United States Patent [19]

Aono

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[45] **Jan. 7, 1975**

[54] **ELECTRONIC FUEL INJECTION CONTROL SYSTEM**

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[73] Assignee: **Nissan Motor Company, Limited,** Yokohama City, Japan

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[30] **Foreign Application Priority Data**

Sept. 22, 1972 Japan 47-94595

[52] **U.S. Cl.** .... **123/32 EA,** 123/119 R

[51] **Int. Cl.** **F02m 51/00,** F02d 5/02

[58] **Field of Search** .... 123/32 EA, 119 R

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Primary Examiner—Charles J. Myhre
Assistant Examiner—Cort Flint

[57] **ABSTRACT**

An injection valve control signal is generated having a pulse width which is a primary function of sensed intake vacuum, and a secondary function of sensed engine speed, engine temperature, and throttle opening.

5 Claims, 11 Drawing Figures

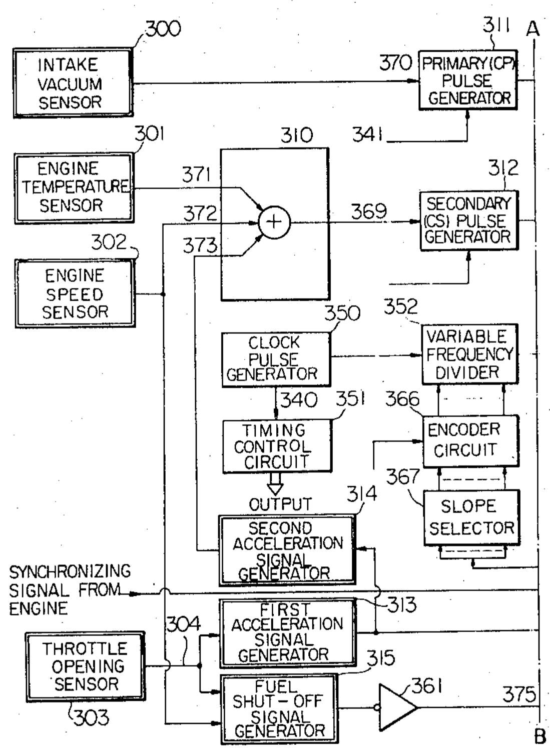


Fig. 1

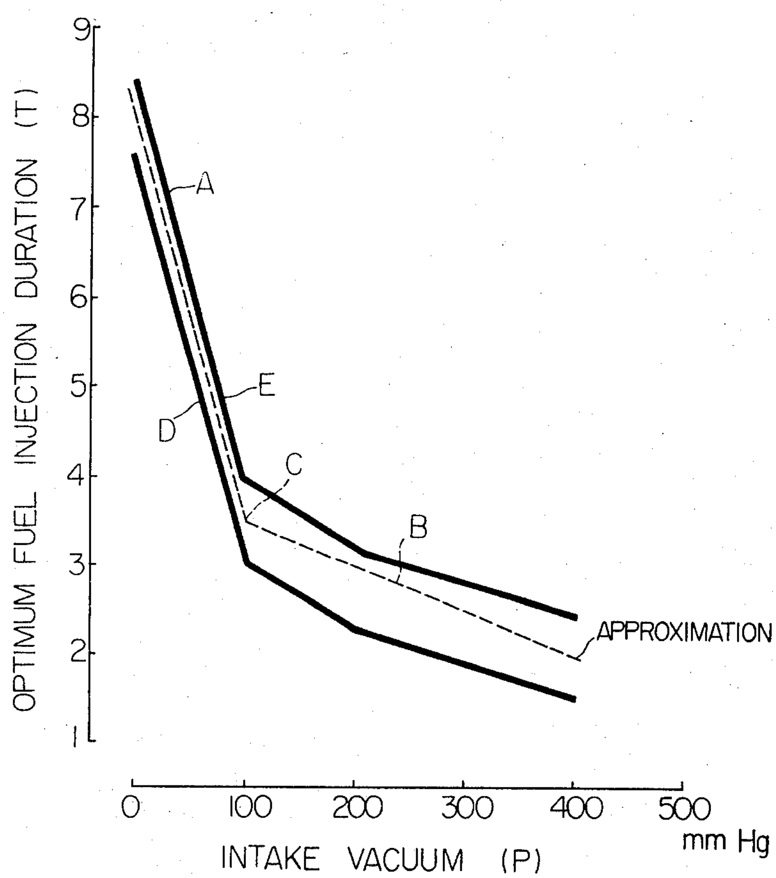
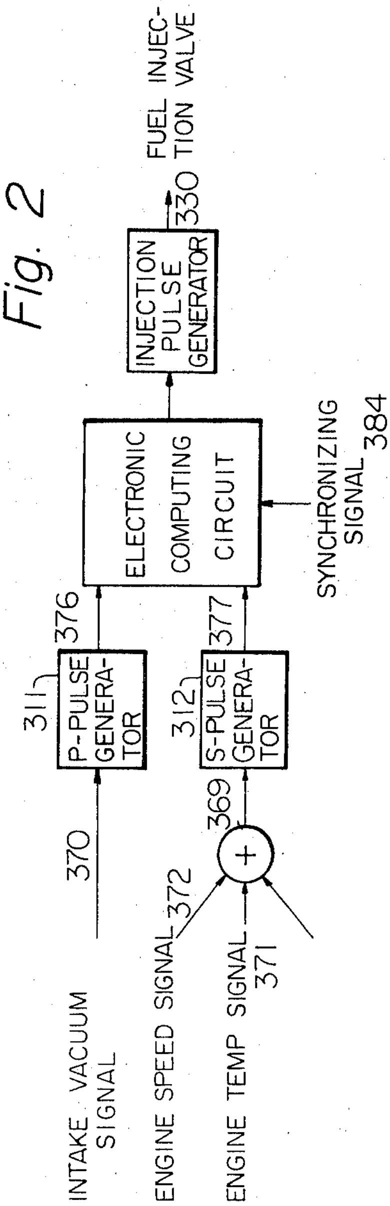

OPTIMUM FUEL INJECTION DURATION (T)
9
8
7
6
5
4
3
2
1
A
E
D
C
B
APPROXIMATION
0
100
200
300
400
500
mm Hg
INTAKE VACUUM (P)

Fig. 2


INTAKE VACUUM SIGNAL
370
311
P-PULSE GENERATOR
376
ENGINE SPEED SIGNAL
372
ENGINE TEMP SIGNAL
371
369
312
S-PULSE GENERATOR
377
ELECTRONIC COMPUTING CIRCUIT
SYNCHRONIZING SIGNAL
384
INJECTION PULSE GENERATOR
330
FUEL INJECTION VALVE

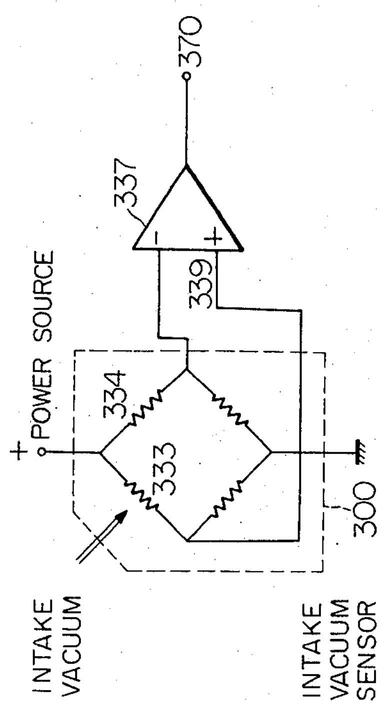

INTAKE VACUUM
INTAKE VACUUM SENSOR
300
POWER SOURCE
334
333
339
337
370

Fig. 5

Fig. 3a

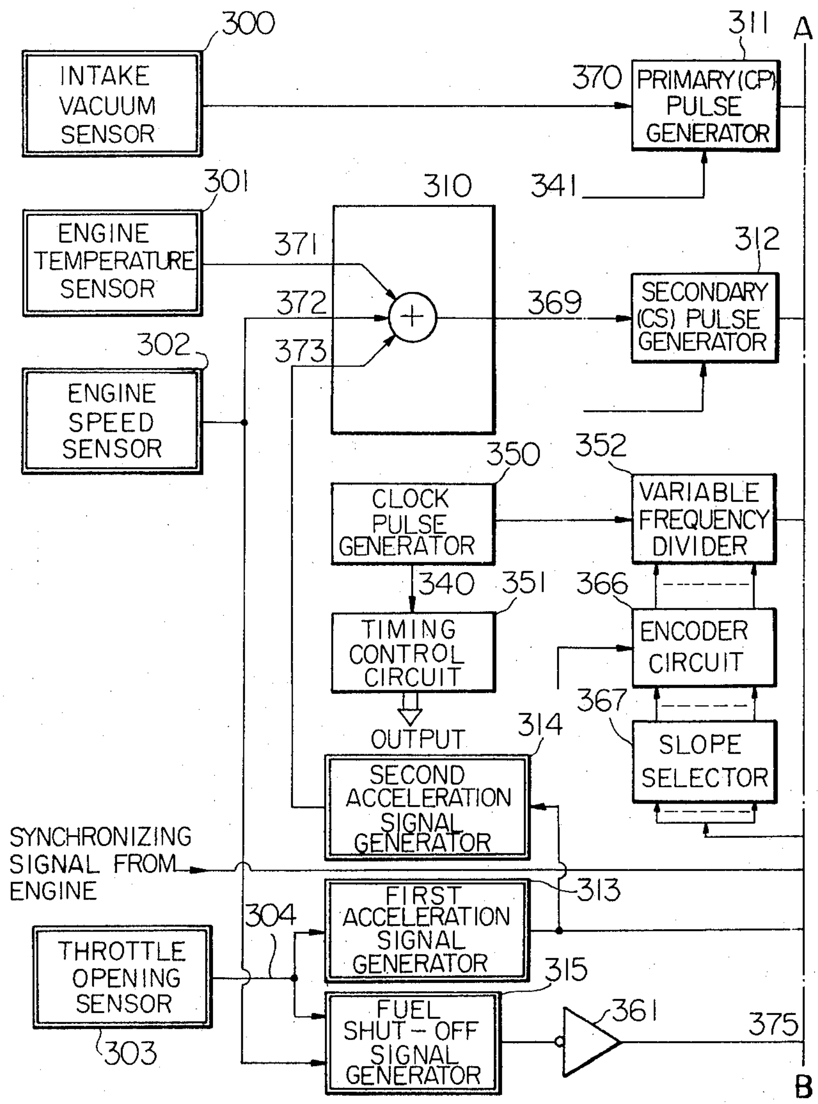
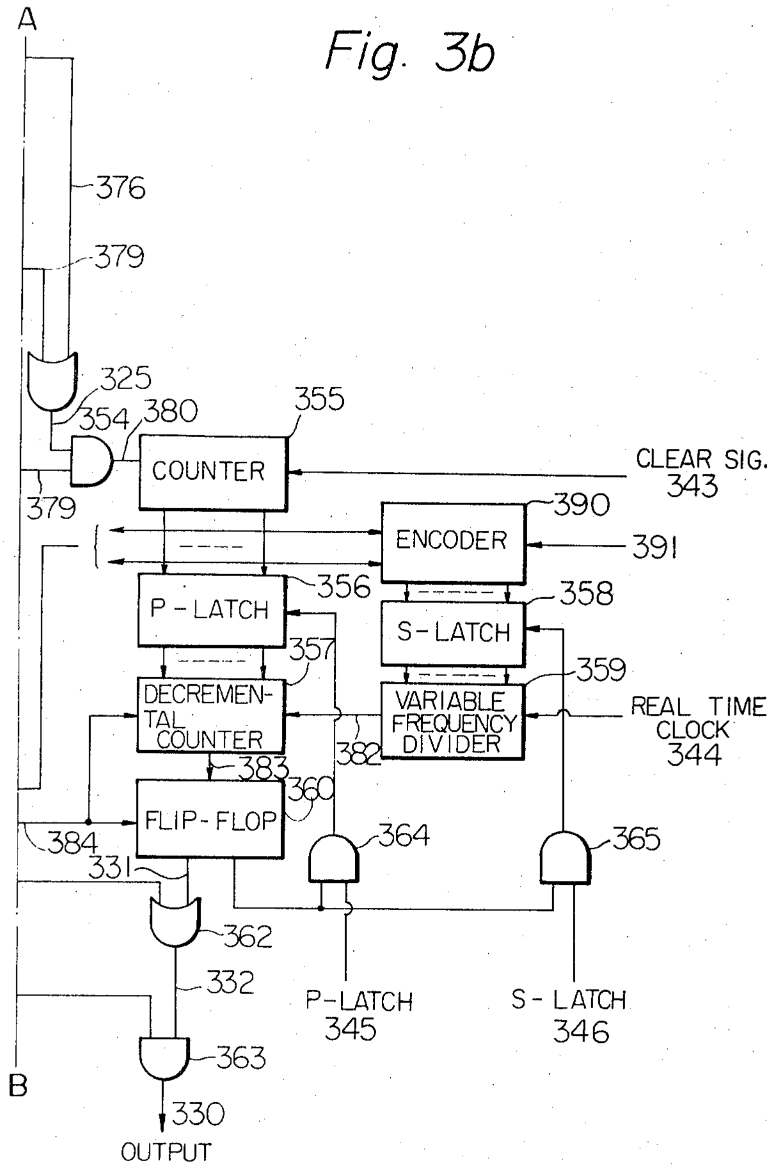

300
INTAKE VACUUM SENSOR
311
A
370
PRIMARY (CP) PULSE GENERATOR
341
301
ENGINE TEMPERATURE SENSOR
310
371
312
372
369
SECONDARY (CS) PULSE GENERATOR
302
373
ENGINE SPEED SENSOR
350
352
CLOCK PULSE GENERATOR
VARIABLE FREQUENCY DIVIDER
340
351
366
TIMING CONTROL CIRCUIT
ENCODER CIRCUIT
OUTPUT
314
367
SECOND ACCELERATION SIGNAL GENERATOR
SLOPE SELECTOR
SYNCHRONIZING SIGNAL FROM ENGINE
313
304
FIRST ACCELERATION SIGNAL GENERATOR
THROTTLE OPENING SENSOR
315
FUEL SHUT-OFF SIGNAL GENERATOR
361
375
303
B

Fig. 3b


A
376
379
325
354
380
355
COUNTER
CLEAR SIG.
343
379
390
ENCODER
391
P - LATCH
356
358
S - LATCH
357
359
DECREMENTAL COUNTER
VARIABLE FREQUENCY DIVIDER
REAL TIME CLOCK
344
382
383
360
FLIP-FLOP
364
365
384
331
362
332
P-LATCH
345
S - LATCH
346
363
B
330
OUTPUT

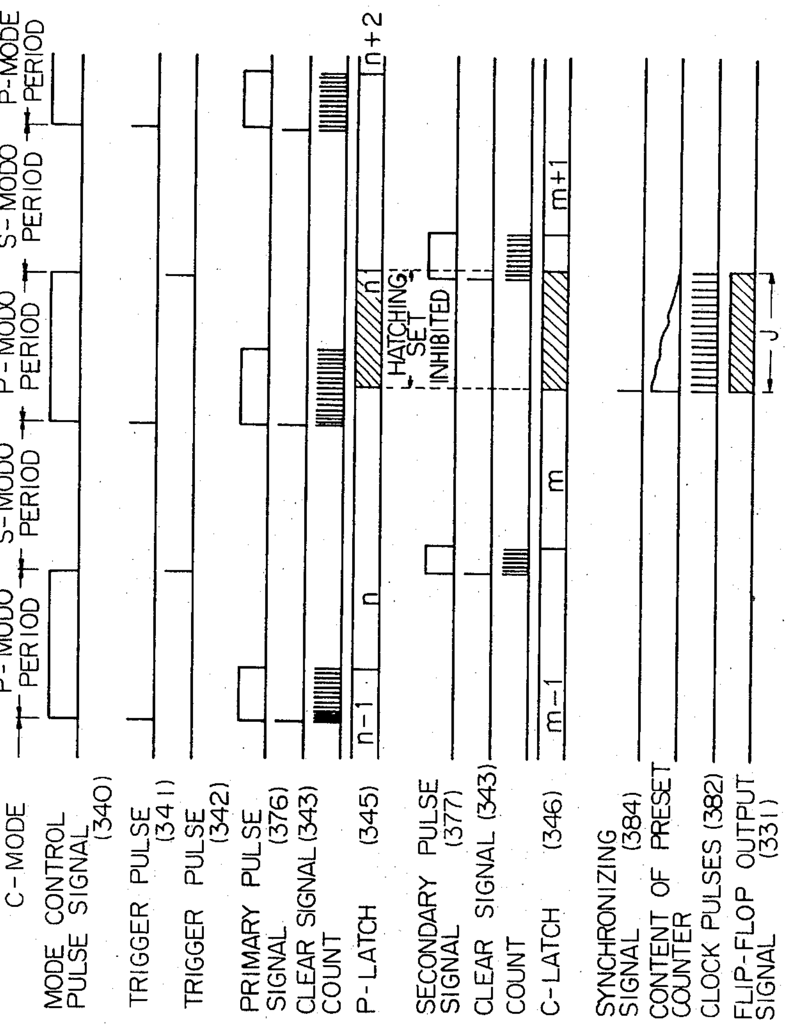

C-MODE
P-MODO PERIOD
S-MODO PERIOD
P-MODO PERIOD
S-MODO PERIOD
P-MODE PERIOD
MODE CONTROL PULSE SIGNAL (340)
TRIGGER PULSE (341)
TRIGGER PULSE (342)
PRIMARY PULSE SIGNAL (376)
CLEAR SIGNAL (343)
COUNT
P-LATCH (345)
n-1
n
n
n+2
HATCHING: SET INHIBITED
SECONDARY PULSE SIGNAL (377)
CLEAR SIGNAL (343)
COUNT
C-LATCH (346)
m-1
m
m+1
SYNCHRONIZING SIGNAL (384)
CONTENT OF PRESET COUNTER
CLOCK PULSES (382)
FLIP-FLOP OUTPUT SIGNAL (331)
J

Fig. 4

Fig. 6

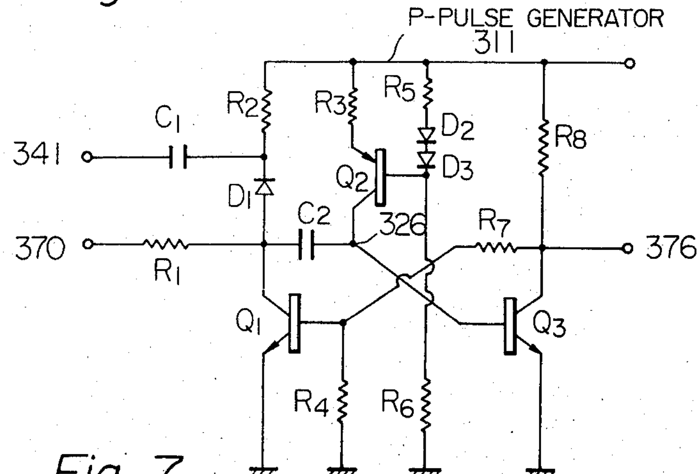

P-PULSE GENERATOR
311
C1
R2
R3
R5
D2
D3
R8
341
Q2
D1
C2
326
R7
370
376
R1
Q1
Q3
R4
R6

Fig. 7

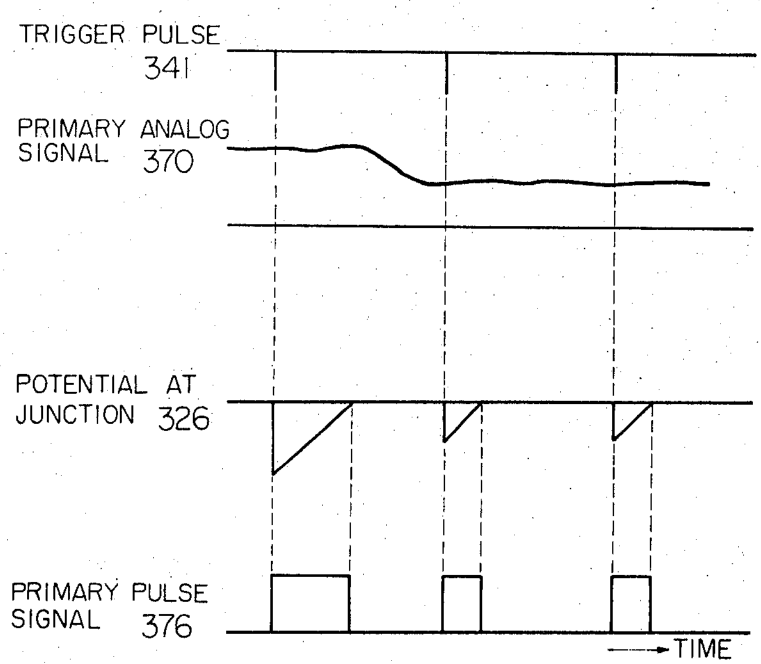

TRIGGER PULSE
341
PRIMARY ANALOG
SIGNAL 370
POTENTIAL AT
JUNCTION 326
PRIMARY PULSE
SIGNAL 376
TIME

Fig. 8

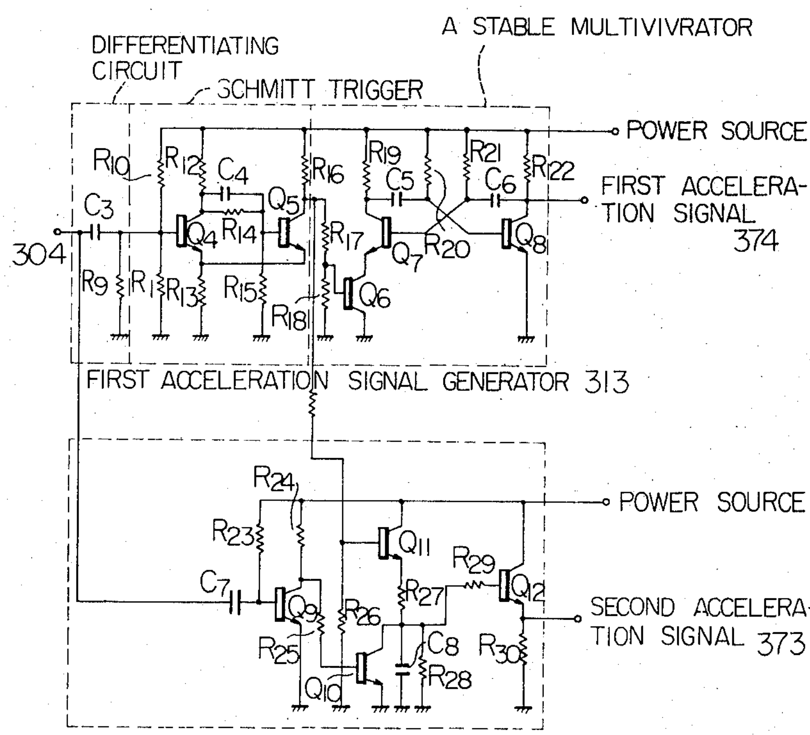
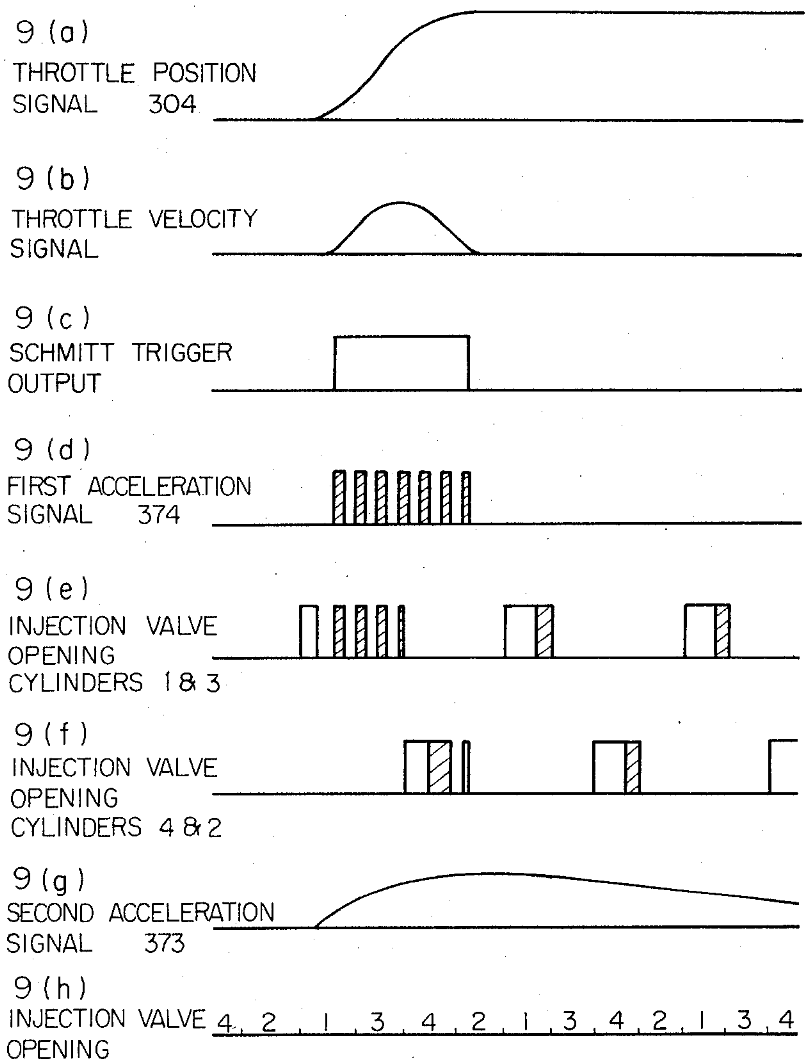
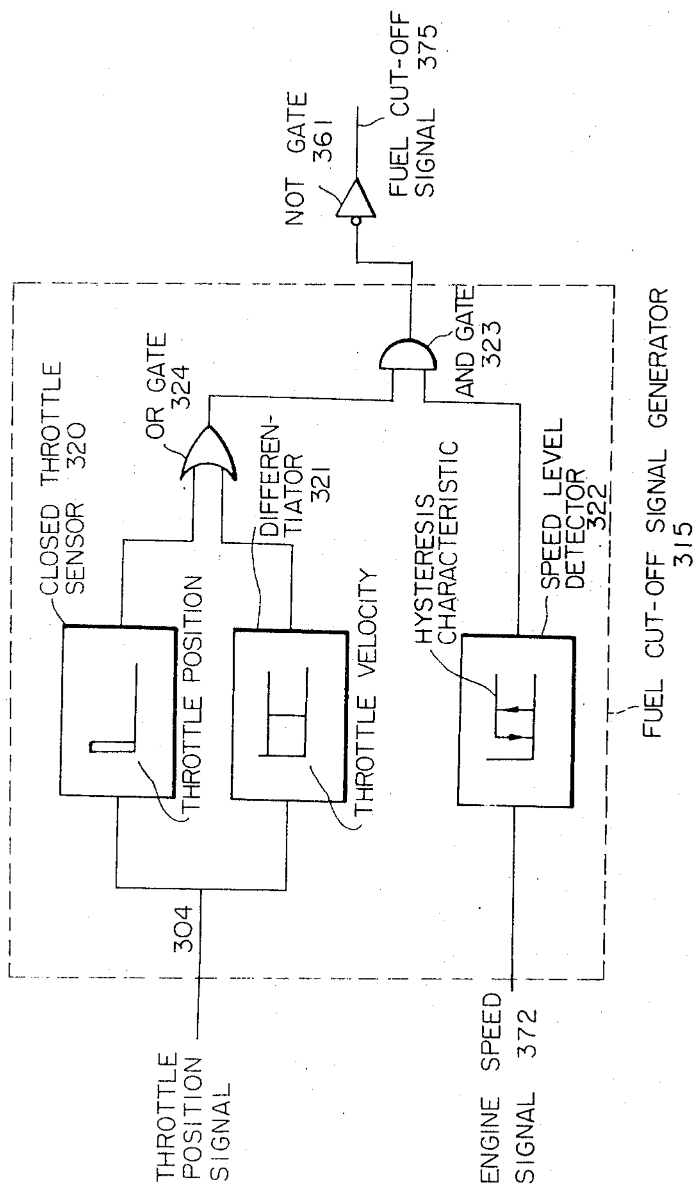

A STABLE MULTIVIVRATOR
DIFFERENTIATING CIRCUIT
SCHMITT TRIGGER
POWER SOURCE
FIRST ACCELERATION SIGNAL 374
304
R10
R12
C4
Q5
R16
R19
C5
R21
C6
R22
C3
Q4
R14
R17
Q7
R20
Q8
R9
R11
R13
R15
R18
Q6
FIRST ACCELERATION SIGNAL GENERATOR 313
R24
POWER SOURCE
R23
Q11
R29
C7
Q9
R27
Q12
R26
SECOND ACCELERATION SIGNAL 373
R25
C8
R30
Q10
R28
SECOND ACCELERATION SIGNAL GENERATOR 314

Fig. 9



FIRING ORDER : 1-3-4-2

Fig. 10


CLOSED THROTTLE SENSOR 320
OR GATE 324
DIFFEREN-TIATOR 321
THROTTLE POSITION
THROTTLE VELOCITY
AND GATE 323
HYSTERESIS CHARACTERISTIC
SPEED LEVEL DETECTOR 322
NOT GATE 361
FUEL CUT-OFF SIGNAL 375
304
THROTTLE POSITION SIGNAL
ENGINE SPEED SIGNAL 372
FUEL CUT-OFF SIGNAL GENERATOR 315

ELECTRONIC FUEL INJECTION CONTROL SYSTEM

The present invention relates to an electronic fuel injection control system for an engine which may be employed in a motor vehicle such as an automobile.

Many prior art attempts have been made to optimally control fuel injection in response to sensed engine operating parameters, but have proven unsatisfactory. A common drawback in prior art electronic fuel injection control systems is that they are based on an analog design, and are therefore subject to inaccuracies resulting from changes in component performance due to variations in ambient conditions.

It is therefore an object of the invention to provide an electronic fuel injection control system for an engine which is reliable and accurate in performance and overcomes the drawbacks of the prior art.

This and other objects, advantages and features of the present invention will become more apparent from the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a graph illustrating a basic design principle of the invention;

FIG. **2** is a simplified block diagram of the invention;

FIG. **3** is a detailed block diagram of a preferred embodiment of the invention;

FIG. **4** is a timing chart for the embodiment of FIG. **3**;

FIG. **5** is a schematic diagram of an example of an intake vacuum sensor according to the invention;

FIG. **6** is a schematic diagram of a pulse generator according to the invention;

FIG. **7** is a graph showing the performance of the pulse generator of FIG. **6**;

FIG. **8** is a schematic diagram of acceleration signal generators shown in FIG. **3**.

FIG. **9** is a timing chart illustrating signals generated by the acceleration signal generators shown in FIG. **8**; and

FIG. **10** is a block diagram of a fuel shut-off system shown in FIG. **3**.

An engine to which the invention is directed has a fuel injection pump which supplies fuel under a predetermined constant pressure to a fuel injection valve. The amount of fuel injected into the engine is thus proportional to the length of time the fuel injection valve is open. It has been determined experimentally that the optimum duration for fuel injection is a primary function of engine intake vacuum (sensed, for example, at the intake manifold), and a secondary function of other engine operating parameters.

Referring to FIG. **1**, optimum fuel injection duration T is shown as a function of intake vacuum P for a typical engine. As is seen, the optimum fuel injection duration T lies within a range between solid lines D and E, since it is a function of other parameters in addition to intake vacuum P. The optimum fuel injection duration T can be approximated as a function of intake vacuum alone by broken lines A and B which intersect at a point C as shown. The slope of the line A is steeper than that of the line B.

FIG. **2** shows the overall configuration of the invention. Intake vacuum, the primary parameter, and secondary parameters such as engine speed, engine temperature, and throttle velocity are sensed as will be described below. An electric primary analog signal **370** having a voltage proportional to the intake vacuum is fed into a primary or P-pulse generator **311**. Electric analog signals, an engine temperature signal **371**, engine speed signal **372** and throttle velocity signal **373**, proportional to the respective parameters, are fed into a functional adder **310**. The P-pulse generator **311** produces an electric primary pulse signal **376** having a pulse width analogous to the voltage of the signal **370**. The adder **310** produces an electric secondary analog signal **369** which has a voltage analogous to the sum of predetermined functions of the signals **371**, **372** and **373**. The signal **369** is fed into a secondary or S-pulse generator **312**, which in turn produces an electric secondary pulse signal **377**. The signals **376** and **377** are then fed into an electronic computing circuit (not designated) which controls an injection pulse generator (not designated) to generate an injection pulse signal **330** having a duration which is a predetermined function of the signals **376** and **377**. Generation of the signal **330** begins when a synchronizing signal **384** is received from an engine unit such as a distributor, in order to initiate fuel injection at a proper timing in the engine operating cycle. Thus, the timing and duration of fuel injection are optimally controlled by an electronic fuel injection control system embodying the invention.

FIG. **3** shows the FIG. **2** embodiment of the invention in more detail. An intake vacuum sensor **300** senses the engine intake vacuum such as at the intake manifold, and feeds the signal **370** into the P-pulse generator **311**. An engine temperature sensor **301**, engine speed sensor **302** and a throttle opening sensor **303** suitably sense the respective parameters and feed the signals **371**, **372** and **373** respectively into the functional adder **310**. A detailed explanation of the signal **373** will follow. The adder **310** generates the signal **369**, which is the sum of selected functions of the voltages of the signals **371**, **372** and **373**, and feeds it into the S-pulse generator **312**. These selected functions are dependent on individual engine design, must be determined experimentally, and a detailed discussion thereof will be omitted for the sake of simplicity.

A clock pulse generator **350** generates mode control pulses **340**, which are fed into a timing control circuit **351**. The circuit **351** then generates at its output trigger pulses **341** and **342**, a clear signal **343**, P-latch and S-latch signals **345** and **346**, and encoder control pulses **391** and **392** respectively which will be described in detail below. Referring also to FIG. **4**, which is a timing chart of important electric signals, the signals **341** and **342** are alternately fed into the generators **311** and **312** respectively, which generate a primary pulse signal **376** and a secondary pulse signal **377** upon receipt of the signals **341** and **342**. The signals **376** and **377** have pulse widths analogous to the voltages of the signals **370** and **369** and are respectively fed into an OR gate **353**. The generator **350** also generates constant frequency clock pulses **378** which are fed into an operational multiplier or variable frequency divider **352**. Variable frequency count pulses **379** are fed from the divider **352** into an AND gate **354**, into which an output signal **325** of the gate **353** is also fed.

When outputs from the gate **353** and the divider **352** are simultaneously received at the inputs of the gate **354**, an output **380** will be fed into a counter **355** which will count the count pulses **379** from the divider **352** for the duration of the signals **376** and **377**. During a P-mode period (see FIG. 4) of the signal **340**, the count pulses **379** will be counted for the duration of the signal **376**, and the total count will be transferred to a P-latch **356**. During an S-mode period of the signal **340**, the count pulses **379** will be counted for the duration of the signal **377**, and the total count will be transferred to an S-latch **358** through an encoder **390**. The operation, as shown in FIG. **4**, is carried out under the control of the encoder control pulses **391** and **302** fed into the encoder **390** and an encoder **366** respectively. Thus, it will be understood that the total count of the counter **355** for the duration of the signal **376** is equal to the pulse width of the signal **376** multiplied by the frequency of the count pulses **379**, and analogous to the sensed intake vacuum multiplied by a selected factor.

An output **381** of the counter **355** is fed into a slope selector **367**, which senses the value of the output **381** (analogous to the intake vacuum) during the P-mode period. The selector **367** feeds a signal (not designated) into the encoder **366** which has a predetermined value if the intake vacuum is higher than, for example 100 mmHg (corresponding to 3.5 ms fuel injection duration), and another predetermined value if the vacuum is lower than 100 mmHg.

Referring back to FIG. **1**, the exemplary intake vacuum value of 100 mmHg corresponds to the point C, and A and B are straight lines. Thus, the optimum fuel injection duration T, as represented by the lines A and B, can be expressed as

$$T = K_1P \text{ for } 0 < P \leq 100 \text{ mmHg and} \quad (1)$$

$$T = K_2P \text{ for } 100 \text{ mmHg} < P < \infty \quad (2)$$

where K_1 and K_2 are constants.

An output (not designated) of the encoder **366** is fed into divider **352** to control the frequency division ratio thereof. The outputs of the selector **367** and encoder **366** are arranged that in response to the sensed level of the output **381** from the counter **355** by the selector **367**, the frequency of the count pulses **379** is K_1 or K_2 for heavy load operation (the line A) and light load operation (the line B) respectively, in accordance with equations (1) and (2). Although FIG. **1** shows the optimum fuel injection duration T as being approximated by the two straight lines A and B, it may be approximated by three or more straight lines or a curve within the scope of the invention. A similar operation takes place during the C-mode period, except that if desired, the divider **352** may be controlled by the encoder **366** in response to the pulse **392** to generate the count pulses **379** at a constant frequency during the S-mode period independent of the value of P. Thus, it will be seen that the generator **350**, divider **352**, AND gate **354**, counter **355**, selector **367**, and encoder **366** constitute a pulse train generator (no numeral) responsive to the primary and secondary pulse signals **376** and **377** respectively, operative to alternately generate primary and secondary pulse train signals (no numerals) respectively, the primary pulse train signal having a first number of pulses (no numeral) which is a first predetermined function of the pulse width of the primary pulse signal **376**, and the secondary pulse train signal having a second number of pulses (no numeral) which is a second predetermined function of the pulse width of the secondary pulse signal **377**, the primary and secondary pulse train signals being stored in the latches **356** and **358** respectively.

An output (no numeral) of the P-latch **356** is fed into a decremental counter **357**, which initially attains a count equal to the first number of pulse, and thereafter counts downward to zero in response to clock pulses **382** fed thereinto from a variable frequency divider **359**, which is similar to the divider **352**. Pulses (no numeral) from a real time clock **344** are fed into the divider **359** to produce the pulses **382**. An output (no numeral) of the S-latch **358** is also fed into the divider **359**. The frequency division ratio of the divider **359** is controlled in a manner similar to that of the divider **352**, such that the frequency of the clock pulses **382** is a third predetermined function of the second number of pulses. The real time clock **344** and the divider **359** thus constitute a variable clock pulse generator (no numeral) responsive to the secondary pulse train signal to generate the clock pulses **382** at a frequency which is the third predetermined function of the second number of pulses.

The synchronizing signal **384** from the engine is fed into the counter **357** and also into a flip-flop **360**. A count signal **383** is fed from the counter **357** into the flip-flop **360**. The counter **357**, initialized to the first number of pulses, begins to count downward to zero upon receipt of the signal **384**, and the counting speed is determined by the frequency of the clock pulses **382**. The signal **384** also sets the flip-flop **360** to a high logic level (not designated). The count signal **383** is generated as long as the counting operation of the counter **357** is being performed, and is terminated when the content of the counter **357** reaches zero. At this time, termination of the signal **383** causes the flip-flop **360** to be reset to a low logic level (not desiganted). Thus, an output signal **331** of the flip-flop **360** fed into an OR gate **362** is logically high for the duration of the counting operation of the counter **357**.

Thus, the flip-flop **360** acts as the injection pulse generator described in reference to FIG. **2**.

It will be seen that the length of time required for the counting operation of the counter **357** is equal to the initial content multiplied by the frequency of count pulses **382**. The counter **357** is thus responsive to the synchronizing signal **384**, the primary pulse train signal and the clock pulses **382**, and is operative to count the first number of pulses at the frequency of the clock pulses **382**. In this manner, a duration J of the high logic level output signal **331** of the flip-flop **360** (injection pulse generator) is

$$J = f_1(P) \times f_3[f_2(a, n, \theta)] \quad (3)$$

where a is the engine temperature, n is the engine speed, θ is the throttle opening, and f_1, f_2 and f_3 are the first, second and third predetermined function respectively.

Another output (not designated) of the flip-flop **360** is fed into AND gate **364** and **365**. The P-latch signal **345** is fed into the gate **364** and the S-latch signal **346** is fed into the gate **365**. By this arrangement, the latches **356** and **358** are inhibited in order to retain their contents while the counting operation of the counter **357** is being performed.

It will be noticed that the pulse train generator, variable clock pulse generator and counter of FIG. **3** constitute the electronic computing circuit of FIG. **2**.

The invention may also include an acceleration compensation system to enrich the air-fuel mixture during acceleration, which includes a power source (not shown), the throttle opening sensor **303**, first and second acceleration signal generators **313** and **314** respectively, and the OR gate **362**. The generators **313** and **314** are shown in FIG. **8**, and a timing chart thereof is presented in FIG. **9**. The generators shown in FIG. **8** are exemplary, and all components are connected as shown. The sensor **303** (FIG. 3) may be a potentiometer, piezo-electric element, or any other device which produces a voltage proportional to the position of the engine throttle valve. The output of the sensor **303** is a throttle position signal **304**, which is applied in parallel to the inputs of the first and second acceleration signal generators **313** and **314**. A capacitor C_3 and a resistor R_9 of the generator **313** constitute a differentiating circuit (no numeral). A circuit comprising transistors Q_4 and Q_5 is a Schmitt trigger, and a circuit comprising transistors Q_6, Q_7 and Q_8 is an astable multivibrator (no numerals). In operation, the throttle position signal **304** (FIG. **7**(*a*)) is differentiated by the differentiating circuit to produce a throttle velocity signal (FIG. **7**(*b*)), which is indicative of an operator's demand to accelerate his engine. If the voltage of the throttle velocity signal is above a threshold level L (FIG. **7**(*b*)) of the Schmitt trigger, the Schmitt trigger will produce an output as shown in FIG. **7**(*c*). If this output is received by the astable multivibrator, it will generate a first acceleration signal **374** (FIG. **7**(*d*)) which is consequently fed into the OR gate **362**. Thus, the gate **362** will produce an output signal **332** in response to at least one of the signal **331** from the flip-flop **360** and the signal **374**.

The output of the Schmitt trigger is also applied to a base of a transistor Q_{11} of the second acceleration signal generator **314**, the emitter of which is connected through a resistor R_{27} to a capacitor C_8. In operation, if the Schmitt trigger produces an output, the capacitor C_8 begins to charge, and if the Schmitt trigger output is interrupted, the capacitor C_8 begins to discharge. In this manner, an output is produced by the generator **314** which is the second acceleration signal **373** shown in FIG. **7**(*g*), which is fed to the adder **310**. (FIGS. **7**(*e*) and **7**(*f*) show the effects of the signals **373** and **374** on the signal **331**. Unhatched pulses represent the output signal **331** of the flip-flop **360**, and hatched pulses are those of the signal **374** which are not coincident with the flip-flop **360** output signal **331**. As is clearly seen, the fuel injection duration *J* is properly increased during engine acceleration.

If desired, the invention may further comprise a fuel shut-off system to inhibit fuel injection during deceleration to reduce the levels of pollutive substances emitted from the engine. An example is shown in FIGS. 3 and **10**, which comprises a fuel cut-off signal generator **315**, a NOT gate **361** and an AND gate **363**. The signal **304** from the throttle opening sensor **303** is fed in parallel into a closed throttle sensor **320** and a differentiator **321** of the generator **315**, outputs of which are connected to inputs of an OR gate **324**. The sensor **320** generates an output signal when the engine throttle is fully closed, and the differentiator **321** differentiates the signal **304** to obtain the throttle velocity, and produces an output signal if the throttle is being moved toward a closed position at a velocity greater than a certain value.

The OR gate **324** thus produces an output signal in response to at least one of these conditions, which is fed into an AND gate **323**. The signal **373** from the engine speed sensor **302** is fed into an engine speed level detector **322**, which feeds an output signal into the AND gate **323** if the sensed engine speed is above a selected value. The AND gate **323** thus produces an output signal if the engine speed is above the selected level and the throttle is closed or being closed rapidly. The output of the AND gate **323** is inverted by a NOT gate **361** to produce a fuel shut-off signal **375** which is fed into the AND gate **363**. The gate **363** thus produces the injection pulse signal **330** if the signal **332** is present and the signal **375** is not present. If desired, the detector **322** may have a hysteresis characteristic as known in the art and shown in FIG. **10**.

A preferred example of the intake vacuum sensor **300** is shown in FIG. **5**, in which resistors **333** to **336** and a differential amplifier **337** are connected to the power source as shown. The resistors **333** to **336** are connected in a bridge arrangement such that the resistors **334** and **335** are of equal value, and a potential difference is produced across leads **338** and **339** proportional to the difference in the values of the resistors **333** and **336**, as is well known in the art. The resistor **333** may be piezo-electric may comprise an intake vacuum actuated diaphragm connected to a potentiometer, or may comprise any other means which has a resistance value which varies in proportion to pressure. The output of the differential amplifier **337** is the signal **370** described in detail above.

FIGS. **6** and **7** show the configuration and operation of a preferred example of the generators **311** and **312**, in which the P-pulse generator **311** only is shown for simplicity. Transistors Q_1, Q_2 and Q_3 and other circuit components are connected to the power source as shown. In operation, the primary analog signal **370** is continuously received, and if the trigger pulse **341** is not being received, the transistor Q_1 is turned off (non-conducting), and the transistors Q_2 and Q_3 are turned on. Thus, the level of the primary pulse signal **376** which is the output of the generator **311** is substantially zero. When the trigger pulse **341** is received, the potential at the base of the transistor Q_3 (or a junction **326**) drops in proportion to the level of the signal **370**. In response, a constant current is caused to flow through the transistor Q_2, the capacitor C_2 and the transistor Q_1 (the transistor Q_2 is adapted to provide constant current flow therethrough), and the transistor Q_1 is therefore turned on and the transistor Q_3 turned off. The level of the signal **376** is thus high, as shown in FIG. **7**. The capacitor C_2 charges until the potential at the junction **326** rises to zero, as shown in FIG. **7**, at which time the level of the signal **376** drops again to substantially zero. In this way, the primary pulse signal **376** is generated in response to the trigger pulse **341** and primary analog signal **370** which has pulses having widths analogous to the voltage level of the primary analog signal **370**.

What is claimed is:

1. An electronic fuel injection control system for an engine, the engine having a fuel injection valve and a synchronizing signal generator to generate an electric synchronizing signal, said control system comprising;

a first sensor to sense a primary operating parameter of the engine and generate an electric primary analog signal analogous thereto;

a second sensor to sense at least one secondary operating parameter of the engine and generate an electric secondary analog signal analogous thereto;

a primary pulse generator responsive to said primary analog signal to generate an electric primary pulse signal having a pulse width analogous thereto;

a secondary pulse generator responsive to said secondary analog signal to generate an electric secondary pulse signal having a pulse width analogous thereto;

a pulse train generator responsive to said primary and secondary pulse signals being operative to alternately generate primary and secondary pulse train signals respectively, said primary pulse train signal having a first number of pulses which is a first predetermined function of the pulse width of said primary pulse signal, and said secondary pulse train signal having a second number of pulses which is a second predetermined function of the pulse width of said secondary pulse signal;

a variable clock pulse generator responsive to said secondary pulse train signal to generate clock pulses at a frequency which is a third predetermined function of said second number of pulses;

a counter responsive to the synchronizing signal, said primary pulse train signal, and said clock pulses, being operative to count said first number of pulses at the frequency of said clock pulses, the counting operation commencing when said synchronizing signal is received;

and an injection pulse generator connected to said counter and operative to generate an injection pulse signal to open the fuel injection valve for the duration of the counting operation of said counter.

2. A control system as claimed in claim **1,** in which said primary operating parameter is the engine intake vacuum.

3. A control system as claimed in claim **2,** in which the engine further has a throttle valve, and in which said at least one secondary operating parameter is at least one of the engine temperature, the engine speed and the velocity of the throttle valve.

4. A control system as claimed in claim **3,** which further comprises an acceleration compensation system being operative to lengthen the pulse width of said injection pulse signal in response to an acceleration demand condition of the engine.

5. A control system as claimed in claim **4,** which further comprises a fuel shut-off system operative to inhibit generation of said injection pulse signal in response to a sensed deceleration condition of the engine.

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