progressively opened and cylinder transfer passage openings **62**, **64** and cylinder exhaust port **66** ar progressively closed causing fuel/air mixture to be drawn into crankcase **3** through port **52** and causing fluid air mixture in cylinder **30** to be retained therein and progressively compressed. When the piston **42** reaches approximately its upward limit of motion or "top dead center" (T.D.C.), sparkplug **70** ignites the fuel/air mixture driving piston **42** downwardly. During the downward movement of the piston, cylinder exhaust port **66** is progressively opened, cylinder transfer port openings **62** and **64** are progressively opened and crankcase inlet **52** is progressively closed causing fuel/air mixture within the crankcase to be compressed and forced through the transfer passages **54**, **56** into cylinder **30**. The inflow of fresh fuel/air mixture into cylinder **30** is physically channeled into the cylinder in a manner to drive out burned exhaust gas within the cylinder out through exhaust port **66**. During the subsequent upward movement of the piston **42**, the abovedescribed cylinder fuel/air compression and crankcase fuel/air intake is again repeated, etc.

IGNITION ASSEMBLY

Ignition assembly **14** comprises a conventional sparkplug mounted within cylinder **34** for igniting the fuel/air mix therein. Sparkplug **70** is conventionally connected to an ignition coil **72** which is, in turn, conventionally connected to an electrical power supply **20** and conventional timing apparatus **74** which may be conventionally linked to crankshaft **46**. In an engine assembly with a plurality of cylinder/crankcase/piston assemblies, each cylinder is provided with a spark plug.

FUEL AIR INPUT ASSEMBLY

Fuel air input assembly **16** includes an air manifold **80** mounted in fluid communication with crankshaft intake port **52**. A throttle valve **82**, which in a preferred embodiment comprises a conventional butterfly valve, divides the air manifold **80** into an upstream portion **84** which is in fluid communication with atmospheric air **8** through conventional air filters, etc. (not shown) and a downstream manifold portion **86** which opens directly into crankcase **36**. In the case of a multiple cylinder engine, there may be a single manifold upstream portion and a plurality of downstream portions, one for each cylinder/crankcase. An electrically operated fuel injector **92** comprising a solenoid valve portion **94** and a gas jet nozzle portion **96** is mounted so as to discharge a gas spray into the downstream manifold portion **86** to produce a fuel/air mixture in the downstream manifold portion which is subsequently drawn into crankcase **36**. The fuel injector may be of a convention commercially available type such as Bosch 280150-007 available from the Robert Bosch Company, or NAPA 217514 available from Echlin, Inc., Branfort, Conn., 06405. The fuel injector **92** is connected at the solenoid valve end thereof to a fuel circulation conduit **98** which is in fluid communication with a fuel reservoir **102** in fuel tank **100**. The fuel circulation conduit comprises a conduit first end **104** connected to a fuel tank outlet **106** and a second end **108** connected to a fuel tank return inlet **110**. An electric fuel pump **112** is provided for pumping fuel, such as gasoline, through the conduit **98**. The electric fuel pump **112** is operably connected in fluid communication with the conduit at a point thereon between the fuel tank outlet **106** and the fuel injector **92**. Conventional speed control circuitry **113** is provided to control the relative pumping speed of the fuel pump in response to a signal from the electronic control assembly **18** as discussed in further detail below. The fuel pump is conventionally connected to the electrical power supply assembly **20** from which it draws its operating energy. A conventional mechanically operated pressure limiting regulator **114** is operatively mounted in the fuel circulation conduit at a point between the fuel injector **92** and the fuel tank return inlet **110**. Pressure regulator **114** prevents the fluid pressure in the circulating conduit from exceeding a predetermined maximum pressure which may be, e.g. 42 psia. A conventional coarse fuel filter **116** may be provided in the circulating conduit between fuel tank outlet **106** and fuel pump **112**. A conventional fine fuel filter **118** may be provided in the circulating conduit between the fuel pump and injector **92**. As shown in phantom in FIG. **1**, the above-described fuel system may be employed to provide fuel to further fuel injectors **120**, **122** which are attached in fluid communication with the circulating conduit between the first fuel injector **92** and the pressure regulator **114**. These fuel injectors **120**, **122** may be mounted in manifold assemblies which may be identical to manifold assembly **16** described above and which are in turn associated with ignition assemblies and cylinder/crankcase piston assemblies **121**, **123** which may be identical to those described above and which may be operably connected to a common electronic control assembly **18** and electrical power supply assembly **20**.

ELECTRONIC CONTROL ASSEMBLY

Electronic control assembly **18** includes a central processing unit **130** described in further detail below which is operably connected to conventional interface circuitry **132** which may comprise conventional analog to digital (A/D) circuitry for converting analog sensor signal inputs to digital signal inputs and which may further comprise conventional digital to analog (D/A) interface circuitry used to convert digital CPU command signals to analog command signals which are used to control various engine operating components as described below.

The electronic control assembly comprises a number of sensors having sensor outputs which are provided to the CPU **130** through interface circuitry **132**. These sensors may include a battery voltage sensor **134**, an air temperature sensor **136**, an engine temperature sensor **138**, an engine speed sensor **140**, an ignition timing sensor **142**, a barometric pressure sensor **144**, and a throttle position sensor **146**. The battery voltage sensor may comprise a conventional sensor or current sensing circuit well-known in the art. The air temperature sensor **136** may comprise a T55101 NAPA sensor mounted in the engine manifold. The engine temperature sensor **138** is mounted on the cooling fins of an air-cooled engine or may comprise a TS 4000 NAPA mounted within the engine cooling water jacket of a liquid cooled engine. The engine speed sensor **140** may comprise a conventional electronic encoder mounted on the crankshaft or associate drive linkage. In such an engine speed sensor configuration, an engine speed value is determined by counting the number of encoder pulses occurring within a fixed time interval. This timing interval may be provided by an external clock pulse signal or a CPU internal clock signal. The ignition timing sensor **142** may comprise an electric signal sensor connected directly to the ignition coil **72** for sensing the time of ignition of each cylinder. In such an ignition timing sensor configuration, the CPU is pro-

grammed to respond to only one cylinder ignition pulse per engine revolution. Thus, for example, in a three cylinder engine, the CPU would respond to only the first ignition coil pulse in each three pulse set associated with a complete engine revolution. Similarly, the ignition timing sensor signal may be derived directly from encoder signal **140** simply through counting the number of encoder pulses which are associated with a single revolution of the engine and generating a timing pulse after the occurrence of such a predetermined number of encoder pulses.

Barometric pressure sensor **144** may be mounted in any convenient location where it is exposed to the atmosphere such as, for example, on the housing of the CPU **130**. The barometric pressure sensor **144** may be any of a number of commercially available sensors such as a Motorola MPX 201. Throttle position **146** senses the relative amount of opening of the throttle butterfly valve **82** and may comprise a conventional potentiometer unit.

The CPU **130** receives and processes the signals from the various sensors described above and generates control signals which are used to control fuel pump speed, to maintain the speed of operation of the fuel pump at a rate which provides a pressure in the circulation conduit portion immediately downstream therefrom which is approximately equal to the preset maximum pressure of the pressure regulator **114**. The CPU **130** also generates control signals which actuate the solenoid valve portion **94** of each fuel injector **92** to selectively open and close and injector to provide a proper amount of fuel injection into the manifold as determined by the CPU. The CPU **130** may also provide a number of other control functions a described in further detail below. The CPU **130**, in a preferred embodiment of the invention, comprises a conventional microprocessor chip **171**, FIG. **5**, such as a Motorola 6502 and a conventional memory chip **173**, FIG. **5**, which may be a PROM or EPROM chip such as, for example, Motorola 2532.

The electronic control assembly may also comprise a CPU temperature control assembly. One embodiment of such a temperature control system is illustrated in FIG. **5** in which CPU **130** is mounted within a relatively small, e.g. 10 cubic inches, CPU protective enclosure box **170** which defines a local CPU environmental enclosure **172**. The box **170** may be 2.5 inches×5 inches×0.75 inches. Also positioned within the CPU environment enclosure are a conventional heating coil **174** having terminals **175**, **177**, which may have a resistance of 50 ohms, and a conventional thermistor **176**, which may be, e.g., an NTC 750 ohm thermistor. The heater element and thermistor are connected as shown in an electronic circuit containing a second resistor **178** having terminals **183**, **185** and having a resistance of 10,000 ohms, and a Darlington transistor **180** having a gate terminal **187**, a collector terminal **189**, and an emitter terminal **191**, which may be a Motorola 6668 which may have an amplification of 400%. The circuit containing the circuit elements **174**, **176**, **178**, **180** is connected to the positive pole of a battery **182** and a ground (or negative pole of a battery) **184**. The battery **182** may also be used to provide power for CPU **130**. Battery **182** may be same or different from the battery **150** used to provide energy to the engine ignition system, etc. The voltage drop across **182**, **184** may be, e.g., 5 volts. The characteristics of the particular circuit elements **174**, **176**, **178**, **180** may be selected to provide a heating energy response to particular temperature conditions such as indicated in FIG. **6** for rapidly heating the CPU environment **172** to a predetermined maximum threshold value such as 60° F. It will thus be seen that the heating circuit indicated generally at **186** is adapted to maintain the CPU at a temperature which is above a predetermined low temperature, e.g. 60° F., below which certain components of the CPU are subject to a greatly increased probability of malfunction. It will of course be appreciated that this predetermined temperature may be chosen to have a value well above a temperature at which malfunction is probable. A heating circuit such as illustrated at FIG. **5** may be provided relatively inexpensively and thus eliminates the need for expensive CPU chips which are adapted to be operable under low temperature conditions. The heating circuit such as illustrated at FIG. **5** is adapted to be particularly effective under conditions associated with the usage of snowmobiles and other winter operated machines such as snowblowers, etc.

ELECTRIC POWER SUPPLY

The engine electric power supply **20** may comprise conventional power supply components such as a battery **150** which may be a conventional 12-volt battery and other power generating devices such as alternator or generator which are represented schematically at **152**. Power to the electronic control assembly **18**, fuel input assembly **16**, and other electrically-operated components may be provided through conventional conductors **154** operably connected to a switching assembly **156** which may be a snowmobile ignition switch, etc.

An engine unit comprising multiple cylinder/crankcase/piston assemblies **12**A, **12**B, **12**C in engine assembly **12** and comprising an ignition assembly with multiple spark plugs **70**A, **70**B, **70** with a common crankshaft **146** and a common electronic control assembly **18** and a common power supply **20** is shown in FIG. **1**A.

Having thus described the overall construction and operation of the two-stroke cycle engine unit **10** in general, certain specific features of the electronic control assembly **18** will now be described in greater detail.

CONTROL SYSTEM FUNCTIONS

The basic functional steps performed by the control assembly central processing unit **130** is illustrated in FIG. **2**. As illustrated at **300**, the control system becomes operational by switching the system on. In a typical use environmental such as when the control system is used in associated with a snowmobile engine, step **300** would be performed by turning the snowmobile ignition switch to the "on" position. As illustrated at **301** switching the system on causes electrical energy to be provided to the CPU which initializes all ports and functions of the CPU. Next, the CPU reads the engine speed and throttle position which are indicated as RPM and T.P., respectively, in block **302**. Next, as indicated in blocks **303–307**, the CPU determines whether or not the engine is to be primed. The sequence of steps **302–307** comprises what will be referred to herein as a "cold start circuit". As indicated at **303**, the CPU determines from the reading taken at **302** whether or not the engine RPM is greater than 0. If engine RPM is greater than 0, the CPU next makes the determination from the throttle position reading of **302** whether or not the throttle position is greater than a predetermined amount, such as 20°, as indicated in block **304**. If throttle position is less than 20°, the CPU decision-making process returns to block **302**. If the throttle position is greater than the predetermined amount and RPM=0, the CPU provides a control command to the engine fuel injector (s) to prime the engine. In a preferred embodiment of the invention, an engine priming pulse of a predetermined fixed duration associated with a predetermined fixed amount of

fuel, e.g. 100 milliliters per injector, is sent to each fuel injector in response to a prime engine command from the CPU. After an initial engine priming function indicated at **305** has been performed, the CPU again reads throttle position as indicated at **306**. After reading the throttle position, the CPU again determines whether or not the throttle position is greater than a predetermined amount such as 20°. If the throttle position is greater than 20°, then the CPU again returns to decision step **306** and repeats step **306**, **307** until the throttle position is less than 20°. In a typical operating environment, this would be the equivalent of waiting for an operator to release an opened throttle lever/pedal. Once the throttle position is reduced to below 20°, as indicated at block **307**, the CPU decision-making processing returns to block **302**, causing the cold circuit decision-making process of blocks **302–307** to be repeated until engine RPM is greater than 0. After engine RPM becomes greater than 0, the CPU reads all of the input values from the various sensors, as shown schematically in FIG. **3**.

Next, as indicated at **309**, the CPU determines a base fuel value from a "fuel map" and the engine speed input and the throttle position input. A fuel map is prepared and stored in permanent memory of the CPU based upon the operating characteristics of the particular engine which is being controlled. The fuel map is prepared and stored in permanent CPU memory in an initial production step before the CPU is used to control the engine. A typical fuel map is illustrated in FIG. **3** in which the horizontal axis is indicative of engine RPM value and the vertical axis, as indicated at the right-hand side of the fuel map, is indicative of throttle position. Throttle position may be expressed, for example, in angular degrees of throttle opening or may be expressed in assigned numbers relating, non-linearly, to throttle opening which enables a higher resolution of the fuel map in certain critical regions of an engine power curve. The data array shown in FIG. **3** indicates the optimum base fuel value in milliliters for an engine fuel injector single pulse under predetermined standard operating conditions for any given engine RPM and throttle position. For example, if the engine RPM is 6000 and the throttle position is **25**, the optimum base fuel value as indicated from the fuel map is 20 milliliters under standard operating conditions. It will, of course, be appreciated that the information provided in the fuel map may be stored in various electronic forms such as in algorithm form as well as look-up table form. It will also be appreciated that the resolution of the fuel map may be provided to conform with the resolution of the RP and throttle position sensing signals and with the resolution requirements of the control system.

The base fuel value from the fuel map (FIG. **4**) reading performed in block **309** and indicated as V-**1** is stored in CPU memory and is modified in steps **310–313** based upon the various input values read in block **308**. As indicated at block **310**, the base fuel value is first modified based on the air temperature input. At a predetermined operating temperature, e.g. standard operation conditions of 70° F., no modification is performed. If the temperature is above or below this predetermined value, then the base fuel value is modified accordingly based upon a predetermined algorithm or look-up table which is stored in permanent memory. Algorithms for engine fuel requirement modification based upon ambient air temperature are well-known in the art. The modified base value determined based upon air temperature modification is indicated as V-**2**.

As indicated in block **311**, the modified base value V-**2** is next further modified based upon the barometric pressure reading. This modification may again be performed by use of a conventional algorithm or look-up table stored in permanent memory. The resulting modified fuel value is indicated as V-**3**.

As indicated in block **312**, modified value V-**3** is next further modified based upon engine temperature. The modified value is indicated as V-**4**. This modification may be made either from a stored algorithm or a stored look-up table which is prepared based upon the particular engine temperature operating characteristics of the subject engine.

Next, as indicated in block **313**, the modified fuel value V-**4**, which is indicative of the total corrected (compensated) fuel amount that each injector should inject into the engine during each revolution thereof for optimum performance, is used to determine the duration of injector opening which is required to provide fuel injector parameters, e.g. with a known, constant fixed fuel pressure and a known, fixed injector orifice size, etc. This duration is indicated at V-**5** and may be expressed in milliseconds. An alternative to modifying base fuel value is sequential steps as described above in **310–312**; relative correction factors may be simultaneously computed based on the variables indicated in **310–312** and a total correction factor may be derived therefrom and applied to the base fuel value to arrive at a total corrected fuel amount V-**4**.

Next, as illustrated in blocks **314** and **315**, the CPU determines whether a predetermined cyclically reoccurring state (repeating once per engine revolution) of the engine, such as, for example, a top dead center position of a selected one of the pistons, has been reached. Once that cyclically reoccurring engine state has been reached, the CPU provides a control command to the fuel injector(s) causing the fuel injector(s) to be opened for the predetermined length of time V-**5** calculated in step **313**. It will be appreciated that for a multiple cylinder engine the injectors may be opened sequentially at a predetermined spacing in time associated with the piston positions in the various cylinders, or all of the injectors may be opened simultaneously. In the preferred embodiment of the invention, all of the injectors are opened simultaneously due to the fact that, with the injection of fuel into the manifold, as opposed to conventional fuel injection into the crankcase, the sequential timing of injectors in unnecessary.

Next, as indicated in block **317**, the engine RPM value from step **308** is compared to a predetermined maximum desired engine RPM such as, for example, 8500 RPM. If the engine speed is less than the predetermined maximum value, then the CPU again returns to operating step **308** and repeats steps **308–317**. If the engine speed is greater than the predetermined value, then, as indicated in block **318**, the CPU provides a control signal which closes the fuel injectors.

Next, as indicated in block **319**, the CPU again reads the RPM input value. If the RPM input value is greater than a predetermined value which may be less than the maximum engine RPM (e.g. 8200 RPM), then the fuel injectors are retained in a closed positioned as indicated in step **318**, and steps **319** and **320** are repeated. If the engine speed is less than 8200 RPM, then the CPU returns to step **308**. Thus, once the engine reaches 8500 RPM, the fuel injectors are closed and remain closed until engine speed drops to 8200 RPM. This total termination of fuel as opposed to conventional speed control methods which simply reduce fuel injection amount or terminate ignition prevents damage to the engine or spark plug fouling associated with such prior art methods.

It will be understood by those with skill in the art that the total corrected (compensated) fuel value may be based on an

average derived from several iterations of sensor inputs and total corrected fuel value calculations. It will also be appreciated that the actual fuel adjustments may be made at intervals less frequent than those in which total fuel value calculations are made, e.g. input readings and fuel value calculations may be made 100 times per second and total fuel injection duration may be adjusted 16 times per second.

The CPU **130** may also control pump speed based upon engine RPM. For example, at engine start up when RPM=0, the fuel pump may be actuated by a control signal from CPU **130** to cause it to run at full speed for one second and then stop until RPM is greater than zero. Above RPM=0, the CPU may cause the pump to run at 50% of its rated capacity (drawing one-half its normal maximum current amount) up to a predetermined engine speed, e.g. 3600 RPM. Above this predetermined speed, the CPU may cause the pump to operate at 100% of its rated capacity. Of course, more than two pumping rates may be provided, if desired, based upon a plurality of different engine RPM ranges. Such an arrangement, as well as providing optimum pressure, reduces energy draw on the electrical power supply at start-up and at low RPM.

As further indicated by FIG. **2**, the switching on of the ignition, etc., at step **300** also operates a control circuit which functions independently from the CPU **130** which performs the functions indicated in steps **300–320**. In this independent circuit, as indicated at step **330**, the temperature in the immediate environment of the chip components (e.g. microprocessor, EPROM, etc.) which comprise CPU **130** is initially determined. Next, as indicated at step **331**, if the temperature within the CPU environment is greater than a predetermined temperature, such as, for example, 60° F., then the system returns to step **330** and cycles between **330** and step **331**. When the temperature in the immediate operating environment of the CPU is sensed to be below the predetermined temperature, then the system actuates a temperature control device, such as a heating coil, to elevate the temperature in the environment of the CPU. Next, as indicated as step **333**, the temperature within the operating environment is again read and compared to a predetermined temperature which may be the same or higher than the minimum temperature of step **331**. If the temperature is below this second predetermined temperature, such as, e.g. 60° F., then the temperature control device continues to operate. If the temperature exceeds this second predetermined temperature, then the operation of the temperature control device is terminated and the system again returns to step **330**.

It will be appreciated that these general control functions described in steps **330–335** apply to any system which is designed to maintain the temperature within a particular environment within a predetermined temperature range. Such temperature control could be performed by any number of conventional heating/air conditioning systems. In the presently preferred embodiment, a temperature control system which is not subject to malfunction at lowered temperatures, e.g—b 60° F., is provided such as illustrated in FIG. **5** and discussed above.

All "Motorola" components indicated herein are commercially available from Motorola, Inc., 8201 E. McDowell Road, Scottsdale, Ariz., 85257-3812. All "NAPA" components indicated herein are commercially available from Echlin, Inc., Branfort, Conn., 06405.

While an illustrative and presently preferred embodiment of the invention has been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed and that the appended claims are intended to be construed to include such variations except insofar as limited by the prior art.

What is claimed is:

1. A fuel injection system for a two-stroke cycle engine of the type comprising at least one cylinder, a crankcase associated with said cylinder, a piston reciprocally mounted in said cylinder and crankcase; a reciprocally openable and closable crankcase inlet for enabling combustible fluid to be drawn into the crankcase, a reciprocally openable and closable transfer port for transferring combustible fluid compressed in said crankcase to said cylinder, an ignition system for igniting compressed combustible fluid in said cylinder, a reciprocally openable and closable exhaust port in said cylinder for enabling exhaust of burned combustible fluid from said cylinder, a crankshaft connected to said piston for transferring mechanical energy from said piston to a drive unit, and an electrical energy supply source including a battery for operating the ignition system and other electrical components, comprising:

a) a fuel injector for injecting fuel to a manifold for combustion within said cylinder;

b) a fuel pump for supplying fuel to said fuel injector;

c) an air temperature sensor for providing a signal indicative of ambient air temperature;

d) an engine speed sensor for providing a signal indicative of a speed of revolution of said engine;

e) a timing sensor for providing a signal indicative of engine timing;

f) a barometric pressure sensor for providing a signal indicative of atmospheric air pressure;

g) a throttle position sensor for providing a signal indicative of an amount of opening of an engine throttle valve;

h) an engine temperature sensor for providing a signal indicative of engine temperature;

i) a look-up table of experimentally determined base fuel injection values at predetermined standard operating conditions is stored according to engine revolution speed and throttle valve opening amount for the two-stroke cycle engine to be fuel-injected; and

j) a processor executing a program performing the following functions:

1) turning said fuel pump on and off,

2) receiving the engine revolution speed signal and the throttle valve opening amount signal, and retrieving a corresponding base fuel injection value from said experimentally determined look-up table,

3) receiving the ambient air temperature signal and calculating an air temperature modification value of the base fuel injection value,

4) receiving the atmospheric air pressure signal and calculating a barometric pressure modification value of the base fuel injection value,

5) receiving the engine temperature signal and calculating an engine temperature modification value to the base fuel injection value,

6) determining a total fuel injection value from the base fuel injection value, the air temperature modification value, the barometric pressure modification value, and the engine temperature modification value,

7) determining an injector open duration interval based upon the total fuel injection value and a known fuel output rate capacity of said fuel injector, and

8) generating a control signal for opening said fuel injector for the determined injector open duration interval in response to the engine timing signal.

2. The fuel injection system of claim 1 wherein the predetermined standard operating conditions include ambient air temperature, atmospheric air pressure, and engine temperature at the time the base fuel injection value are experimentally determined.

3. The fuel injection system of claim 2 wherein the air temperature modification value, the barometric pressure modification value, and the engine temperature modification value are determined based upon the predetermined standard operating conditions.

4. The fuel injection system of claim 1 wherein said processor program generates a priming control signal in response to the engine revolution speed signal and the throttle valve open amount signal.

5. The fuel injection system of claim 1 wherein said engine temperature sensor is an engine block temperature sensor.

6. The fuel injection system of claim 1 including a battery voltage sensor for providing a signal indicative of battery voltage, and wherein said processor receives the battery voltage signal.

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