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INT CL^7 **F02D 21/08 , F02M 25/07**
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(54) Abstract Title
Air/fuel ratio control system

(57) A system is disclosed for estimating engine flows, including exhaust gas flow from an exhaust manifold of an internal combustion engine to an intake manifold of the engine and airflow into an engine cylinder. The system comprises a flow control valve (70) having a variable orifice positioned in an exhaust gas recirculation path (72) between the exhaust manifold (48) and intake manifold (44) of the engine; a fixed orifice area (76) located in said path and downstream of said valve (70); and a computer (12) for

- determining a first signal related to pressure between said fixed orifice area and said flow control valve,
- determining a second signal related to pressure downstream of said fixed orifice area,
- calculating a third signal related to the exhaust gas flow based on said first signal and said second signal, and
- determining a fourth signal related to the airflow based on said second signal and said third signal.

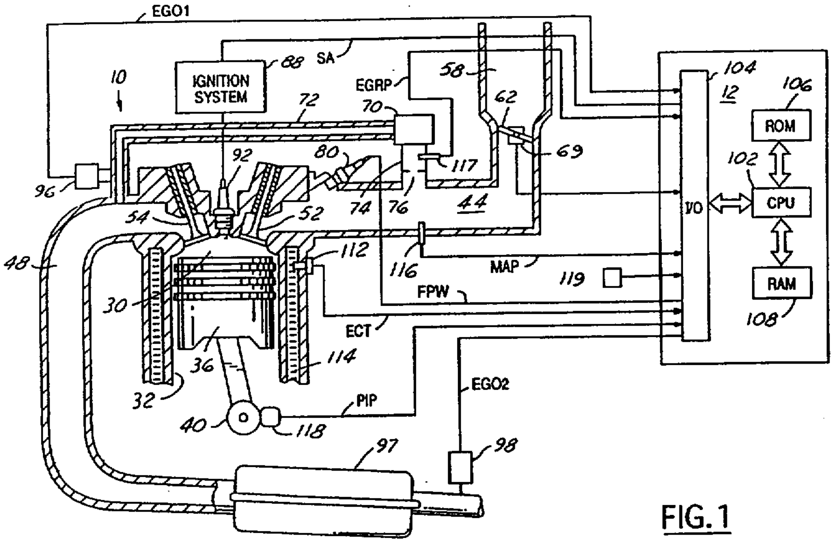

FIG.1

GB 2 351 563 A

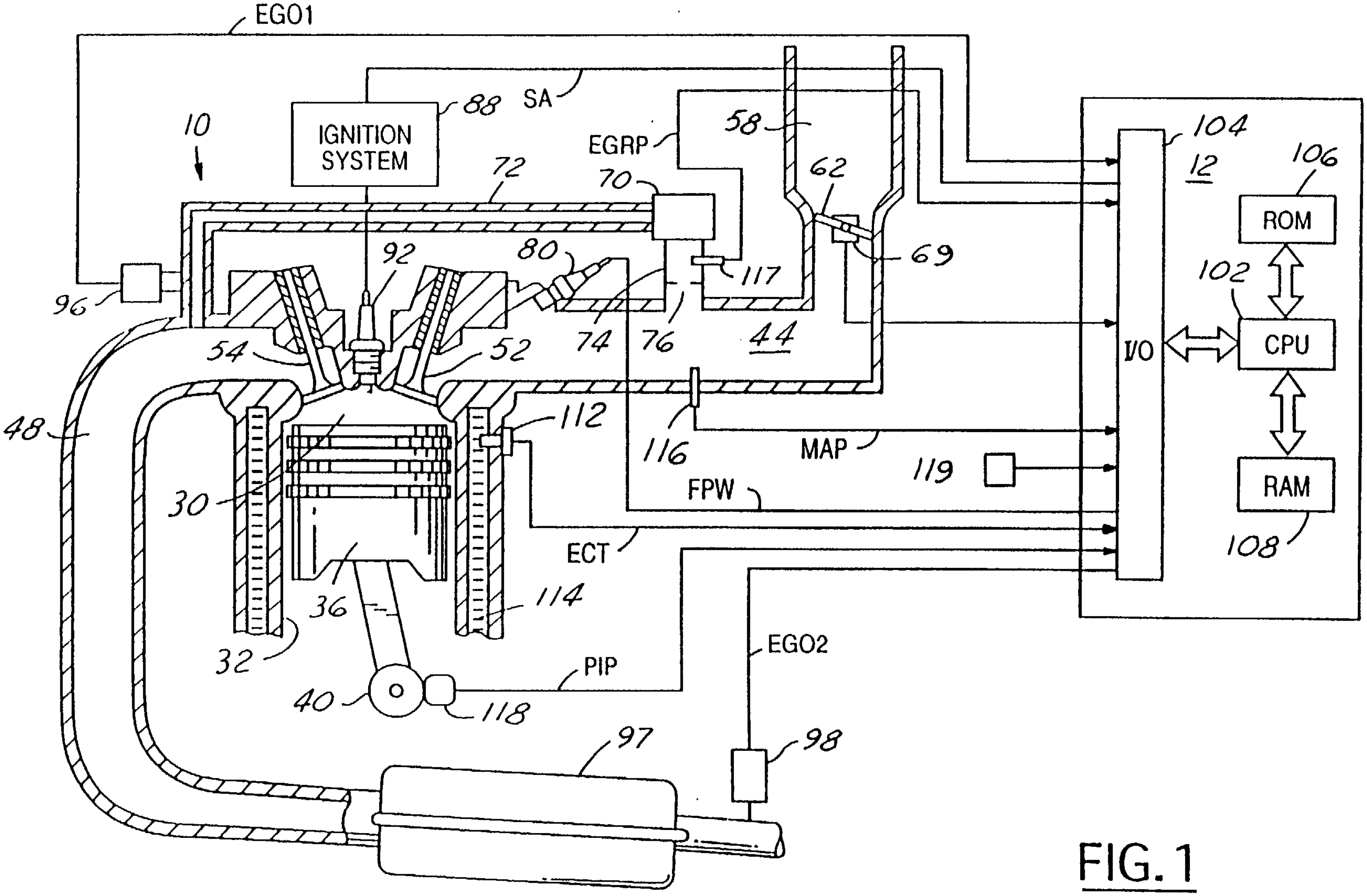
EGO1
SA
88
IGNITION SYSTEM
10
72
EGRP
70
58
62
69
117
92
80
96
54
52
74
76
44
104
12
106
ROM
102
CPU
I/O
RAM
108
48
30
112
116
MAP
119
FPW
ECT
36
114
32
40
118
PIP
EGO2
97
98

FIG. 1

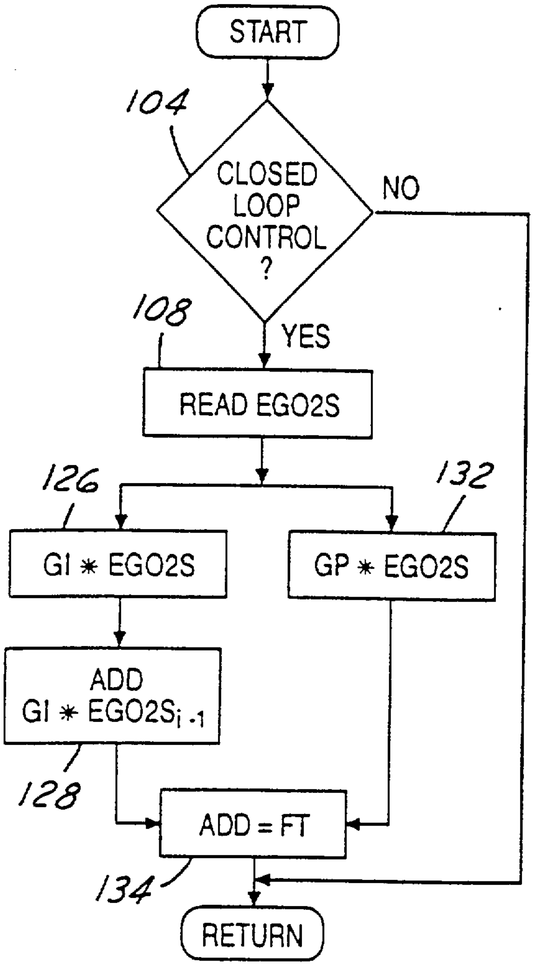
START
104
CLOSED LOOP CONTROL ?
NO
108
YES
READ EGO2S
126
132
GI ∗ EGO2S
GP ∗ EGO2S
ADD GI ∗ EGO2S$_{i-1}$
128
ADD = FT
134
RETURN

FIG. 2

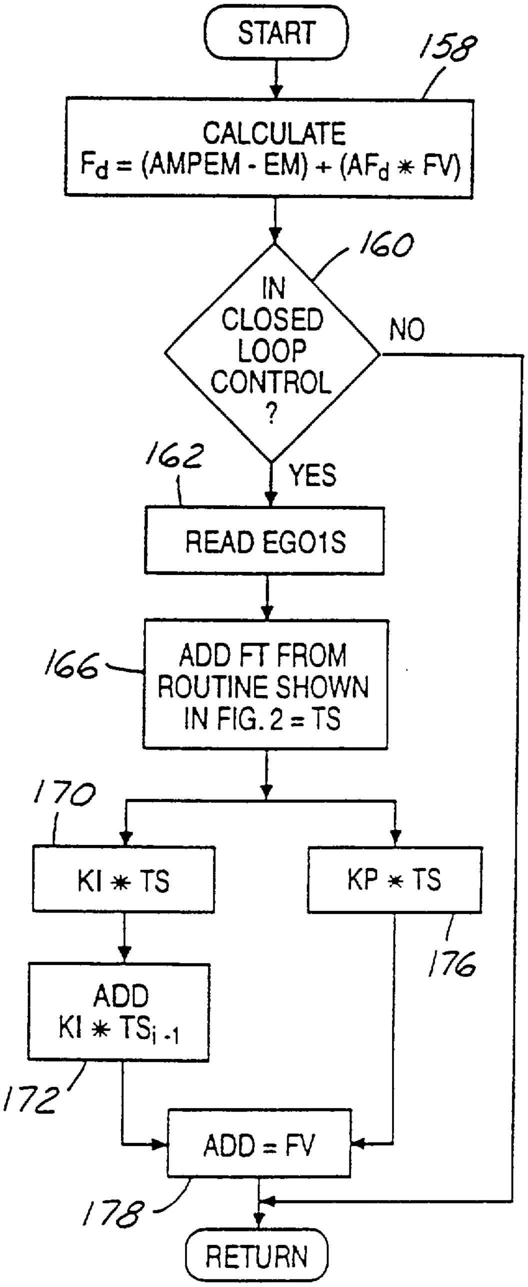
START
158
CALCULATE F_d = (AMPEM - EM) + (AF_d ∗ FV)
160
IN CLOSED LOOP CONTROL ?
NO
162
YES
READ EGO1S
166
ADD FT FROM ROUTINE SHOWN IN FIG. 2 = TS
170
KI ∗ TS
KP ∗ TS
176
ADD KI ∗ TS$_{i-1}$
172
ADD = FV
178
RETURN

FIG. 3

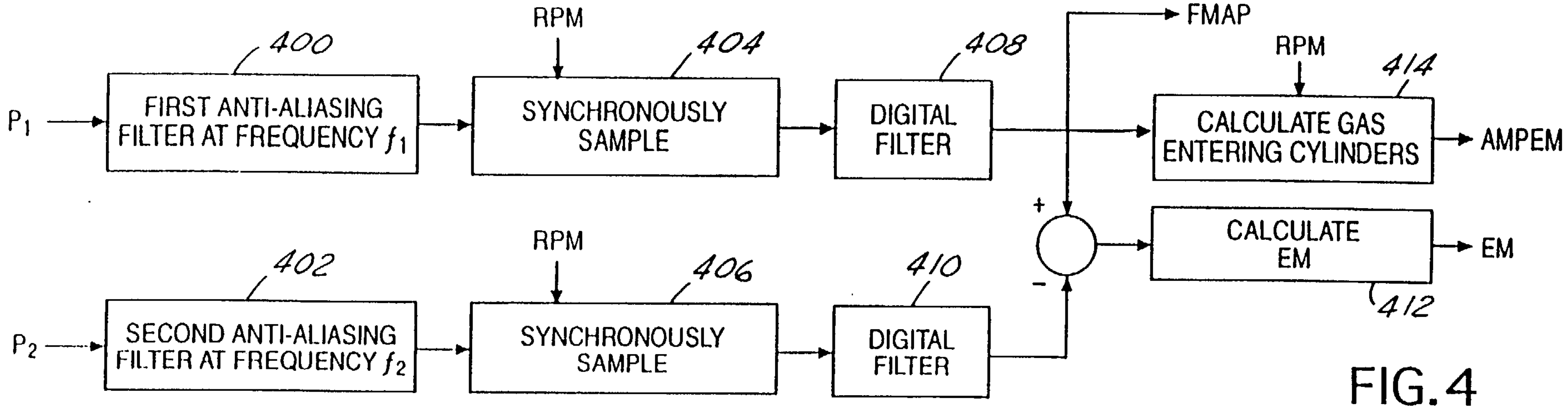
P1
FIRST ANTI-ALIASING FILTER AT FREQUENCY f_1
400
RPM
SYNCHRONOUSLY SAMPLE
404
DIGITAL FILTER
408
FMAP
RPM
CALCULATE GAS ENTERING CYLINDERS
414
AMPEM
P2
SECOND ANTI-ALIASING FILTER AT FREQUENCY f_2
402
RPM
SYNCHRONOUSLY SAMPLE
406
DIGITAL FILTER
410
+
−
CALCULATE EM
412
EM

FIG. 4

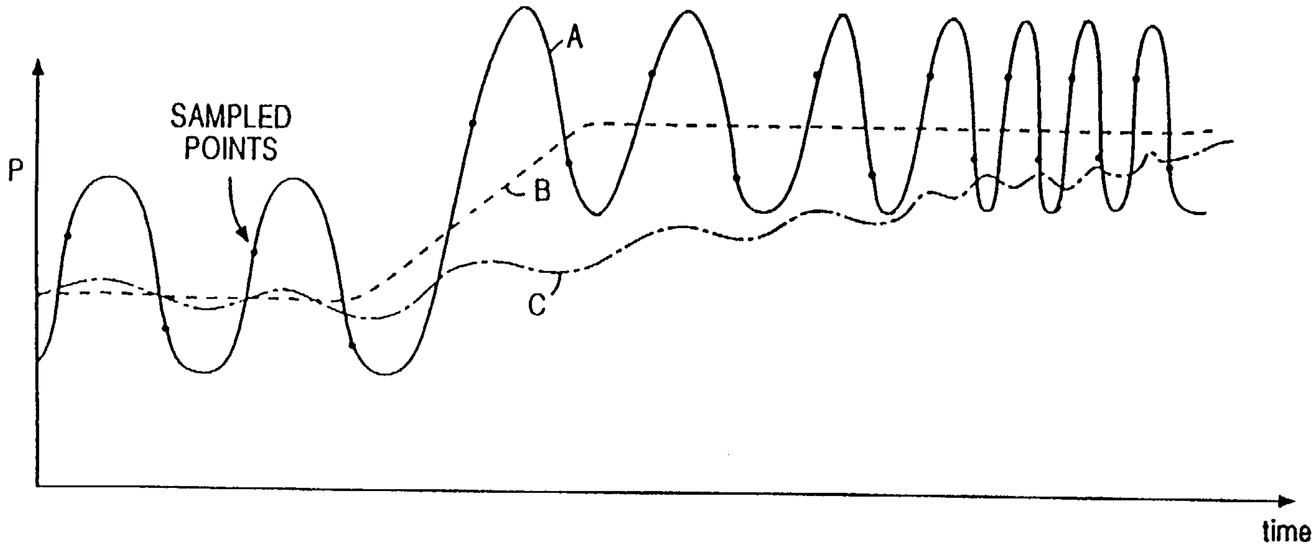
P
SAMPLED POINTS
A
B
C
time

FIG. 5

4/15

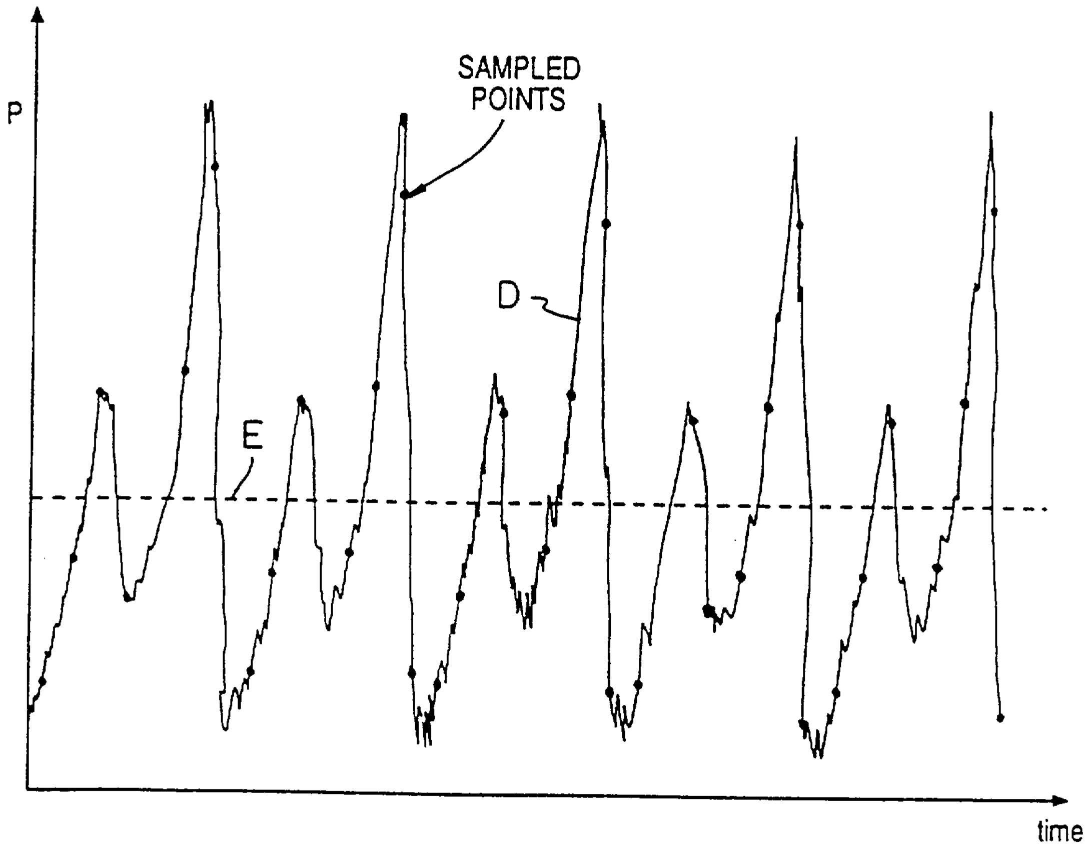

FIG.6

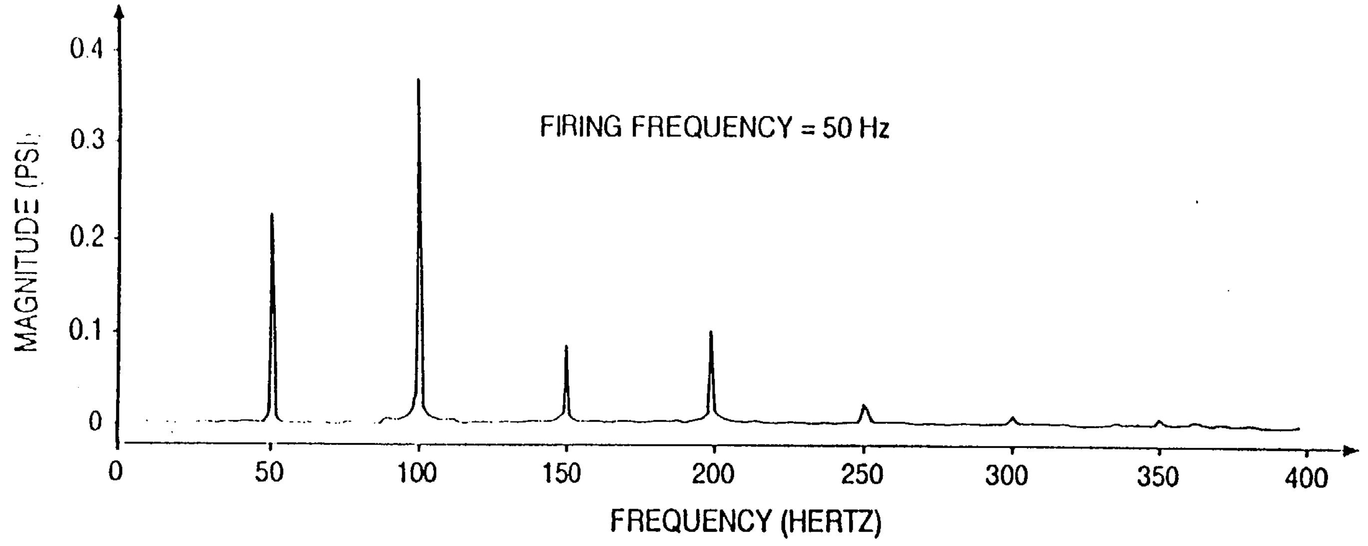
MAGNITUDE (PSI)
0.4
0.3
0.2
0.1
0
FIRING FREQUENCY = 50 Hz
0
50
100
150
200
250
300
350
400
FREQUENCY (HERTZ)

FIG.7A

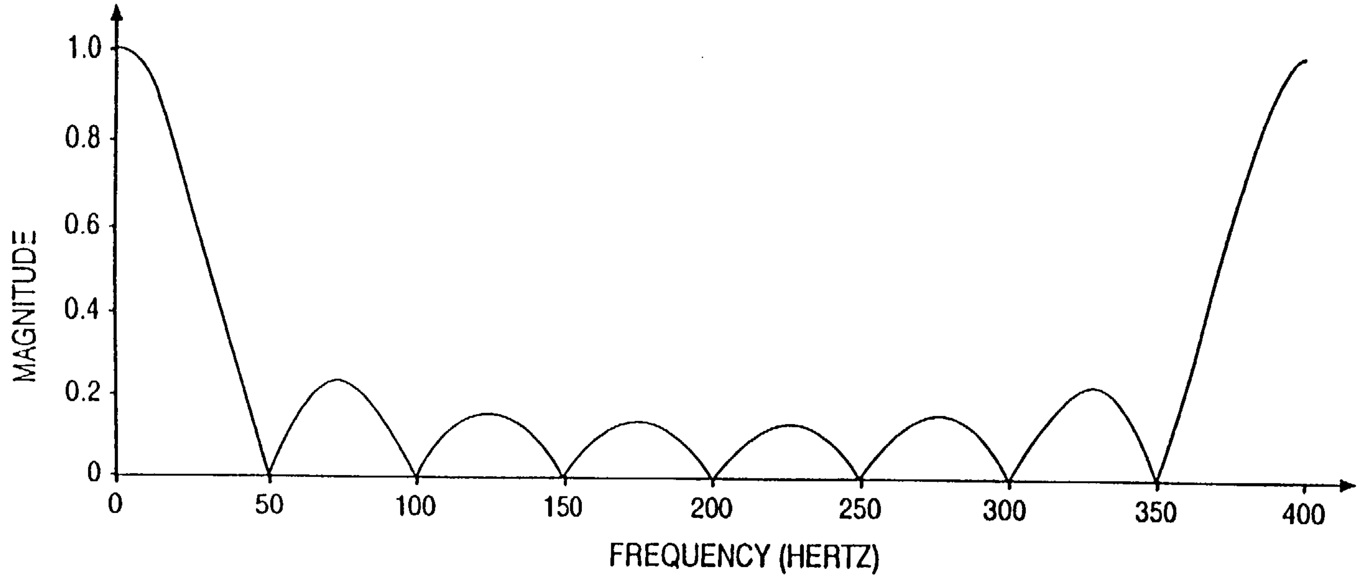
MAGNITUDE
1.0
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
FREQUENCY (HERTZ)

FIG.7B

AIR/FUEL RATIO CONTROL SYSTEM

The present invention relates to a system for estimating engine flows for use in an air/fuel ratio control system for an internal combustion engine.

Reference is made to copending Patent Application No. 9912595.7 which is based on the same disclosure as the present invention and contains claimed directed to a method for calculating air flow in an internal combustion engine, the method comprising sensing an engine speed of the engine; synchronously sampling a first pressure sensor with a frequency proportional to a firing frequency of the engine; filtering said synchronously sampled first pressure with a filter to remove oscillations at frequencies proportional to said firing frequency; and calculating a mass of gas entering a cylinder of the engine responsive to said first filtered pressure and said engine speed.

According to the present invention, there is provided a system for estimating engine flows, including exhaust gas flow from an exhaust manifold of an internal combustion engine to an intake manifold of the engine and airflow into an engine cylinder, the system comprising:

a flow control valve having a variable orifice positioned in an exhaust gas recirculation path between the exhaust manifold and intake manifold of the engine;

a fixed orifice area located in said path and downstream of said valve; and

a computer for determining a first signal related to pressure between said fixed orifice area and said flow control valve, determining a second signal related to pressure downstream of said fixed orifice area, calculating a third signal related to the exhaust gas flow based on said first signal and said second signal, and determining a fourth signal related to the airflow based on said second signal and said third signal.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of an engine in which the invention is used to advantage;

Figures 2 - 4 are high level flowcharts of various operations performed by a portion of the embodiment shown in Figure 1;

Figures 5 - 6 are examples of a fluctuating waveform on which the invention is used to advantage; and

Figures 7A and 7B are plots showing frequency content of a pressure signal and an example of a notch filter's magnitude frequency characteristics.

Internal combustion engine 10 comprising a plurality of cylinders, one cylinder of which is shown in Figure 1, is controlled by electronic engine controller 12. Engine 10 includes combustion chamber 30 and cylinder walls 32 with piston 36 positioned therein and connected to crankshaft 40. Combustion chamber 30 is shown communicating with intake manifold 44 and exhaust manifold 48 via respective intake valve 52 and exhaust valve 54. Intake manifold 44 is shown communicating with throttle body 58 via throttle plate 62. Throttle position sensor 69 measures position of throttle plate 62. Exhaust manifold 48 is shown coupled to exhaust gas recirculation valve 70 via exhaust gas recirculation tube 72. Exhaust gas recirculation valve 70 is also coupled to intake manifold 44 via orifice tube 74. Orifice tube 74 has orifice 76 for restricting flow therein. Intake manifold 44 is also shown having fuel injector 80 coupled thereto for delivering liquid fuel in proportion to the pulse width of signal FPW from controller 12. Fuel is delivered to fuel injector 80 by a conventional fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown). Alternatively, the engine may be configured such that the fuel is injected directly into the cylinder of the engine, which is known to those skilled in the art as a direct injection engine.

Conventional distributorless ignition system 88 provides ignition spark to combustion chamber 30 via spark plug 92 in response to controller 12. Two-state exhaust gas oxygen sensor 96 is shown coupled to exhaust manifold 48 upstream of catalytic converter 97. Two-state exhaust gas oxygen sensor 98 is shown coupled to exhaust manifold 48 downstream of catalytic converter 97. Sensor 96 provides signal EGO1 to controller 12 which converts signal EGO1 into two-state signal EGO1S. A high voltage state of signal EGO1S indicates exhaust gases are rich of a reference air/fuel ratio and a low voltage state of converted signal EGO1 indicates exhaust gases are lean of the reference air/fuel ratio. Sensor 98 provides signal EGO2 to controller 12 which converts signal EGO2 into two-state signal EGO2S. A high voltage state of signal EGO2S indicates exhaust gases are rich of a reference air/fuel ratio and a low voltage state of converted signal EGO2S indicates exhaust gases are lean of the reference air/fuel ratio.

Controller 12 is shown in Figure 1 as a conventional microcomputer including: microprocessor unit 102, input/output ports 104, read only memory 106, random access memory 108, and a conventional data bus. Controller 12 is shown receiving various signals from sensors coupled to engine 10, in addition to those signals previously discussed, including: engine coolant temperature (ECT) from temperature sensor 112 coupled to cooling sleeve 114; a measurement of manifold pressure (MAP) from manifold pressure sensor 116 coupled to intake manifold 44; a measurement of exhaust gas recirculation pressure (EGRP) from exhaust pressure sensor 117 coupled to orifice tube 74 upstream of orifice 76, a profile ignition pickup signal (PIP) from Hall effect sensor 118 coupled to crankshaft 40, and an engine speed signal (RPM) from engine speed sensor 119. In a preferred aspect of the present invention, engine speed sensor 119 produces a predetermined number of equally spaced pulses every revolution of the crankshaft.

Referring now to Figure 2, a flowchart of a routine performed by controller 12 to generate fuel trim signal FT is now described. A determination is first made whether closed-loop air/fuel control is to be commenced (step 122) by monitoring engine operation conditions such as temperature. When closed-loop control commences, signal EGO2S is read from sensor 98 (step 124) and subsequently processed in a proportional plus integral controller as described below.

Referring first to step 126, signal EGO2S is multiplied by gain constant GI and the resulting product added to products previously accumulated (GI * $EGO2S_{i-1}$) in step 128. Stated another way, signal EGO2S is integrated each sample period (i) in steps determined by gain constant GI. During step 132, signal EGO2S is also multiplied by proportional gain GP. The integral value from step 128 is added to the proportional value from step 132 during addition step 134 to generate fuel trim signal FT.

The routine executed by controller 12 to generate the desired quantity of liquid fuel delivered to engine 10 and trimming this desired fuel quantity by a feedback variable related both to sensor 98 and fuel trim signal FT is now described with reference to Figure 3. During step 158, an open-loop fuel quantity is first determined by dividing the difference between inducted mass air flow (AMPEM, created from the signal FMAP and RPM as described later herein with particular reference to Figure 4), which includes both fresh charge and exhaust gas recirculation, and exhaust gas recirculation estimate (EM), which is described later herein with particular reference to Figure 4, by desired air/fuel ratio AFd which is typically the stoichiometric value for gasoline combustion. However, setting AFd to a rich value will result in operating the engine in a rich state. Similarly, setting AFd to a lean value will result in operating the engine in a lean state. Also, signal AMPEM is constructed from FMAP and RPM in the common speed density method known to those skilled in the art and can be easily empirically determined. This open-loop fuel quantity is then adjusted, in this example divided, by feedback variable FV.

After determination that closed-loop control is desired (step 160) by monitoring engine operating conditions such as temperature (ECT), signal EGO1S is read during step 162. During step 166, fuel trim signal FT is transferred from the routine previously described with reference to Figure 2 and added to signal EGO1S to generate trim signal TS.

During steps 170-178, a proportional plus integral feedback routine is executed with trimmed signal TS as the input. Trim signal TS is first multiplied by integral gain value KI (step 170), and the resulting product added to the previously accumulated products (step 172). That is, trim signal TS is integrated in steps determined by gain constant KI each sample period (i) during step 172. A product of proportional gain KP times trimmed signal TS (step 176) is then added to the integration of KI * TS during step 178 to generate feedback variable FV.

Calculating exhaust gas recirculation estimate (EM) is now described with particular reference to the diagram shown in Figure 4. In particular, Figure 4 shows how the upstream pressure (p1), which is signal EGRP in this example, and downstream pressure (p2), signal MAP in this example, are processed to form the signal EM. First, in block 400, upstream pressure p1 is processed through a first filter known to those skilled in the art as an anti-aliasing filter with a cut-off frequency equal to f1. Similarly, in block 402, downstream pressure p2 is processed through a second anti-aliasing filter with a cut-off frequency equal to f2. In some applications, it is unnecessary to use either the first or the second anti-aliasing filter because the geometry of the exhaust gas recirculation creates a mechanical filter that removes the unwanted high frequencies. Further frequencies f1 and f2 are set considerably higher than the necessary control bandwidth.

Next, in block 404, the result of block 400 is synchronously sampled with an engine rotation signal, such as, for example, RPM, such that the sampling is at a rate proportional to the firing frequency of the engine. For example the sampling rate could be twice the firing frequency of the engine. The proportion is generally chosen such that the sampling is at a rate of twice the highest harmonic frequency that contains significant energy. Also, as would be obvious to one of ordinary skill in the art and suggested by this disclosure, any multiple of firing frequency greater than that determined above could be used. If, for example, the exhaust gas recirculation and engine geometry are such that higher order harmonics are present in the upstream pressure signal p1, such as, for example, harmonics of twice or four times the firing frequency, a sampling rate of four or eight times the firing frequency may be necessary. Similarly, in block 406, the result of block 402 is synchronously sampled with engine speed signal RPM, such that the sampling is at a rate proportional to the firing frequency of the engine. Additionally, it is not necessary that the sampling rate be equal in blocks 404 and 406. For example, block 404 could synchronously sample at twice the firing frequency of the engine and block 406 could sample at eight times the firing frequency of the engine.

Alternatively, as is obvious to one of ordinary skill in the art and suggested by this disclosure, the pressure signal could be sampled at a frequency substantially proportional to the dominant frequency contained in the signal. This dominant frequency is usually equal to firing frequency. Thus, sampling at a rate proportional this dominant frequency could be accomplished using a circuit known to those skilled in the art as a phase-locked loop. However, because the phase locked loop scheme is sometimes searching for the dominant frequency during transients, this process may be suspended based on a change of position in throttle plate 62. During the transition, an open loop estimate of how the change in throttle plate 62 affects exhaust gas recirculation and manifold pressure must be obtained. This can be done using a predetermined map obtained through testing or analytical procedures and is known to those skilled in the art, where the transient behaviour is estimated based on change of position in throttle plate 62 and other operating conditions, such as for example engine speed.

Next, digital filters in blocks 408 and 410 process the results of blocks 404 and 406. The digital filters, represented by G(z) or G'(z) used in blocks 408 and 410 are known to those skilled in the art as digital notch filters. In this application, each notch filter removes the firing frequency (and higher harmonics if necessary) of the engine. The equation below represents an example of a notch filter in the discreet domain for sampling at a rate of twice the firing frequency. Use of notch filter G(z) is also described later herein with particular reference to Figure 5.

$$G(z) = (1+ z^{-1})/2$$

If the sampling were done at a rate of eight times the firing frequency, then the following notch filter would be used as described by G'(z). Again, while this removes unwanted frequencies, transient performance is not hindered. Use of a notch filter such as G'(z) is described later herein with particular reference to Figure 6 and 7.

$$G'(z) = (1+ z^{-1} + z^{-2} + z^{-3} + z^{-4} + z^{-5} + z^{-6} + z^{-7})/8$$

The digital filter may be different between blocks 408 and 410 and different than that shown above if necessary, such as if, for example, the geometry of the exhaust gas recirculation system was such that the certain frequencies were excessively amplified due to resonances. Also, the filter may be different between blocks 408 and 410 if block 404 synchronously sampled at twice the firing frequency of the engine and block 406 sampled at eight times the firing frequency of the engine.

The pressure difference is then created by subtracting the output of block 410, which is filtered manifold pressure FMAP, from the output from block 408. This pressure difference is then used in block 412 to create signal EM through a predetermined map or equation between pressure difference and exhaust gas recirculation flow, and, if necessary, engine operating conditions. For example, exhaust gas temperature may be used to adjust the calculation of exhaust gas recirculation flow.

Also, in block 414, signals FMAP and RPM are used to calculate the mass of gas flow entering the cylinder (AMPEM). The common speed density equations known to those skilled in the art are used to convert the filtered manifold absolute pressure with the engine speed to the total mass of gas (exhaust gas and fresh air charge) entering the cylinder. If necessary, these basic equations can be modified by engine operating conditions, such as for example gas temperature, or any other condition known to those skilled in the art and suggested by this disclosure.

Thus, an estimate of the exhaust gas recirculation and fresh air entering the cylinder is obtained that is substantially free of unwanted frequencies yet retains a bandwidth that is much greater than would be obtained with conventional filtering methods. Thus, the estimate can more accurately track transient operation and yield more accurate air/fuel ratio control.

An example of synchronously sampling a waveform is now described with particular reference to the plot shown in Figure 5. A fluctuating pressure signal, shown by the solid line and labelled A, is sampled with a frequency equal to twice the frequency of the actual signal. The sampled values are shown by points. The reconstructed waveform based on the synchronously sampled values and the filter previously described herein with particular reference to the function G(z) is shown as the dotted line and labelled B.

For comparison, a signal using a conventional low pass filter, which is required for conventional sampling schemes, is shown by a dash dot line and labelled C. In this example, the exhaust gas recirculation estimate formed using the synchronous sampling will yield a more accurate value that will allow for better overall air/fuel ratio control.

Another example of synchronously sampling a waveform is now described with particular reference to the plot shown in Figure 6. A fluctuating pressure, shown by the solid line and labelled D, is sampled with a frequency equal to eight times the frequency of the lowest harmonic order. This signal represents a typical exhaust pressure during steady state operating conditions. The sampled values are shown by points. The reconstructed waveform based on the synchronously sampled values and the filter previously described herein with particular reference to the function G'(z) is shown as the dotted line and labelled E. This result could not be obtained unless the sampled values are all perfectly spaced with the rotation of the engine, the synchronous sampling frequency was such that it was twice the highest significant harmonic frequency of the pressure signal, and the appropriate notch filter was used. In this example, the air flow entering the cylinder estimate formed using the synchronous sampling will yield an accurate value that will allow for optimal air/fuel ratio control.

Now referring to Figure 7A-7B and in particular to Figure 7A, the plot shows the frequency content of the pressure waveform shown in Figure 6. This pressure could represent, for example, the exhaust manifold pressure for a steady state firing frequency of the engine of approximately 50 Hz. Figure 7B shows a plot of the magnitude versus frequency of the filter G'(z). Thus, the scheme previously described herein with particular reference to Figure 4, comprises (in the frequency domain) multiplying the plots of Figures 7A and 7B. This shows that the mean value, or DC component as known to those skilled in the art, is preserved. The result is a signal substantially free of undesirable frequencies for mean value model computations.

There are also other alternative embodiments of the present invention. For example, using a synchronous sampling scheme is not dependent on the orifice being located downstream of the exhaust gas recirculation flow control valve. The scheme could be employed using a pressure sensor upstream and a pressure sensor downstream of the orifice, with the exhaust gas recirculation flow control valve still between the downstream pressure sensor and the intake manifold, as in current production vehicles. Furthermore, the method is not restricted to flow measurement with an orifice. Other flow measurement techniques known to those skilled in the art could be used with the above described method such as, for example, a venturi, a pitot tube, or a laminar flow element.

CLAIMS

1. A system for estimating engine flows, including exhaust gas flow from an exhaust manifold of an internal combustion engine to an intake manifold of the engine and airflow into an engine cylinder, the system comprising:

a flow control valve having a variable orifice positioned in an exhaust gas recirculation path between the exhaust manifold and intake manifold of the engine;

a fixed orifice area located in said path and downstream of said valve; and

a computer for determining a first signal related to pressure between said fixed orifice area and said flow control valve, determining a second signal related to pressure downstream of said fixed orifice area, calculating a third signal related to the exhaust gas flow based on said first signal and said second signal, and determining a fourth signal related to the airflow based on said second signal and said third signal.

2. A system as claimed in Claim 1, wherein said computer serves further to calculate a fuel injection amount based on said fourth signal.

3. A system as claimed in Claim 1 or 2, further comprising an absolute pressure sensor for providing said second signal.

4. A system as claimed in any preceding claim, further comprising an absolute pressure sensor for providing said first signal.

5. A system as claimed in Claim 4, wherein said third signal is a related to a difference between said first signal and said second signal.

6. A system as claimed in any preceding claim, wherein determining said fourth signal related to the airflow further comprises determining a sum of airflow and exhaust gas flow based on said second signal, determining exhaust gas flow based on said third signal, and calculating the airflow by subtracting the exhaust gas flow from said sum.

7. A system as claimed in Claim 6, wherein determining exhaust gas flow further comprising determining exhaust gas flow based on a difference between said first signal and said second signal.

8. A system as claimed in Claim 1, wherein said computer further adjusts said fuel injection amount based on a feedback signal from an exhaust gas sensor coupled downstream of the engine.

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13

Application No:	GB 0011155.9	**Examiner:**	Rebecca Villis
Claims searched:	All	**Date of search:**	20 October 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): F1B (BBB); G1N (NACDX), (NACG), (NACV), (NAJCR)

Int Cl (Ed.7): F02D 21/08; F02M 25/07

Other: Online: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	US 5613479 (FORD)	1-5,7
Y	US 5390649 (MIENER et al)	1-5,7
Y	JP 560077543 (TOYOTA)	1,3-5,7

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		