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(54) Adaptive electronic injection fuel delivery control system.

(57) An adaptive electronic injection fuel delivery control system wherein a processing unit (10) receives and processes input signals proportional to the air intake pressure (P) and temperature (T) in the manifold of the engine, and supplies an output value (Q_b) indicating the amount of fuel to be injected for achieving a substantially correct stoichiometric air/fuel ratio. The above value (Q_b) is subsequently corrected by two coefficients (K_{02} and K_{ad}), the first calculated in closed-loop manner by integrating the difference between the signal generated by an exhaust sensor (20) and a reference voltage value (V_{st}), and the second by interpolating a set of values comprising the inverse of the air intake value (1/(Q)), and previously measured values of the K_{02} parameter.

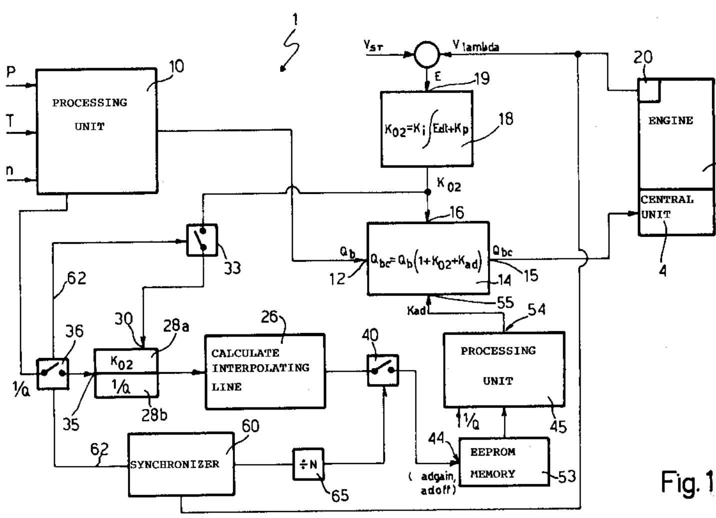

Fig.1

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The present invention relates to an adaptive electronic injection fuel delivery control system.

Known electronic injection systems feature an electronic control system with a processing unit for receiving and processing input signals proportional to air pressure and temperature in the intake manifold and engine speed, and supplying an output value (Q_b) indicating the amount of fuel to be injected for achieving a substantially correct stoichiometric air/fuel ratio.

The output value (Q_b), which is normally determined on the basis of memorized tables, is modified by monitoring the composition of the exhaust gas by means of a sensor housed inside the exhaust manifold, and which supplies a signal ranging from 0 to 1 V, depending on whether the air/fuel mixture contains more or less fuel as compared with the required stoichiometric ratio.

The sensor signal is integrated to obtain a correction factor (K_{02}) which is applied to the calculated fuel quantity value (Q_b) to give a correct fuel quantity (Q_{bc}). Fuel delivery is thus controlled in closed-loop manner by virtue of feeding back the signal supplied by the sensor.

The above type of correction, however, is not adaptable to all engine operating conditions. In the case of transient operating conditions in particular (corresponding for example to a sharp variation in supply pressure), the correction factor (K_{02}), being set to a fixed value, fails to provide for adequately correcting the fuel quantity calculated by the processing unit, so that the resulting air/fuel ratio differs substantially from the required stoichiometric ratio.

Moreover, by virtue of the mean value of K_{02} being other than zero, a certain amount of time is taken for it to be restored to said mean value when switching from an open-loop to a closed-loop condition (e.g. following a transient state).

It is an object of the present invention to provide a system designed to overcome the drawbacks of known injection systems, by ensuring the air/fuel ratio is maintained within the stoichiometric ratio under all operating conditions.

According to the present invention, there is provided an internal combustion engine electronic fuel injection system comprising a processing unit receiving information signals relative to engine speed (n) and air supply (Q) to the manifold of said engine, and in turn comprising first loop processing means for calculating a theoretical fuel quantity (Q_b) as a function of said information signals; second processing means for calculating a first parameter (K_{02}) with which to correct said fuel quantity (Q_b) as a function of a signal generated by an exhaust sensor; third processing means for calculating a second parameter (K_{ad}) with which to correct said theoretical fuel quantity (Q_b); and fourth processing means for calculating a correct fuel quantity (Q_{bc}); characterized by the fact that said third processing means comprise means for memorizing a first set of data comprising the values of said first parameter (K_{02}) measured at successive instants in time; means for memorizing a second set of data comprising the values of a quantity (1/(Q)) as a function of said information signals and measured at successive instants in time; a unit for interpolating said first and second sets of data for calculating an interpolation function, said function interpolating a set of points having said first and second sets of data as its coordinates; and further processing means for calculating from said function the value of said second parameter (K_{ad}) as a function of said quantity (1/(Q)).

The present invention will be described with reference to the accompanying drawings, in which:

Fig.1 shows a schematic view of the system according to the present invention;

Fig.s 2a and 2b show operating block diagrams of the Fig.1 system.

Number 1 in Fig.1 indicates an adaptive system for controlling the fuel delivery of a central unit 4 of a petrol engine 6.

System 1 comprises a processing unit 10 supplied with three signals proportional to the air pressure at the intake manifold (P), air temperature in the intake manifold (T), and engine speed (n), and connected at the output to a first input 12 of a processing unit 14, the output 15 of which is connected to central unit 4.

On the basis of air pressure (P) and temperature (T) in the manifold, processing unit 10 calculates (via the ideal gas law) the air intake (Q) of engine 6, which value is subsequently used for calculating a quantity proportional to the amount of fuel (Q_b) to be supplied to engine 6 for achieving a correct air/fuel ratio.

For this purpose, unit 10 determines, on the basis of memorized tables, and at any rate in known manner, a theoretical fuel quantity (Q_b) as a function of air intake (Q) and engine speed (n), which value (Q_b) is purely a rough estimate of the optimum value, which is subsequently corrected as described later on.

Unit 14 presents a second input 16 connected to a proportional-integral regulator 18, the input 19 of which is supplied with a signal (E) representing the difference between a reference signal (V_{st}) and a signal (V_{lambda}) generated by a sensor 20 in the exhaust manifold of engine 6.

Regulator 18 calculates a correction variable K_{02} on the basis of signal E at input 19 and according to the equation:

$$K_{02} = Ki^* \int (E)dt + Kp$$

where Ki and Kp are constants, the values of which variable are supplied to input 16.

On the basis of the signals at its inputs, unit 14 calculates a correct fuel quantity Q_{bc} according to the equation:

$$Q_{bc} = Q_b{}^*(1 + K_{02} + K_{ad})$$

where Q_b is the theoretical fuel quantity calculated by unit 10; K_{02} the correction variable calculated by block 18; and K_{ad} an adaptive variable as explained later on.

System 1 also comprises a processing unit 26 input-connected to two RAM memories 28a and 28b, the first having an input 30 connected to input 16 of circuit 14 via the interposition of an electronic switch 33, and the second having an input 35 supplied, via the interposition of an electronic switch 36, with signals as a function of the inverse of the air intake (1/Q) of engine 6. Memories 28a and 28b thus respectively contain the values of correction variable K_{02} and the inverse of air intake (1/Q) sampled by switches 33 and 36 when these are closed.

Processing unit 26 is output-connected, via electronic switch 40, to input 44 of a permanent EEPROM memory 53, the output of which is connected to processing unit 45.

The output 54 of processing unit 45 is connected to input 55 of processing unit 14.

Unit 26 processes the data in memories 28a and 28b using the least recursive squares method to calculate the line minimizing the squares of the distances from a set of points, the x and y axes of which correspond respectively to the values of 1/Q and parameter K_{02}.

Said line is determined on the basis of its known term (adgain) and its angular coefficient (adoff).

Circuit 45 cooperates with EEPROM memory 53, which is supplied at input 44 with data corresponding to the (adgain) and (adoff) values, and supplies circuit 45 with the memorized data for calculating coefficient K_{ad} as a function of the (Q) values according to the equation:

$$K_{ad} = (adoff) / (Q) + (adgain)$$

where (adoff) and (adgain) are the values stored in EEPROM memory 53.

System 1 also comprises a synchronizing circuit 60 input-connected to sensor 20 and which provides for synchronously switching electronic switches 33 and 36 connected to circuit 60 over a common control line 62, and which are closed whenever the signal generated by sensor 20 switches from roughly 0 to 1 V or vice versa.

Circuit 60 is also connected, via the interposition of a dividing-by-N circuit 65, to electronic switch 40, so that switch 40 is closed and data transferred from unit 26 to circuit 53 at each N number of switch operations of sensor 20.

Operation of the Fig.1 system will be described with reference to the operating block diagrams in Fig.s 2a and 2b.

To begin with (Fig.2a), block 100 determines air pressure (P) at the intake manifold, air temperature (T) in the intake manifold, and engine speed (n).

Block 110 then calculates the air intake (Q) of engine 6 on the basis of the air pressure (P) and temperature (T) determined in block 100, and goes on to block 120.

Block 120 calculates theoretical fuel quantity Q_b on the basis of air intake (Q) and engine speed (n), which calculation is made in known manner using memorized tables wherein each pair of intake (Q) and speed (n) values corresponds to a given theoretical fuel quantity value (Q_b).

Block 120 then goes on to block 130, which provides, in closed-loop manner, for calculating correction variable K_{02} on the basis of signal E at input 19 of regulator 18, according to the following equation:

$$K_{02} = Ki * \int (E)dt + Kp$$

where Ki and Kp are constants.

Block 130 is followed by block 140, which reads the (adoff) and (adgain) values in EEPROM memory 53, after which block 150 calculates adaptive coefficient K_{ad} as a function of (Q) according to the equation:

$$K_{ad} = (adoff) / (Q) + (adgain)$$

Block 150 is followed by block 160, which determines whether system 1 is operating in closed-loop manner. If it is, block 160 goes on to block 170 (Fig.2b). If it is not, block 160 goes on to block 180, which calculates the correct fuel quantity (Q_{bc}) according to the equation:

$$Q_{bc} = (Q_b)^*(1 + K_{ad})$$

and then goes back to block 100.

Block 170 (Fig.2b) calculates the correct fuel quantity (Q_{bc}) according to the equation:

$$Q_{bc} = (Q_b) * (1 + K_{ad} + K_{02})$$

and then goes on to block 190, which performs a conditional jump according to the speed (n) of engine 6. More specifically, if engine speed (n) is below a first limit value (n1), block 190 goes on to block 200a; if (n) falls between said first limit value (n1) and a second limit value (n2), block 190 goes on to block 200b; if (n) is greater than said second limit value (n2), block 190 goes on to block 200c.

As blocks 200a, 200b and 200c and the respective downstream blocks perform the same functions, the same numbering system accompanied by the letters a, b and c is used for all three, and the following description therefore limited to blocks (a).

Block 200a provides for memorizing in RAM memories 28a and 28b the values of K_{02} and (1/-(Q)) at each switch operation of sensor 20.

Block 200a is followed by block 210a by which the data contained in memories 28a and 28b is processed using the least recursive squares method to calculate the line minimizing the squares of the distances from a set of points, the x and y axes of which respectively correspond to the (1/Q) and K_{02} values.

Said line is determined on the basis of its known term (adgain) and its angular coefficient (adoff).

Block 210a is followed by block 220a, which determines whether the content (K) of a counter has reached the maximum limit value (N). If it has, block 220a goes on to block 230a. If it has not, block 220a goes on to block 300 (Fig.2a) by which the content of the counter is increased one unit (logic operation $K=K+1$), and which then goes back to block 100.

Block 230a provides for memorizing the (adgain) and (adoff) values in permanent memory 53, and is followed by block 240a, which resets the content of the counter (logic operation K-0) and then goes back to block 100.

The system according to the present invention thus provides for overcoming the drawbacks typically associated with known systems.

According to the present invention, in fact, the theoretical fuel quantity (Q_b) is satisfactorily corrected under all operating conditions (even when that effected by parameter K_{02} is inadequate, e.g. in open-loop mode); and the calculated correct fuel quantity (Q_{bc}) provides for achieving an air/fuel ratio substantially corresponding to the stoichiometric ratio. This is due to the fact that, as experiments have shown, over a limited speed (n) range and under correct operating conditions of the loop comprising sensor 20, parameter K_{02} is related substantially linearly to the inverse of the air intake 1/(Q).

Consequently, by memorizing the K_{02} and 1/-(Q) values at different times and within predetermined speed (n) ranges, it is possible to determine the lines in question via interpolation, and so employ the resulting data when the operating conditions of the engine are such as to impair correction of Q_b solely on the basis of K_{02}. The system according to the present invention is particularly effective during transient states wherein closed-loop control by K_{02} is interrupted and K_{02} set to a fixed value.

By virtue of the above "learning" procedure being performed continually, the present invention provides for keeping track of any variation in the operation of the engine (due, for example, to ageing or wear), thus ensuring adequate correction of the calculated fuel quantity (Q_{bc}) at all times and, consequently, optimum performance of the engine.

To those skilled in the art it will be clear that changes may be made to the system as described and illustrated herein without, however, departing from the scope of the present invention.

For example, processing unit 10 may be supplied with an input signal proportional to air intake (Q) as measured by a flow detector in the intake manifold, thus enabling air intake (Q) to be determined directly, with no need for measuring the signals proportional to air intake pressure (P) and temperature (T) at the intake manifold.

Claims

1. An internal combustion engine electronic fuel injection system comprising a processing unit (10) receiving information signals relative to engine speed (n) and air supply (Q) to the manifold of said engine, and in turn comprising first loop processing means for calculating a theoretical fuel quantity (Q_b) as a function of said information signals; second processing means (18) for calculating a first parameter (K_{02}) with which to correct said fuel quantity (Q_b) as a function of a signal generated by an exhaust sensor; third processing means (26, 28a, 28b, 45) for calculating a second parameter (K_{ad}) with which to correct said theoretical fuel quantity (Q_b); and fourth processing means (14) for calculating a correct fuel quantity (Q_{bc}); characterized by the fact that said third processing means (26, 28a, 28b, 45) comprise means (28a) for memorizing a first set of data comprising the values of said first parameter (K_{02}) measured at successive instants in time; means (28b) for memorizing a second set of data comprising the values of a quantity (1/(Q)) as a function of said information signals and measured at successive instants in time; a unit (26) for interpolating said first and second sets of data for calculating an interpolation function, said function interpolating a set of points having said first and second sets of data as its coordinates; and further processing means (45) for calculating from said function the value of said second parameter (K_{ad}) as a function of said quantity (1/(Q)).

2. A system as claimed in Claim 1, characterized by the fact that said interpolation function is a line minimizing the sum of the squares of the distances from said set of points.

3. A system as claimed in Claim 1 or 2, characterized by the fact that said quantity is a function of the air supply (Q) to said engine.

4. A system as claimed in Claim 3, characterized by the fact that said quantity is the inverse of the air supply (Q) to said engine.

5. A system as claimed in any one of the foregoing Claims, characterized by the fact that said fourth processing means (14) calculate said correct fuel quantity (Q_{bc}) as a function of said theoretical fuel quantity (Q_b) and said first (K_{02}) and second (K_{ad}) parameters.

6. A system as claimed in Claim 5, characterized by the fact that said processing means (14) calculate the correct fuel quantity value (Q_{bc}) by multiplying the theoretical fuel quantity value (Q_b) by a term equal to the sum, increased by one unit, of said first (K_{02}) and second (K_{ad}) parameters.

7. A system as claimed in Claim 3 or 4, characterized by the fact that said air supply is calculated according to the ideal gas law, on the basis of signals proportional to the pressure (P) and temperature (T) of the air supplied to the manifold of said engine.

8. A system as claimed in Claim 3 or 4, characterized by the fact that it comprises a flow detector in the intake manifold for determining said air supply (Q).

9. A system as claimed in any one of the foregoing Claims, characterized by the fact that said first processing means (10) calculate said theoretical fuel quantity (Q_b) on the basis of memorized tables.

10. A system as claimed in any one of the foregoing Claims, characterized by the fact that said memorizing means (28a, 28b) comprise at least one RAM memory.

11. A system as claimed in any one of the foregoing Claims, characterized by the fact that said second means comprise means for calculating said first correction parameter (K_{02}) by integrating the signal generated by said sensor (20).

12. A system as claimed in any one of the foregoing Claims, characterized by the fact that the values of said first parameter (K_{02}) and said quantity are memorized at each switch operation of said sensor (20).

13. A system as claimed in any one of the foregoing Claims, characterized by the fact that it comprises decision-making means (190) for selecting from a number of means (210a, 210b, 210c) for interpolating said second and first set of data; said decision-making means (190) selecting one of said interpolating means (210a, 210b, 210c) for calculating a respective interpolation function.

14. A system as claimed in Claim 13, characterized by the fact that said decision-making means (190) select said interpolating means (210a, 210b, 210c) on the basis of the speed (n) of said engine (6).

15. A system as claimed in Claim 14, characterized by the fact that said interpolating means (210a, 210b, 210b) employ subsets of said first and said second set of data, each subset comprising data acquired within a predetermined speed (n) range.

16. A system as claimed in any one of the foregoing Claims, characterized by the fact that it comprises means (40, 65) for transferring parameters ((adgain), (adoff)) of said interpolating function to further memorizing means (53) following a given number (N) of switch operations of said sensor (20).

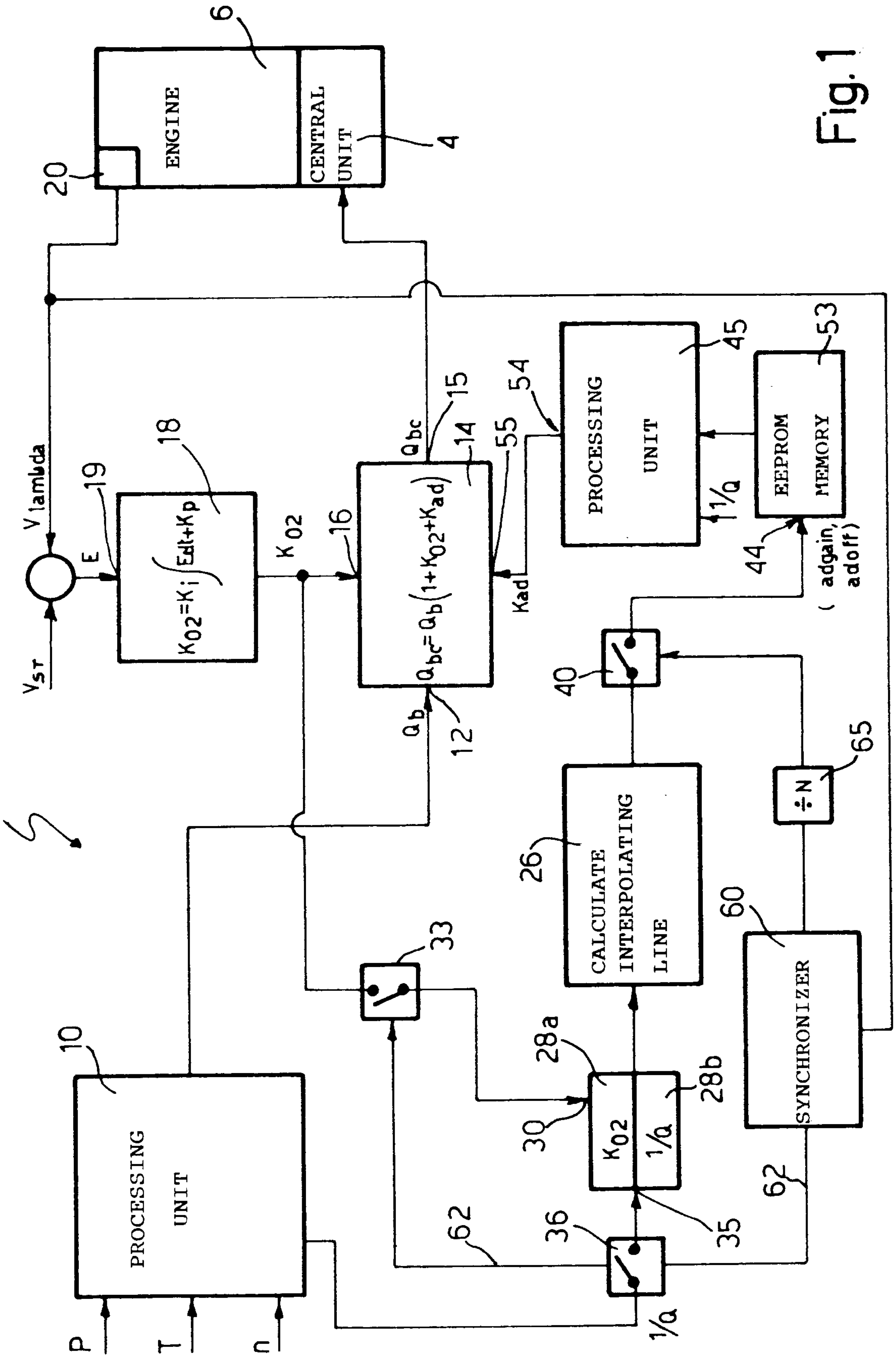

ENGINE
CENTRAL UNIT
PROCESSING UNIT
EEPROM MEMORY
CALCULATE INTERPOLATING LINE
SYNCHRONIZER
PROCESSING UNIT
$K_{O2}=K_i\int E\,dt+K_p$
$Q_{bc}=Q_b(1+K_{O2}+K_{ad})$
V_{lambda}
V_{ST}
E
K_{O2}
Q_{bc}
Q_b
K_{ad}
1/Q
÷N
(adgain, adoff)
P
T
n
1
4
6
10
12
14
15
16
18
19
20
26
28a
28b
30
33
35
36
40
44
45
53
54
55
60
62
65

Fig. 1

Fig. 2a

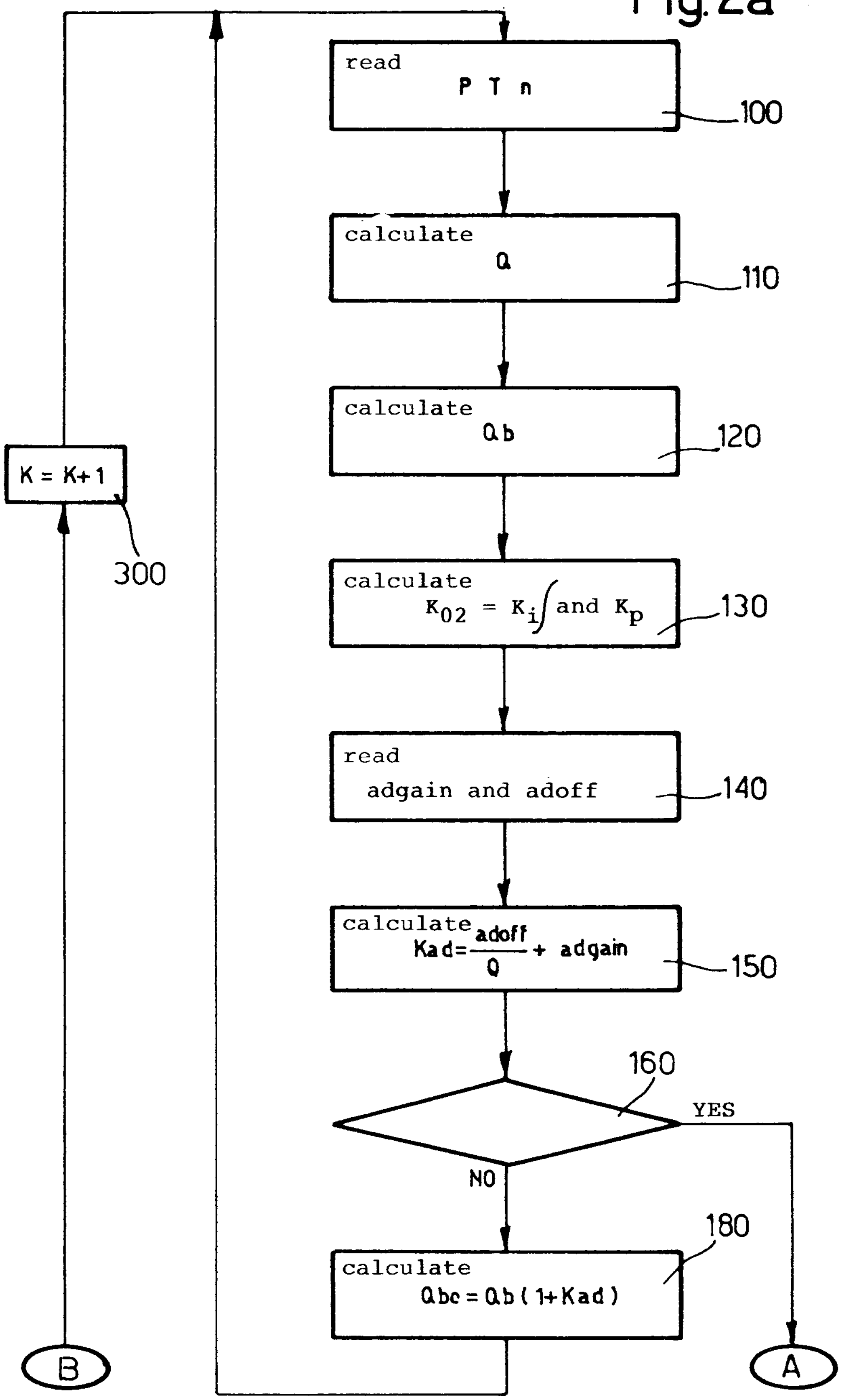
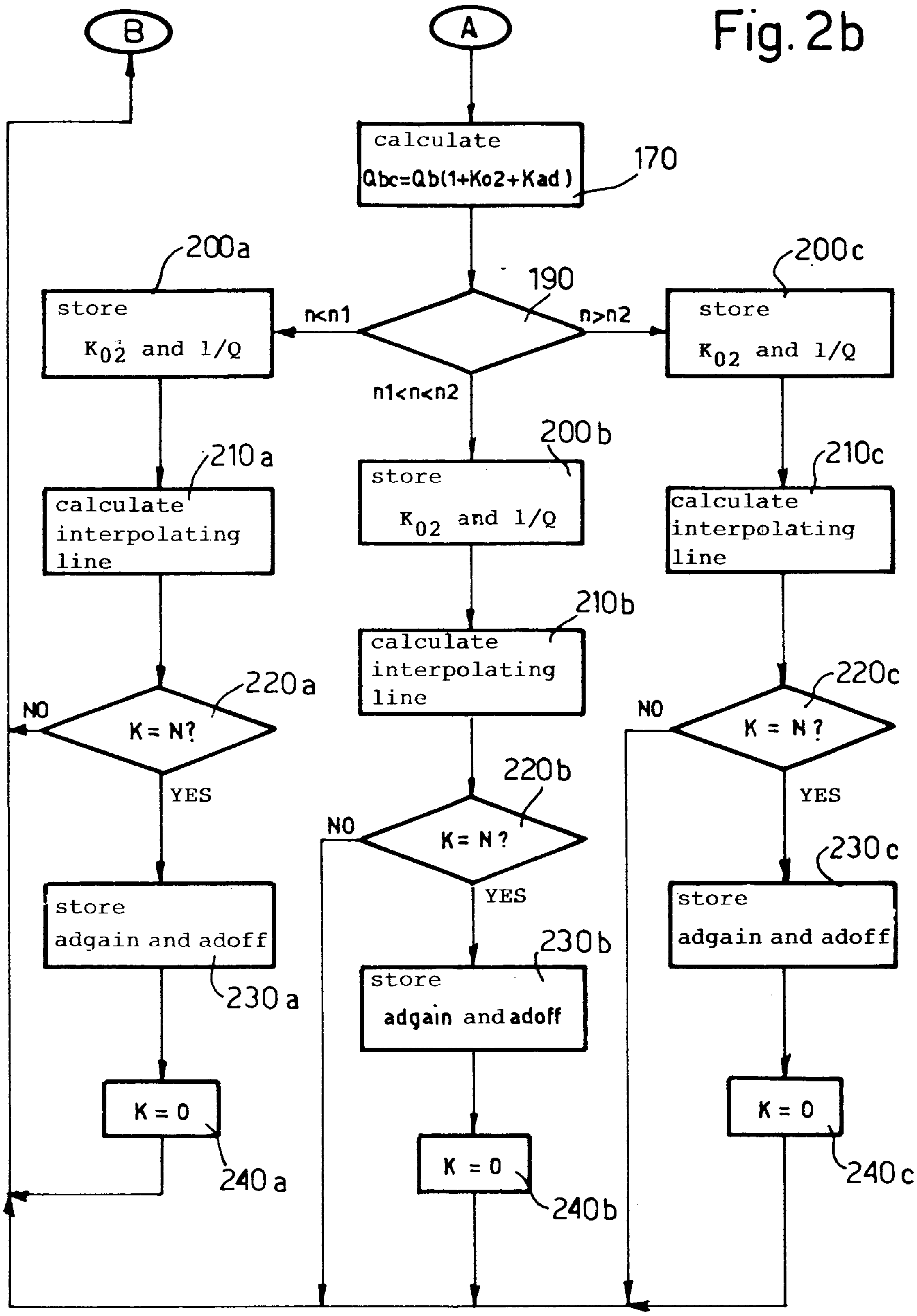

read
P T n
100
calculate
Q
110
calculate
Qb
120
calculate
K02 = Ki∫ and Kp
130
read
adgain and adoff
140
calculate
Kad = adoff/Q + adgain
150
160
YES
NO
180
calculate
Qbc = Qb(1+Kad)
K = K+1
300
B
A

Fig. 2b


B
A
calculate
Qbc=Qb(1+Ko2+Kad)
170
200a
190
200c
store
K02 and 1/Q
n<n1
n>n2
store
K02 and 1/Q
n1<n<n2
200b
210a
store
K02 and 1/Q
210c
calculate
interpolating
line
calculate
interpolating
line
210b
calculate
interpolating
line
220a
220c
NO
K = N?
NO
K = N?
YES
YES
220b
NO
K = N?
230c
store
adgain and adoff
YES
store
adgain and adoff
230b
230a
store
adgain and adoff
K = 0
K = 0
240a
K = 0
240c
240b