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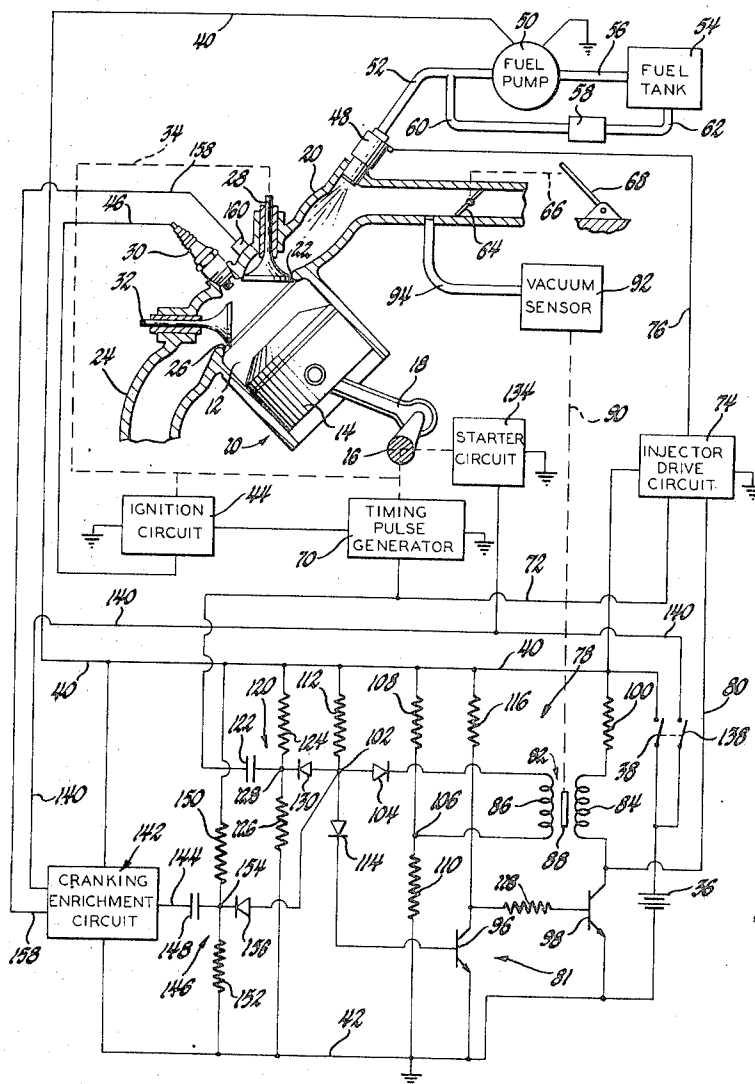
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[54] FUEL SUPPLY SYSTEM FOR AN INTERNAL
COMBUSTION ENGINE PROVIDING TIMED
CRANKING ENRICHMENT
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ABSTRACT: In an electronic fuel injection system, fuel is applied to an internal combustion engine for the duration of individual control pulses developed in synchronization with the rotation of the engine. The engine-starting sequence is divided into alternate cranking periods and resting periods. During each cranking period, additional control pulses are supplied at a frequency which is inversely related to the temperature of the engine. Further, the additional control pulses are supplied only during an enrichment interval. The minimum duration of the enrichment interval is determined as a direct function of the duration of the cranking period. The maximum duration of the enrichment interval is determined as a direct function of the duration of the preceding resting period and as an inverse function of the duration of the previous cranking period.



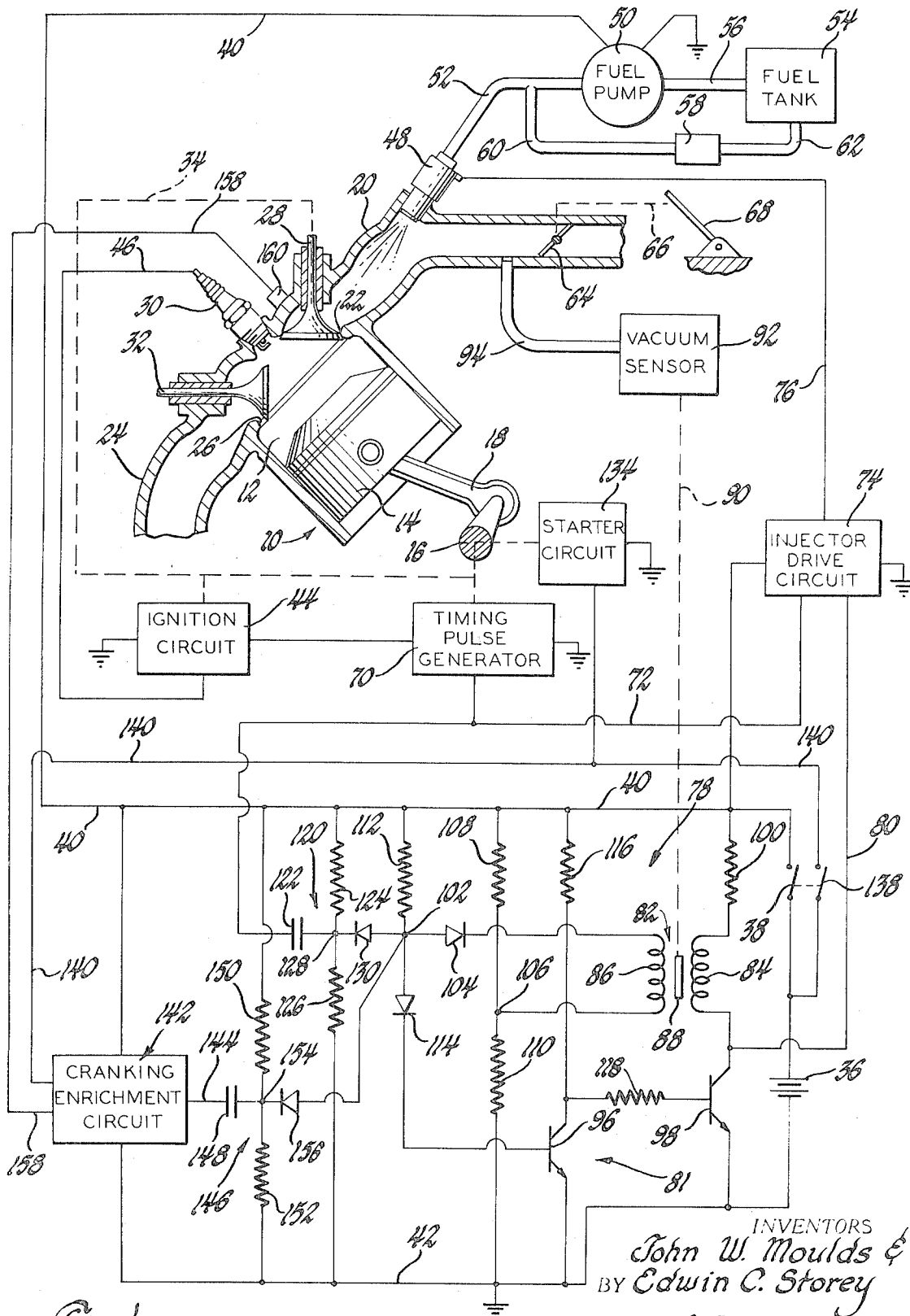


Fig. 1

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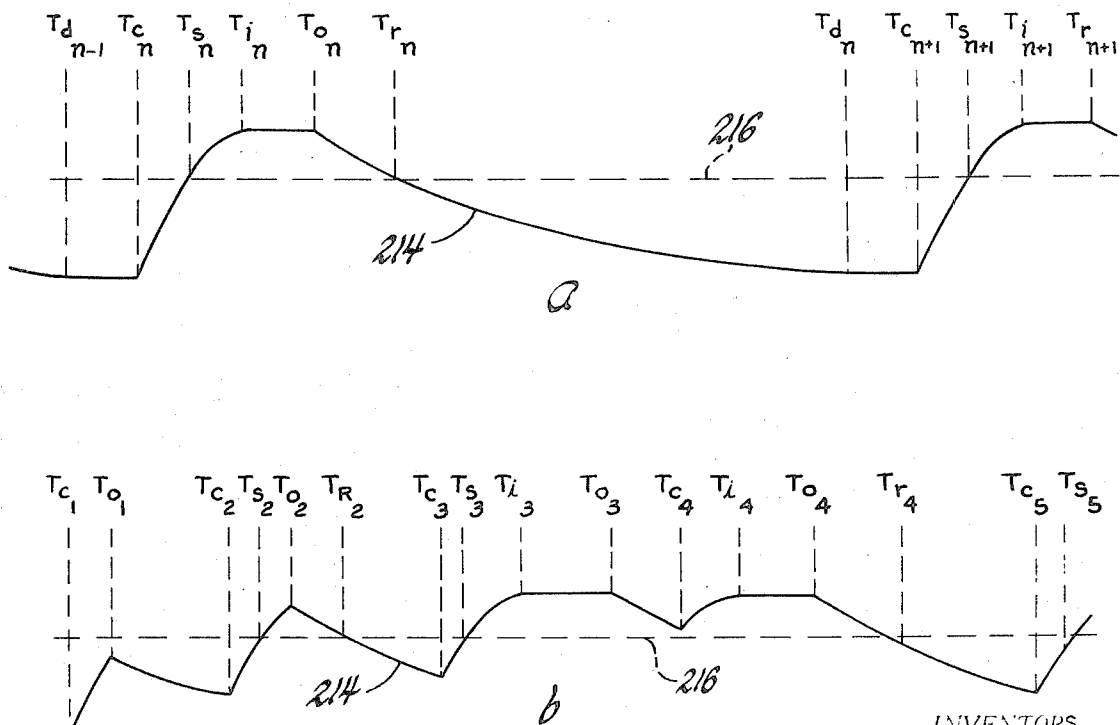
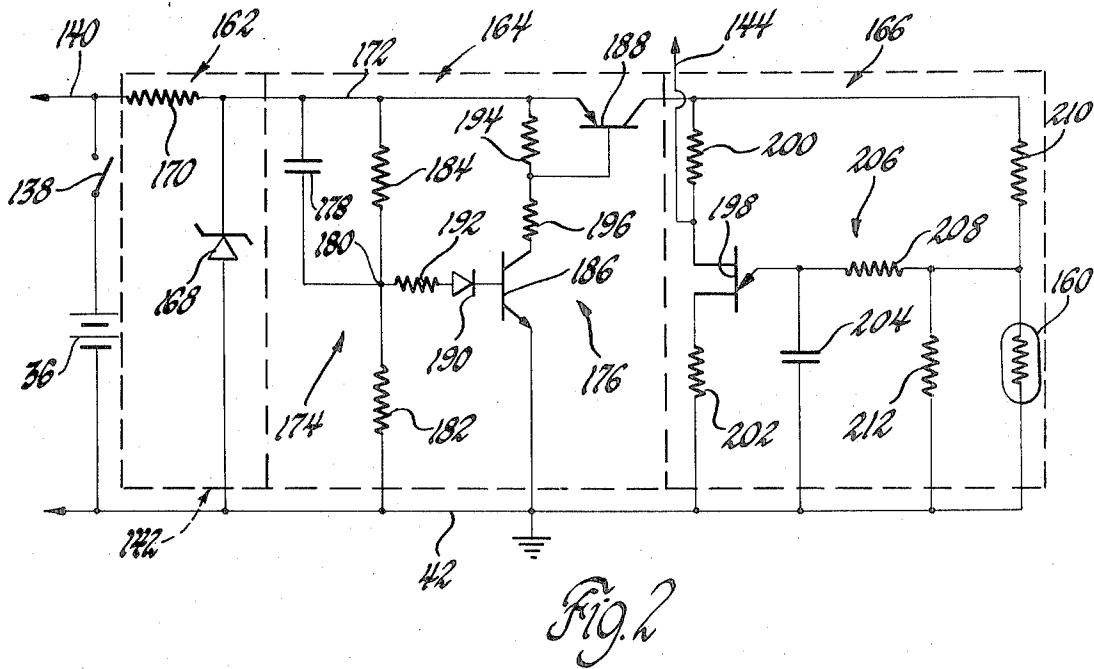


Fig. 3

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FUEL SUPPLY SYSTEM FOR AN INTERNAL COMBUSTION ENGINE PROVIDING TIMED CRANKING ENRICHMENT

The present invention relates to a fuel supply system for an internal combustion engine. More particularly, the invention relates to an electronic fuel injection system for increasing the amount of fuel applied to an internal combustion engine during cranking.

In a well-known electronic fuel injection system, fuel is deposited within the intake manifold of an engine at a constant flow rate for the duration of individual control pulses developed in synchronization with the rotation of the engine. Since the engine rotation is relatively low during cranking, the number of control pulses normally produced is generally insufficient to apply enough fuel to the engine to ensure reliable starting. Further, some of the applied fuel tends to condense within the intake manifold of the engine during cold cranking. Accordingly, additional control pulses are produced during a cranking period to increase the amount of fuel applied to the engine to facilitate quick starting. In addition, since the total fuel condensation decreases as the engine temperature increases, the frequency of the additional control pulses is varied as an inverse function of the temperature of the engine.

With the previously described electronic fuel injection system, the engine will ordinarily start quickly during a cranking period. However, when engine starting does not rapidly take place, the engine soon becomes flooded with fuel due to the continual supply of additional control pulses. Therefore, according to one aspect of the invention, the additional control pulses are supplied during a limited enrichment interval during each cranking period. In a preferred embodiment of the invention, a switching circuit changes states to define the duration of the enrichment interval as a direct function of the time interval during which a control voltage provided by a timing circuit increases below a reference level.

Further, if the engine initially fails to start, the engine-starting sequence becomes a series of alternate cranking periods and resting periods determined by the operator. When the resting periods are disproportionately shorter than the enrichment intervals within the cranking periods, the engine again soon becomes flooded with fuel due to an excessive number of additional control pulses. Accordingly, in another aspect of the invention, the maximum duration of an enrichment interval is determined as a direct function of the duration of the previous resting period up to a predetermined limit. Hence, the greater the duration of the preceding resting period, the greater the maximum duration of the succeeding enrichment interval. In a preferred embodiment of the invention, the magnitude from which the control voltage begins to increase is directly related to the duration of the previous resting period.

In addition, once the engine is initially flooded, the engine will remain flooded if the successive cranking periods and resting periods occur in rapid order. Consequently, as contemplated by a further aspect of the invention, the maximum duration of an enrichment interval is determined as an inverse function of the duration of the previous cranking period up to a predetermined limit. More particularly, the maximum duration of an enrichment interval is inversely related to the duration of the previous cranking period in excess of the previous enrichment interval. Thus, the greater the duration of the preceding cranking period, the lesser the duration of the succeeding enrichment interval. In a preferred form of the invention, the magnitude from which the control voltage begins to increase is conversely related to the duration of the previous cranking time period.

Moreover, if additional control pulses are supplied after the termination of a cranking period and the initiation of a resting period, the engine also soon becomes flooded with fuel due to the continual supply of control pulses in the absence of engine cranking. Therefore, according to yet another aspect of the invention, the minimum duration of an enrichment interval is determined as a direct function of the present cranking

period. More particularly, the enrichment interval is terminated when the cranking period is terminated. In a preferred embodiment of the invention, the control voltage is prevented from increasing after the cranking period is terminated.

These and other aspects and advantages of the invention will become more apparent by reference to the following detailed description of the preferred embodiment when considered in conjunction with the accompanying drawing, in which:

FIG. 1 is a schematic diagram of an electronic fuel injection system incorporating the principles of the invention.

FIG. 2 is a schematic diagram of a cranking enrichment circuit incorporating the principles of the invention.

FIG. 3 is a graphic diagram of several waveforms useful in explaining the principles of the invention.

Referring to FIG. 1, an internal combustion engine 10 for an automotive vehicle includes a combustion chamber or cylinder 12. A piston 14 is mounted for reciprocation within the cylinder 12. A crankshaft 16 is supported for rotation within the engine 10. A connecting rod 18 is pivotally connected between the piston 14 and the crankshaft 16 for rotating the crankshaft within the engine 10 when the piston 14 is reciprocated within the cylinder 12.

An intake manifold 20 is connected with the cylinder 12 through an intake port 22. An exhaust manifold 24 is connected with the cylinder 12 through an exhaust port 26. An intake valve 28 is slidably mounted within the top of the cylinder 12 in cooperation with the intake port 22 for regulating the entry of combustion ingredients into the cylinder 12 from the intake manifold 20. A spark plug 30 is mounted in the top of the cylinder 12 for igniting the combustion ingredients within the cylinder 12 when the spark plug 30 is energized. An exhaust valve 32 is slidably mounted in the top of the cylinder 12 in cooperation with the exhaust port 26 for regulating the exit of combustion products from the cylinder 12 into the exhaust manifold 24. The intake valve 28 and the exhaust valve 32 are driven through a suitable linkage 34 which conventionally includes rocker arms, lifters, and a cam shaft.

An electrical power supply is provided by the vehicle battery 36. An ignition switch 38 connects the battery 36 between a powerline 40 and a ground line 42 when closed. A conventional ignition circuit 44 is electrically connected to the power line 40 and is mechanically connected with the crankshaft 16 of the engine 10. Further, the ignition circuit 44 is connected through a spark cable 46 to the spark plug 30. In a conventional manner, the ignition circuit 44 energizes the spark plug 30 in synchronization with the rotation of the crankshaft 16 of the engine 10. Hence, the ignition circuit 44 combines with the ignition switch 38 and the spark plug 30 to form an ignition system.

A fuel injector 48 is mounted on the intake manifold 20 for injecting fuel into the intake manifold 20 at a constant flow rate when the injector 48 is energized. Conventionally, the injector 48 may include a valve having a plunger which is driven to a fully opened position against a bias spring in response to the energization of a solenoid and which is driven to a fully closed position by the bias spring when the solenoid is deenergized. However, it is to be understood that the fuel injector 48 may be virtually any suitable constant flow rate valve.

A fuel pump is connected to the fuel injector 48 by a conduit 52 and to the vehicle fuel tank 54 by a conduit 56 for pumping fuel from the fuel tank 54 to the fuel injector 48. Preferably, the fuel pump 50 is connected to the powerline 40 to be electrically driven from the vehicle battery 36. Alternately, the fuel pump 50 could be connected to the crankshaft 16 to be mechanically driven from the engine 10. A pressure regulator 58 is connected to the conduit 52 by a conduit 60 and is connected to the fuel tank 54 by a conduit 62 for regulating the pressure of the fuel applied to the fuel injector 48. Thus, the fuel injector 48 combines with the fuel tank 54, the fuel pump 50 and the pressure regulator 58 to form a fuel supply system.

A throttle 64 is rotatably mounted within the intake manifold 20 for regulating the flow of air into the intake manifold 20 in accordance with the position of the throttle 64. The throttle 64 is connected through a suitable linkage 66 with the vehicle accelerator pedal 68. As the accelerator pedal 68 is depressed, the throttle 64 is opened to increase the flow of air into the intake manifold 20. Conversely, as the accelerator pedal 68 is released, the throttle 64 is closed to decrease the flow of air into the intake manifold 20.

In operation, fuel and air are combined within the intake manifold 20 to form an air/fuel mixture. The fuel is injected into the intake manifold 20 at a constant flow rate by the fuel injector 48 in response to the energization. The precise amount of fuel deposited within the intake manifold 20 is regulated by a fuel supply control system which will be described later. The air enters the intake manifold 20 from the air intake system (not shown) which conventionally includes an air filter. The precise amount of air admitted into the intake manifold 20 is determined by the position of the throttle 64. As previously described, the position of the accelerator pedal 68 controls the position of the throttle 64.

As the piston 14 initially moves downward within the cylinder 12 on the intake stroke, the intake valve 28 is opened away from the intake port 22 and the exhaust valve 32 is closed against the exhaust port 26. Accordingly, combustion ingredients in the form of the air/fuel mixture within the intake manifold 20 are drawn by negative pressure through the intake port 22 into the cylinder 12. As the piston 14 subsequently moves downward within the cylinder 12 on the compression stroke, the intake valve 28 is closed against the intake port 22 so that the air/fuel mixture is compressed between the top of the piston 14 and the top of the cylinder 12. When the piston 14 reaches the end of its upward travel on the compression stroke, the spark plug 30 is energized by the ignition circuit 44 to ignite the air/fuel mixture. The ignition of the air/fuel mixture starts a combustion reaction which drives the piston 14 downward within the cylinder 12 on the power stroke. As the piston 14 again moves upward within the cylinder 12 on the exhaust stroke, the exhaust valve 32 is opened away from the exhaust port 26. As a result, the combustion products in the form of various exhaust gasses are pushed by positive pressure out of the cylinder 12 through the exhaust port 26 into the exhaust manifold 24. The exhaust gasses pass out of the exhaust manifold 24 into the exhaust system (not shown) which conventionally includes a muffler and an exhaust pipe.

Although the structure and operation of only a single combustion chamber or cylinder 12 has been described, it will be readily appreciated that the illustrated internal combustion engine 10 may include additional cylinders 12 as desired. Similarly, additional fuel injectors 48 may be provided as required. However, as long as the fuel injectors 48 are mounted on the intake manifold 20, the number of additional fuel injectors 48 need not necessarily bear any fixed relation to the number of additional cylinders 12. Alternately, the fuel injector 48 may be directly mounted on the cylinder 12 so as to inject fuel directly into the cylinder 12. In such instance, the number of additional fuel injectors 48 would necessarily equal the number of additional cylinders 12. At this point, it is to be understood that the illustrated internal combustion engine 10, together with all of its associated equipment, is shown only to facilitate a more complete understanding of the inventive fuel supply control system.

A timing pulse generator 70 is connected with the crankshaft 16 for developing timing pulses having a frequency which is proportional to and synchronized with the rotating speed of the crankshaft 16. The timing pulses are applied to a timing line 72. Preferably, the timing pulse generator 70 is some type of inductive speed transducer coupled with a bistable circuit. However, the timing generator 70 may be virtually any suitable pulse producing device such as a multiple contact rotary switch.

An injector drive circuit 74 is connected to the powerline 40 and to the timing line 72. Further, the injector drive circuit

74 is connected through an injection line 76 to the fuel injector 48. The injector drive circuit 74 is responsive to the timing pulses produced by the timing pulse generator 70 to energize the fuel injector valve 48 in synchronization with the speed of the crankshaft 16 in much the same manner as the ignition circuit 44 energizes the spark plug 30. The length of time for which the fuel injector 48 is energized by the drive circuit 74 is determined by the width of duration of the control pulses produced by a modulator or control pulse generator 78 which will be more fully described later. The control pulses are applied by the control pulse generator 78 to the injector drive circuit 74 over a control line 80 in synchronization with the timing pulses produced by the timing pulse generator 70. In other words, the injector drive circuit 74 is responsive to the coincidence of a timing pulse and a control pulse to energize the fuel injector 48 for the duration or width of the control pulse.

The injector drive circuit 74 may be virtually any amplifier circuit capable of logically executing the desired coincident pulse operation. However, where additional fuel injectors 48 are provided, it may be necessary that the injector drive circuit 74 also select which one or ones of the fuel injectors 48 are to be energized on each respective timing pulse. As an example, where the fuel injectors 48 are mounted on the intake manifold 20, they may be divided into two separate groups which are alternately energized on successive ones of the timing pulses. Conversely, where the fuel injectors 48 are mounted directly on additional cylinders 12, the timing pulses may be applied to operate a counter which individually selects the fuel injectors 48 for energization.

The control pulse generator 78 includes a monostable multivibrator or blocking oscillator 81. The blocking oscillator 81 includes a control transducer 82 having a primary winding 84 and a secondary winding 86 which are variably inductively coupled through a movable magnetizable core 88. The deeper the core 88 is inserted into the primary and secondary windings 84 and 86, the greater the inductive coupling between the primary winding 84 and the secondary winding 86. The movable core 88 is mechanically connected through a suitable linkage 90 with a vacuum sensor 92. The vacuum sensor 92 communicates with the intake manifold 20 of the engine 10 downstream from the throttle 64 through a conduit 94 thereby to monitor the negative pressure within the intake manifold 20. The vacuum sensor 92 moves the core 88 within the control transducer 82 to regulate the inductive coupling between the primary and secondary windings 84 and 86 as an inverse function of the vacuum within the intake manifold 20. Therefore, as the vacuum within the intake manifold 20 decreases in response to the opening of the throttle 64, the core 88 is inserted deeper within the control transducer 82 to proportionately increase the inductive coupling between the primary winding 84 and the secondary winding 86.

The monostable multivibrator or blocking oscillator 81 further includes a pair of NPN-junction transistors 96 and 98. The primary winding 84 is connected from the collector electrode of the transistor 98 through a limiting resistor 100 to the powerline 40. The secondary winding 86 is connected from an input junction 102 through a steering diode 104 to a bias junction 106 between a pair of biasing resistors 108 and 110 which are connected in series between the powerline 40 and the ground line 42. A biasing resistor 112 is connected between the junction 102 and the power line 40. The base electrode of the transistor 96 is connected through a steering diode 114 to the junction 102. The emitter electrodes of the transistors 96 and 98 are connected directly to the ground line 42. The collector electrode of the transistor 96 is connected through a biasing resistor 116 to the powerline 40 and is connected through a biasing resistor 118 to the base electrode of the transistor 98.

Further, the control pulse generator 78 includes a differentiator 120 provided by a capacitor 122 and a pair of resistors 124 and 126. The resistors 124 and 126 are connected in series between the powerline 40 and the ground line 42.

The capacitor 122 is connected from the timing line 72 to a junction 128 between the resistors 124 and 126. A steering diode 130 is connected from the junction 128 between the resistors 124 and 126 to the input junction 102. In operation, timing pulses are applied through the timing line 72 to the differentiator 120. The differentiator 120 develops negative trigger pulses at the junction 128 in response to the timing pulses. The diode 130 applies the trigger pulses from the junction 128 to the junction 102.

The modulator or control pulse generator 78 is generally well known in the fuel injection art. Accordingly, since it is only incidental to the present invention, its operation will not be described in great detail. In operation, the monostable multivibrator or blocking oscillator 81 switches from a stable state to an unstable state in response to a decrease in the voltage at the input junction 102 below a predetermined threshold level. The voltage appearing at the junction 102 comprises a feedback voltage provided by the control transducer 82 and a bias voltage provided by the resistors 108, 110 and 112. Specifically, when the voltage at the junction 102 rises above the threshold level, the transistor 96 is rendered fully conductive through the coupling action of the diode 114 and the transistor 98 is rendered fully nonconductive through the biasing action of the resistor 118.

With the feedback voltage absent, the bias voltage provided by the resistors 108, 110 and 112 normally maintains the voltage at the junction 102 above the threshold voltage so that the transistor 96 is normally turned on and the transistor 98 is normally turned off. However, when a negative trigger pulse arrives at the junction 102, the voltage at the junction 102 immediately drops below the threshold level. Consequently, the transistor 96 is turned off through the coupling action of the diode 114 and the transistor 98 is turned on through the biasing action of the resistors 116 and 118. With the transistor 98 turned on, a control pulse is initiated on the control line 80. The level of the control pulse is defined by the saturation voltage drop of the transistor 98.

With the transistor 98 turned on, a current is established in the primary winding 84 of the control transducer 82 to develop the feedback voltage across the secondary winding 86 of the control transducer 82. The feedback voltage initially instantaneously decreases from the level of the bias voltage to a lower level and subsequently gradually increases back to the level of the bias voltage. The feedback voltage is coupled through the diode 104 to the junction 102 to hold the voltage at the junction 102 below the threshold level. Consequently, the transistor 96 remains turned off and the transistor 98 remains turned on.

The lower level of the feedback voltage is determined by the inductive coupling between the primary and secondary windings 84 and 86 of the control transducer 82. In turn, the inductive coupling between the primary and secondary windings 84 and 86 is defined by the position of the movable core 88. The rate at which the feedback voltage increases from the lower level back to the level of the bias voltage is fixed by the L/R time constant of the primary winding 84 and the limiting resistor 100. As the feedback voltage increases, the voltage at the junction 102 eventually rises above the threshold level. Accordingly, the transistor 96 is turned on and the transistor 98 is turned off. With the transistor 98 turned off, the control pulse on the control line 80 is terminated. Thus, the duration of the control pulses occurring on the control line 80 is determined by the vacuum sensor 92 and the control transducer 82 as an inverse function of the vacuum within the intake manifold 20 of the engine 10.

A starter circuit 134 is mechanically connected with the crankshaft 16 of the engine 10 through a suitable linkage 136. A starter switch 138 connects the vehicle battery 36 with the starter circuit 134 through a starting line 140. When the starter switch 138 is closed, the starter circuit 134 is actuated to initiate cranking of the engine 10. When the starter switch 138 is opened, the starter circuit 134 is deactivated to terminate cranking of the engine 10. Preferably, the starter

switch 138 is ganged with the ignition switch 38 in the conventional manner. When ganged, the ignition switch 38 is closed when the starter switch 138 is in the starting position, but the starter switch 138 is opened when the ignition switch 38 is in the running position. Conventionally, the starter circuit 134 includes a starter solenoid and a starter motor. Thus, the starter circuit 134 combines with the starter switch 138 to form a starting system.

During cranking of the engine 10 by the starter circuit 134, the rotation of the crankshaft 16 is relatively slow. As a result, the frequency of the timing pulses produced by the timing pulse generator 70 is relatively low. Consequently, the frequency of the control pulses produced by the control pulse generator 78 is also low. With the number of control pulses reduced during cranking of the engine 10, the amount of fuel deposited into the intake manifold 20 by the fuel injector 48 is generally insufficient to ensure reliable starting of the engine 10. In addition, when the engine 10 is cold, some of the applied fuel tends to condense upon the walls of the intake manifold 20 and upon the surface of the intake valve 28. As a result, the amount of fuel actually drawn from the intake manifold 20 through the intake port 22 past the intake valve 28 into the cylinder 12 is substantially reduced during cold cranking of the engine 10. For these reasons, a cranking enrichment circuit 142 is provided for increasing the number of control pulses developed by the control pulse generator 78 during cranking of the engine 10.

The cranking enrichment circuit 142 is connected between the power line 40 and the ground line 42. The cranking enrichment circuit 142 includes an input connected through the starting line 140 to the starter switch 138. Correspondingly, the cranking enrichment circuit 142 includes an output connected through an output line 144 to a differentiator 146 in the control pulse generator 78. The differentiator 146 is provided by a capacitor 148 and a pair of resistors 150 and 152. The resistors 150 and 152 are connected in series between the powerline 40 and the ground line 42. The capacitor 148 is connected between the output line 144 of the cranking enrichment circuit 142 and a junction 154 between the resistors 150 and 152. A steering diode 156 is connected from the junction 154 between the resistors 150 and 152 to the input junction 102 in the monostable multivibrator or blocking oscillator 81.

In a manner to be more fully described later, the cranking enrichment circuit 142 is responsive to cranking of the engine 10, when the starter switch 138 is closed to produce cranking pulses on the output line 144. The cranking pulses produced by the cranking enrichment circuit 142 are applied through the output line 144 to the differentiator 146. The differentiator 146 develops negative trigger pulses at the junction 154 in response to the cranking pulses. The diode 156 applies the trigger pulses from the junction 154 to the junction 102. As previously described, the monostable multivibrator or blocking oscillator 81 produces control pulses in response to the occurrence of the trigger pulses at the input junction 102. Hence, additional control pulses are developed by the control pulse generator 78 during cranking of the engine 10.

As might be expected, the total amount of fuel which is condensed upon the walls of the intake manifold 20 and upon the surface of the intake valve 28 is inversely related to the temperature of the engine 10. Therefore, as the engine temperature increases, an increasing amount of fuel is drawn from the intake manifold 20 through the intake port 22 past the intake valve 28 into the cylinder 12 tending to flood the engine 10 with excess fuel. Accordingly, the cranking enrichment circuit 142 includes an input connected through a sensing line 158 to a heat sensor 160 mounted on the top of the cylinder 12 adjacent the intake valve 28 for monitoring the temperature of the engine 10. Preferably, the heat sensor 160 is provided by a negative temperature coefficient resistor or thermistor. The thermistor 160 controls the frequency of the cranking pulses produced by the cranking enrichment circuit 142 as an inverse function of the temperature of the engine 10. Thus, the

amount of fuel applied to the engine 10 during cranking is compensated for variations in the temperature of the engine 10.

Ordinarily, the engine 10 will start quickly when cranked by the starter circuit 134. However, if the engine 10 initially fails to start, the starting sequence may become a series of alternate cranking periods and resting periods under control of the vehicle operator. A cranking period may be defined as that time interval during which the starter switch 138 is closed to actuate the starter circuit 134. A resting period may be defined as that time interval during which the starter switch 138 is opened to deactuate the starter circuit 134.

However, as will be more fully described later, the cranking enrichment circuit 142 produces the cranking pulses only during a limited enrichment interval. This prevents the engine 10 from becoming excessively flooded with fuel due to a continual supply of cranking pulses from the cranking enrichment circuit 142 in the absence of engine starting. Preferably, the enrichment interval begins when the starter switch 138 is closed to actuate the starter circuit 134 and initiate cranking of the engine 10. Similarly, the enrichment interval ends when the starter switch 138 is opened to deactuate the starter circuit 134 and terminate cranking of the engine 10. Hence, the minimum possible duration of an enrichment interval is directly related to the duration of the instant cranking period. This prevents the engine 10 from becoming flooded with fuel due to a continual supply of cranking pulses from the cranking enrichment circuit 142 in the absence of engine cranking.

Further, the maximum possible duration of an enrichment interval is directly related to the duration of the preceding resting period up to a predetermined limit. This prevents severe flooding of the engine 10 due to an excessive number of cranking pulses produced by the cranking enrichment circuit 142 when the resting periods are disproportionately shorter than the cranking periods. In addition, the maximum possible duration of an enrichment interval is inversely related to the duration of the preceding cranking period up to a predetermined limit. More specifically, the maximum possible duration of an enrichment interval is inversely related to the duration of the preceding cranking period in excess of the preceding enrichment interval. This prevents continued flooding of the engine 10 due to a constant oversupply of cranking pulses from the cranking enrichment circuit 142 when the successive cranking periods and resting periods occurred in rapid order after initial engine flooding.

Referring to FIG. 2, the cranking enrichment circuit 142 comprises a voltage regulator 162, a cranking timer 164 and a cranking oscillator 166. The voltage regulator 162 includes a Zener diode 168 and a limiting resistor 170 connected in series between the starting line 140 and the ground line 42. A regulated supply line 172 is connected to the junction between the diode 168 and the resistor 170. A regulated voltage is applied to the supply line 172 by the voltage regulator 162. The level of the regulated voltage is determined by the voltage divider action of the diode 168 and resistor 170.

The cranking timer 164 includes an integrating or timing circuit 174 and a switching circuit 176. The timing circuit 174 includes a control capacitor 178 connected between the supply line 172 and a control junction 180. A charging resistor 182 is connected between the junction 180 and the ground line 42. A discharging resistor 184 is connected between the junction 180 and the supply line 172. The switching circuit 176 includes an NPN-junction transistor 186 and a PNP-junction transistor 188. The base electrode of the transistor 186 is connected through a blocking diode 190 and a biasing resistor 192 to the control junction 180. The emitter electrode of the transistor 186 is connected directly to the ground line 42. The base electrode of the transistor 188 is connected to a junction between a pair of biasing resistors 194 and 196 which are connected in series between the collector electrode of the transistor 186 and the supply line 172. The emitter electrode of the transistor 188 is connected directly to the supply line 172. The collector electrode of the transistor 188 is connected with the cranking pulse generator or cranking oscillator 166.

The cranking oscillator 166 includes a unijunction transistor 198. The output line 144 of the cranking enrichment circuit 142 is connected directly to the upper base electrode of the transistor 198. Further, the upper base electrode of the transistor 198 is connected through a biasing resistor 200 to the collector electrode of the transistor 188. The lower base electrode of the transistor 198 is connected through a biasing resistor 202 to the ground line 42. A timing capacitor 204 is connected between the emitter electrode of the transistor 198 and the ground line 42. In addition, the emitter electrode of the transistor 198 is connected with a voltage divider network 206. The voltage divider network 206 includes the heat sensor or thermistor 160. Moreover, the voltage divider network 206 includes biasing resistors 208, 210 and 212. The resistor 208 is connected in series with the thermistor 160 between the emitter electrode of the transistor 198 and the ground line 42. The resistor 210 is connected in series with the thermistor 160 between the collector electrode of the transistor 188 and the ground line 42. The resistor 212 is connected in parallel across the thermistor 160.

Referring to FIGS. 2 and 3, the timing circuit 174 produces a control voltage 214 across the control capacitor 178 in response to operation of the starter switch 138. When the starter switch 138 is closed, the starter circuit 134 is actuated to initiate cranking of the engine 10. Simultaneously, the control voltage 214 commences to vary in an increasing sense as the control capacitor 178 charges through the resistor 182. In addition, the capacitor 178 also charges somewhat through the emitter-base junction of the transistor 186, the diode 190 and the resistor 192. The control voltage 214 increases at an excursion rate primarily determined by the RC charging time constant provided by the control capacitor 178 and the charging resistor 182. The control voltage 214 continues to increase until the capacitor 178 becomes fully charged or the starter switch 138 is opened.

When the starter switch 138 is opened, the starter circuit 134 is deactuated to terminate cranking of the engine 10. Simultaneously, the control voltage 214 commences to vary in a decreasing sense as the control capacitor 178 discharges through the resistor 184. The diode 190 prohibits the capacitor 178 from discharging through the base-collector junction of the transistor 186 and the resistors 192, 194 and 196. The excursion rate at which the control voltage 214 decreases is determined by the RC discharging time constant provided by the control capacitor 178 and the discharging resistor 184. The control voltage 214 continues to decrease until the capacitor 178 becomes fully discharged or the starter switch 138 is closed.

The switching circuit 176 is operable between a set state and a reset state in response to the relationship between the control voltage 214 and a reference level 216. When the control voltage 214 is below the reference level 216, the switching circuit 176 is in the set state. In the set state, the transistors 186 and 188 are rendered fully conductive. Conversely, when the control voltage 214 is above the reference level 216, the switching circuit 176 is in the reset state. In the reset state, the transistors 186 and 188 are rendered fully nonconductive. More particularly, as the control voltage 214 reaches the reference level 216 in an increasing sense, the transistor 186 is rendered fully conductive through the biasing action of the diode 190 and the resistor 192. With the transistor 186 turned on, the transistor 188 is likewise rendered fully conductive through the biasing action of the resistors 194 and 196. Similarly, as the control voltage 214 reaches the reference level 216 in a decreasing sense, the transistor 186 is rendered fully nonconductive through the biasing action of the diode 190 and the resistor 192. With the transistor 186 turned off, the transistor 188 is likewise rendered fully nonconductive through the biasing action of the resistor 194. Hence, the reference level 216 is determined with respect to the control voltage 214 by the bearing resistor 194 in conjunction with the threshold level of the transistor 186.

The cranking pulse generator or cranking oscillator 166 is energized when the switching circuit 176 is in the set state and

is deenergized when the switching circuit 176 is in the reset state. The oscillator 166 initiates the production of cranking pulses on the output line 144 when energized and terminates the production of cranking pulses on the output line 144 when deenergized. More particularly, when the switching circuit 176 is in the set state, the transistor 186 is turned on to energize the oscillator 166 from the regulated supply line 172. The oscillator 166 operates in a conventional unijunction relaxation mode to produce cranking pulses on the output line 144. The frequency of the cranking pulses is determined by the RC time constant provided by the timing capacitor 204 in conjunction with the thermistor 160 and the resistors 208, 210 and 212 of the voltage divider network 206. As previously described, the resistance of the thermistor 160 is inversely related to the temperature of the engine 10, or more properly, the temperature of the cylinder 12. Accordingly, the frequency of the cranking pulses is also inversely related to the temperature of the engine 10.

It will now be apparent that a cranking period may be defined to extend from the time when the starter switch 138 is closed until the time when the starter switch 138 is next opened. Similarly, a resting period may be defined to extend from the time when the starter switch 138 is opened until the time when the starter switch 138 is next closed. In addition, a set interval may be defined as extending from the time when the starter switch 138 is closed until the earlier of the time when the control voltage 214 next reaches the reference level 216 or the time when the starter switch 138 is next opened. Correspondingly, a reset interval may be defined as extending from the time when the starter switch 138 is opened until the earlier of the time when the control voltage 214 next reaches the reference level 216 or the time when the starter switch 138 is next closed. Further, since the cranking enrichment circuit 142 produces cranking pulses on the output line 144 only during the set interval, the set interval represents an enrichment interval.

FIG. 3a depicts the excursion of the control voltage 214 over a complete operating cycle of the cranking enrichment circuit 142. At time T_{c_n} the starter switch 138 is closed to actuate the starter circuit 134 and initiate cranking of the engine 10. Assuming the capacitor 178 became fully discharged at time $T_{d_{n-1}}$, the control voltage 214 is at a minimum level. As a result, the transistors 186 and 188 are turned on and the oscillator 166 is energized to initiate the production of cranking pulses on the output line 144. During the time interval $T_{c_n}-T_{i_n}$, the control voltage 214 increases as the capacitor 178 charges in accordance with the RC time constant provided by the capacitor 178 and the resistor 182. At time T_{s_n} the control voltage 214 reaches the reference level 216. Accordingly, the transistors 186 and 188 are turned off and the oscillator 166 is deenergized to terminate the production of cranking pulses on the output line 144. At time T_{i_n} the control voltage 214 reaches a maximum level as the capacitor 178 becomes fully charged. During the time interval $T_{i_n}-T_{o_n}$, the control voltage 214 remains constant at the maximum level.

At time T_{o_n} the starter switch 138 is opened to deactuate the starter circuit 134 and terminate cranking of the engine 10. During the time interval $T_{o_n}-T_{d_n}$, the control voltage 208 decreases as the capacitor 178 discharges in accordance with the RC time constant provided by the capacitor 178 and the resistor 184. At time T_{r_n} the control voltage reaches the reference level 216 in a decreasing sense. However, since the starter switch 138 is closed, the transistors 186 and 188 remain turned off and the oscillator 166 remains deenergized. At time T_{d_n} the control voltage 214 reaches the minimum level as the capacitor 178 becomes fully discharged. During the time interval $T_{d_n}-T_{c_{n+1}}$, the control voltage 214 remains at the minimum level. At time $T_{c_{n+1}}$ the starter switch 138 is again closed to actuate the starter circuit 134 and initiate cranking of the engine 10.

Although only the operating cycle $T_{c_n}-T_{c_{n+1}}$ is shown in its entirety, it is to be noted that there exists a preceding operating cycle $T_{c_{n-1}}-T_{r_n}$ and a succeeding operating cycle $T_{c_{n+1}}-T_{r_{n+2}}$

It will be recognized that the time interval $T_{c_n}-T_{o_n}$ represents a full cranking period and the time interval $T_{o_n}-T_{c_{n+1}}$ represents a full resting period. In addition, a maximum set interval or enrichment interval is represented by the time interval $T_{c_n}-T_{s_n}$ and a maximum reset interval is represented by the time interval $T_{o_n}-T_{r_n}$. The maximum possible duration of the set interval or enrichment interval $T_{c_n}-T_{s_n}$ is a direct function of the duration of the preceding resting period $T_{o_{n-1}}-T_{c_n}$ up to a predetermined limit defined by a maximum effective resting interval $T_{o_{n-1}}-T_{d_{n-1}}$. Alternately, the maximum possible duration of the reset interval $T_{o_n}-T_{r_n}$ is an inverse function of the duration of the preceding cranking period $T_{c_n}-T_{o_n}$ up to a predetermined limit defined by a maximum effective cranking interval $T_{c_n}-T_{i_n}$. More specifically, the maximum possible duration of the reset interval $T_{o_n}-T_{r_n}$ is inversely related to the duration of the preceding cranking period $T_{c_n}-T_{o_n}$ in excess of the duration of the preceding set interval or enrichment interval $T_{c_n}-T_{s_n}$.

Of course, it will be appreciated that the time T_{o_n} , when the starter switch 138 is opened, can occur anytime after the time T_{c_n} when the starter switch 138 is closed. The time T_{o_n} marks the termination of the cranking period $T_{c_n}-T_{o_n}$ and the initiation of the resting period $T_{o_n}-T_{c_{n+1}}$. As the time T_{o_n} moves toward the time T_{i_n} , the following reset interval is represented by the time interval $T_{o_n}-T_{r_n}$ which remains unchanged at a maximum interval. As the time T_{o_n} moves away from the time T_{i_n} toward the time T_{s_n} , the following reset interval is represented by the time interval $T_{o_n}-T_{r_n}$ which proportionately decreases. As the time T_{o_n} moves away from the time T_{s_n} toward the time T_{c_n} , the reset interval is nonexistent. Hence, as previously described, the duration of a reset interval is inversely related to the duration of the previous cranking period. Further, as the time T_{o_n} moves away from the time T_{s_n} toward the time T_{c_n} , the set interval or enrichment interval is represented by the time interval $T_{c_n}-T_{o_n}$ which proportionately decreases. Thus, the minimum possible duration of a set interval or enrichment interval is a direct function of the duration of the present cranking period.

Similarly, the time $T_{c_{n+1}}$ when the starter switch 138 is closed can occur anytime after the time T_{o_n} when the starter switch 138 is opened. The time $T_{c_{n+1}}$ marks the termination of the resting period $T_{o_n}-T_{c_{n+1}}$ and the initiation of the cranking period $T_{c_{n+1}}-T_{o_{n+1}}$. As the time $T_{c_{n+1}}$ moves toward the time T_{d_n} , the following set interval or enrichment interval is represented by the time interval $T_{c_{n+1}}-T_{s_{n+1}}$ which remains unchanged at a maximum interval. As the time $T_{c_{n+1}}$ moves away from the time T_{d_n} toward the time T_{r_n} , the following set interval or enrichment interval is represented by the time interval $T_{c_{n+1}}-T_{s_{n+1}}$ which proportionately decreases. As the time $T_{c_{n+1}}$ moves away from the time T_{r_n} toward the time T_{o_n} , the following set interval or enrichment interval is nonexistent. Thus, the duration of a set interval or enrichment interval is directly related to the duration of the previous resting period. Further, as the time $T_{c_{n+1}}$ moves away from the time T_{r_n} toward the time T_{o_n} , the reset interval is represented by the time interval $T_{o_n}-T_{c_{n+1}}$ which proportionately decreases. Hence, the minimum possible duration of a reset interval is a direct function of the duration of the present resting period.

FIG. 3b depicts the excursion of the control voltage 214 during a hypothetical portion of an engine starting sequence which illustrates the previously described operation of the cranking enrichment circuit 142. During the first cranking period $T_{c_1}-T_{o_2}$, the set interval is represented by the time interval $T_{c_1}-T_{o_1}$. Throughout the first resting period $T_{o_1}-T_{c_2}$, the reset interval is nonexistent. Over the second cranking period $T_{c_2}-T_{o_2}$, the set interval or enrichment interval is represented by the time interval $T_{c_2}-T_{s_2}$. During the second resting time period $T_{o_2}-T_{c_3}$, the reset interval is represented by the time interval $T_{o_2}-T_{r_2}$. Over the third cranking period $T_{c_3}-T_{o_3}$, the set interval or enrichment interval is represented by the time interval $T_{c_3}-T_{s_3}$. During the third resting period $T_{o_3}-T_{c_4}$, the reset interval is represented by the time interval $T_{o_3}-T_{r_3}$. Throughout the fourth cranking interval $T_{c_4}-T_{o_4}$, the set

interval or enrichment interval is nonexistent. During the fourth resting period $T_{o_n}-T_{r_n}$, the reset interval is represented by the time interval $T_{o_n}-T_{r_n}$.

Referring to FIGS. 2 and 3a, the maximum duration of the set interval or enrichment interval $T_{c_n}-T_{s_n}$ may be adjusted by changing the RC charging time constant provided by the capacitor 178 and the resistor 182. Similarly, the maximum duration of the reset interval $T_{o_n}-T_{r_n}$ may be adjusted by changing the RC discharging time constant provided by the capacitor 178 and the resistor 184. Further, both the maximum duration of the set interval or enrichment interval $T_{c_n}-T_{s_n}$ and the maximum duration of the reset interval $T_{o_n}-T_{r_n}$ may be altered by changing the reference level 216 provided by the resistor 192 in conjunction with the threshold level of the transistor 186. Preferably, the maximum duration of the set interval or enrichment interval $T_{c_n}-T_{s_n}$ is selected so that the engine 10 becomes flooded with excess fuel just prior to the time T_{s_n} . In addition, the maximum effective resting interval $T_{o_n}-T_{d_n}$ is preferably substantially longer than the maximum effective cranking interval $T_{c_n}-T_{i_n}$.

As applied to a typical eight cylinder internal combustion engine, the following values for the respective time intervals were found to yield satisfactory results:

TIME INTERVALS	SECONDS
Maximum set interval or enrichment interval ($T_{c_n}-T_{s_n}$)	3
Maximum effective cranking interval ($T_{c_n}-T_{i_n}$)	6
Maximum reset interval ($T_{o_n}-T_{r_n}$)	4
Maximum effective resting interval ($T_{o_n}-T_{d_n}$)	30

It will now be apparent that the present invention provides an electronic fuel injection system having a timed cranking enrichment circuit 142 for preventing excessive flooding of the engine. However, it is to be understood that the previously described embodiment of the invention is shown for illustrative purposes only and that various modifications and alterations may be made to it without departing from the spirit and the scope of the invention. As an example, the cranking pulses produced by the cranking enrichment circuit 142 could be applied through an appropriate drive circuit to directly energize an extra fuel injector mounted on the intake manifold 20 upstream of the fuel injector 48.

What is claimed is:

1. In an internal combustion engine system, the combination comprising: starter means connected with the engine for operation from a deactuated condition to an actuated condition to crank the engine, the starter means defining a cranking period while in the actuated condition and defining a resting period while in the deactuated condition, successive cranking periods and resting periods forming a starting sequence; timing pulse generating means connected with the engine for producing timing pulses in synchronization with the rotation of the engine; cranking pulse generating means for producing cranking pulses when energized; cranking timer means including a timing circuit connected with the starter means for developing a control voltage which varies in a first sense at a first rate when the starter means is in the actuated condition and which varies in a second sense at a second rate when the starter means is in the deactuated condition, the cranking timer means further including a switching circuit connected between the timing circuit and the cranking pulse generating means for energizing the cranking pulse generating means during an enrichment interval extending from the time when the starter means is actuated until the earlier of the time when the starter means is deactuated and the time when the control voltage reaches a reference level, the enrichment interval thereby exhibiting a minimum duration determined as a direct function of the duration of the present cranking period and exhibiting a maximum duration determined as a direct function of the duration of the previous resting period in the starting sequence and as an inverse function of the duration of the

previous cranking period in the starting sequence in excess of the previous enrichment interval; control pulse generating means connected with the timing pulse generating means and with the cranking pulse generating means for producing control pulses in response to the occurrence of the timing pulses and the cranking pulses, the control pulse generating means including transducer means connected with the engine for determining the duration of the control pulses as a function of at least one engine operating parameter; and means including fuel injection means connected between the control pulse generating means and the engine for injecting fuel into the engine at a substantially constant rate for the duration of each of the control pulses thereby to facilitate engine starting.

2. In an internal combustion engine system including an intake manifold, the combination comprising: starter means connected with the engine for operation from a deactuated condition to an actuated condition to crank the engine, the starter means defining a cranking period while in the actuated condition and defining a resting period while in the deactuated condition, successive cranking periods and resting periods forming a starting sequence; timing pulse generating means connected with the engine for producing timing pulses in synchronization with the rotation of the engine; cranking pulse generating means for producing cranking pulses when energized, the cranking pulse generating means including heat sensor means connected with the engine for determining the frequency of the cranking pulses as an inverse function of the temperature of the engine; cranking timer means including a timing circuit connected with the starter means for developing a control voltage which varies in a first sense at a first rate when the starter means is in the actuated condition and which varies in a second sense at a second rate when the starter means is in the deactuated condition, the cranking timer means further including a switching circuit connected between the timing circuit and the cranking pulse generating means for energizing the cranking pulse generating means during an enrichment interval extending from the time when the starter means is actuated until the earlier of the time when the starter means is deactuated and the time when the control voltage reaches a reference level, the enrichment interval thereby exhibiting a minimum duration determined as a direct function of the duration of the present cranking period and exhibiting a maximum duration determined as a direct function of the duration of the previous resting period in the starting sequence and as an inverse function of the duration of the previous cranking period in the starting sequence in excess of the previous enrichment interval; control pulse generating means connected with the timing pulse generating means and with the cranking pulse generating means for producing control pulses in response to the occurrence of the timing pulses and the cranking pulses, the control pulse generating means including transducer means connected with the engine for determining the duration of the control pulses as a function of at least one engine operating parameter; and means including fuel injection means connected between the control pulse generating means and the intake manifold of the engine for injecting fuel into the intake manifold of the engine at a substantially constant rate for the duration of each of the control pulses thereby to facilitate engine starting by compensating for fuel condensation within the intake manifold.

3. In an internal combustion engine system, the combination comprising: starter means connected with the engine for initiating cranking of the engine when actuated and for terminating cranking of the engine when deactuated, the starter means defining a cranking period while actuated and defining a resting period while deactuated, successive cranking periods and resting periods forming a starting sequence; cranking timer means connected with the starter means for defining an enrichment interval beginning when the starter means is actuated and having a maximum duration directly related to the duration of the previous resting period; in the starting sequence and means including fuel injection means connected between the cranking timer means and the engine for applying

extra fuel to the engine only during the enrichment interval thereby to facilitate engine starting.

4. In an internal combustion engine system, the combination comprising: starter means connected with the engine for initiating cranking of the engine when actuated and for terminating cranking of the engine when deactuated, the starter means defining a cranking period when actuated and defining a resting period when deactuated, successive cranking periods and resting periods forming a starting sequence; cranking timer means connected with the starter means for defining an enrichment interval having a minimum duration directly related to the duration of the present cranking period and having a maximum duration directly related to the duration of the previous resting period in the starting sequence and inversely related to the duration of the previous cranking period; in the starting sequence and means including fuel injection means connected between the cranking timer means and the engine for applying extra fuel to the engine only during the enrichment interval thereby to facilitate engine starting.

5. In an internal combustion engine system, the combination comprising: starter means connected with the engine for operation from a deactuated condition to an actuated condition to crank the engine, the starter means defining a cranking period while in the actuated condition and defining a resting period while in the deactuated condition, successive cranking periods and resting periods forming a starting sequence; cranking timer means connected with the starter means for switching between set and reset states, the cranking timer means switching from the reset state to the set state in response to the expiration of a set interval following actuation of the starter means and switching from the set state to the reset state in response to the expiration of a reset interval following deactuation of the starter means, the duration of the set interval determined as a direct function of the duration of the previous resting period in the starting sequence in excess of the previous reset interval and the duration of the reset interval determined as a direct function of the duration of the previous cranking period in the starting sequence in excess of the previous set interval; and means including fuel injection means connected between the cranking timer means and the engine for applying extra fuel to the engine only during the set interval thereby to facilitate engine starting.

6. In an internal combustion engine system, the combination comprising: starter means connected with the engine for initiating cranking of the engine when manually actuated and for terminating cranking of the engine when manually deactuated, the starter means defining a cranking period while actuated and defining a resting period while deactuated, successive cranking periods and resting periods forming a starting sequence; cranking timer means including an integrating circuit connected with the starter means for developing a control

voltage, the control voltage varying in a first sense at a first rate when the starter means is actuated and varying in a second sense at a second rate when the starter means is deactuated, the cranking timer means further including a switching circuit connected with the integrating circuit for operation between first and second states, the switching circuit operating from the first state to the second state when the control voltage reaches a reference level during the cranking period and operating from the second state to the first state when the control voltage reaches the reference level during the resting period, the switching circuit thereby residing in the first state during an enrichment interval having a maximum duration directly related to the duration of the previous resting period in the starting sequence and inversely related to the duration of the previous cranking period in the starting sequence in excess of the previous enrichment interval; and means including fuel injection means connected between the cranking timer means and the engine for applying extra fuel to the engine only during the enrichment interval thereby to facilitate engine starting.

7. In an internal combustion engine system, the combination comprising: starter means connected with the engine for initiating cranking of the engine when manually actuated and for terminating cranking of the engine when manually deactuated, the starter means defining a cranking period when actuated and defining a resting period when deactuated, successive cranking periods and resting periods forming a starting sequence; cranking timer means including a capacitor for developing a control voltage thereacross, a charging circuit connected with the capacitor for charging the capacitor to increase the control voltage at a charge rate when the starter means is actuated, a discharging circuit connected with the capacitor for discharging the capacitor to decrease the control voltage at a discharge rate when the starter means is deactuated, the cranking timer means further including a switching circuit connected with the capacitor for defining an enrichment interval extending from the time when the starter means is actuated until the earlier of the time when the starter means is deactuated and the time when the control voltage reaches a reference level, the enrichment interval thereby exhibiting a minimum duration determined as a direct function of the duration of the present cranking period and exhibiting a maximum duration determined as a direct function of the duration of the previous resting period in the starting sequence and as an inverse function of the duration of the previous cranking period in the starting sequence in excess of the previous enrichment interval; and means including fuel injection means connected between the cranking timer means and the engine for applying extra fuel to the engine only during the enrichment interval thereby to facilitate engine starting.

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