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(54) **Electronic throttle control system**

(57) An electronic throttle control system is described where a throttle position sensor has multiple slopes depending on the operating region. At low throttle positions, a greater slope, and thus a greater sensitivity is provided, thereby increasing control resolution. At greater throttle positions, a lower slope, and thus lower sensitivity is provided. In this way, an output signal that varies across the entire operating region of the throttle is provided for monitoring and control, while improved performance at low throttle angles can be simultaneously achieved. A method for learning a transition region is also described.

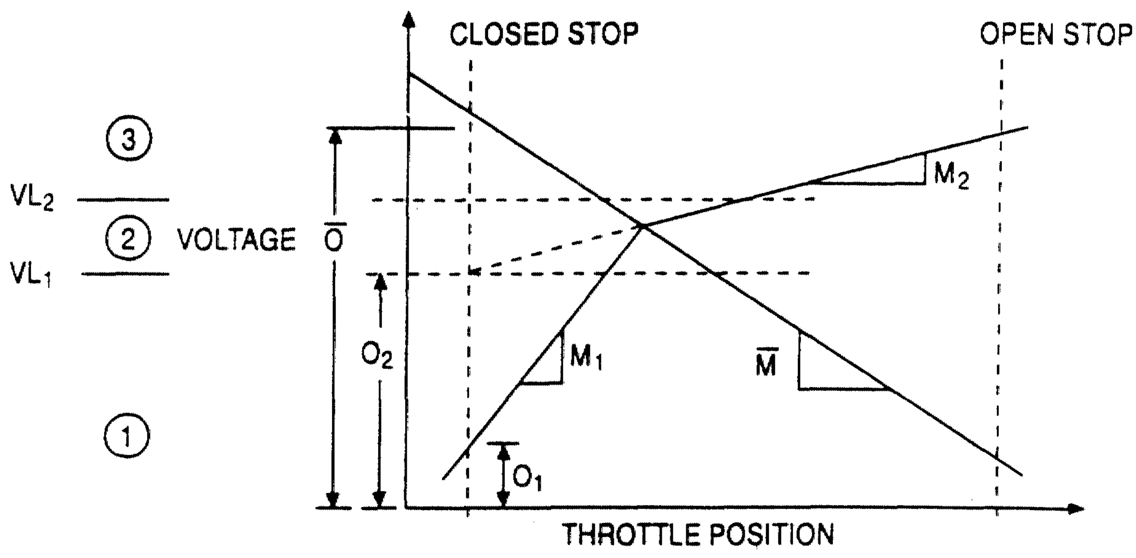

FIG. 4

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Description

[0001] The field of the invention relates to electronically controlled throttle units in vehicles having a drive unit.

[0002] In some engines, an electronically controlled throttle is used for improved performance. In such systems, position of the throttle is controlled via closed loop feedback control. Typically, to provide redundancy multiple throttle position sensors are provided.

[0003] One method to provide two throttle position sensors uses sensors of different gradients, each linear over the entire operating range, another uses gradients of opposite sign. Still other methods use saturating sensors. These methods are described U.S. Patents 5,136,880; 5,260,877; and 4,693,111, respectively.

[0004] The inventors herein have recognised some disadvantages of the above approaches. In particular, when a high resolution saturating sensor and a low resolution sensor are used together, there is a saturated region where the saturating sensor provides less information than the unsaturated region. Alternatively, when different gradients are used, each linear over the entire region, the analogue to digital converters are over-specified and under-utilised to accommodate the low resolution sensor. Another disadvantage with prior approaches is that multiple tracks, interconnections between the tracks, and wiper arms may be required to provide multiple outputs having different characteristics.

[0005] An approach to solve the above prior art disadvantages would be to have a sensor with two output signals. The first output signal would be linear over the entire operating region. The second output signal would have two segments, each of said segments having a different resistivity. The second output would therefor have two segments, each with a different gradient, and having a point of non-linearity.

[0006] Having a sensor with two operating regions gives that opportunity to obtain high resolution at low throttle angles, and thereby have better airflow control, as well as obtain information throughout the operating range without over-specifying and under-utilising A/D converters.

[0007] However, the inventors herein have recognised a disadvantage with such a sensor. In particular, the output having two segments may have variation due to manufacturing. As such, the point of non-linearity may have increased error. Such error may cause degraded control.

[0008] An object of the present invention is to provide electronic throttle control system and sensor.

[0009] The above object is achieved and disadvantages of prior approaches overcome by a method for an electronically controlled throttle including first and second position sensors, the second position sensor having a first characteristic in a first operating range and a second characteristic in a second operating range, comprising: reading a first output of the first sensor; reading a second output of the second sensor; and learning a transition region between the first operating range and the second operating range based on said first output and said second output.

[0010] By learning a transition region between the first operating range and the second operating, it is possible to learn any point of non-linearity and provide compensation to minimise errors.

[0011] An advantage of the above aspect of the invention is the potential for improved steady state accuracy.

[0012] An advantage of the above aspect of the invention is the potential for improved monitoring accuracy.

[0013] The object and advantages of the invention claimed herein will be more readily understood by reading an example of an embodiment in which the invention is used to advantage with reference to the following drawings wherein:

Figure 1 is a block diagram of a vehicle illustrating various components related to the present invention;

Figure 2a is a schematic diagram of the position sensor;

Figures 2b,4 are graphs showing output characteristics of the sensor;

Figures 3,5, and 6 are block diagrams of embodiments in which the invention is used to advantage.

[0014] Internal combustion engine 10, comprising a plurality of cylinders, is controlled by electronic engine controller 12. Engine 10 can be a port fuel injected engine, a directed injected engine, a gasoline engine, a diesel engine, or any other type of engine utilising redundant position sensors. Engine 10 is coupled to intake 20 and exhaust 22. A throttle 24 is positioned in intake 20. Position sensor 30, described later herein with particular reference to Figure 2, is coupled to throttle 24.

[0015] Controller 12 is shown in Figure 1 as a conventional microcomputer including: microprocessor unit 102, input/output ports 104, an electronic storage medium for executable programs and calibration values shown as read only memory chip 106 in this particular example, random access memory 108, keep alive memory 110, and a conventional data bus. Controller 12 is shown receiving various signals from sensors 40 coupled to engine 10, in addition to signals from position sensor 30. Controller 12 is also shown sending various signals to actuators 44 coupled to engine 10. Additionally, an electric motor 46 is coupled to throttle 24 and receives a control signal from controller 12 to control position of throttle 44, as well as engine torque, or vehicle acceleration.

[0016] Referring now to Figure 2, and in particular to Figure 2a, position sensor 30 is shown. In this particular depiction, position sensor 30 is shown as an unrolled version of a rotary (angular) sensor. Those skilled in the art will recognise, in view of this disclosure, that the present invention is applicable to angular position sensors for measuring angular deflection as will as displacement position sensors for measuring deflection in a uniform direction, i.e., along a line.

[0017] Sensor 30 has substrate 200 which supports tracks 210 and 212. First track 210 and second track 212 are tracks of resistive material that are used to produce two potentiometer signals (S1, S2). Additional tracks can be placed on substrate 200 without departing from the present invention. Second track 212 has two contiguous segments, first segment 220 and a second segment 222. Track 212 is produced by applying the first track segment of a first resistivity on the substrate, and applying, contiguous to said first track segment, a second track segment having a second resistivity on the substrate. Conductive path 214 supplies a grounded, or low voltage signal to first segment 220 of track 212. Conductive path 214 also supplies a grounded, or low voltage signal, to an opposite end of track 210 as that of track 212. Conductive path 226 supplies a supply voltage signal to second segment 222 of track 212, as well as, to an opposite end of track 210 as that of track 212. Wipers 228 and 230 provide signals S1 and S2 to conductive paths 232 and 234 respectively. First and second segment of track 212 have different material properties. In particular, they provide different resistivities. In the embodiment depicted in Figure 2a, the different resistivities are provided by different track widths. Those skilled in the art will recognise, in view of this disclosure, various other methods of having two segments, each with different resistivities.

[0018] Referring now to Figure 2b, a graph showing the output voltage characteristics of sensor 30 are shown versus wiper position. θk identifies the point where the two segments of track 212 transition. This region may be a sharp point, as illustrated in Figure 2b, or might have some curvature, and thus there would be a transition region, the size of which depends on the manufacturing process chosen to produce the two segments.

[0019] Continuing with Figure 2b, opposite polarity of signals S1 and S2 is obtained by conductive paths 214 and 226 being connected to opposite ends of tracks 212 and 210. Similarly, the two linear segments of signal S2, each having a different slope, are obtained by having two segments (220, 222) of track 212, each having a different resistivity. Lines 240 and 242 represent the closed stop and open stop of throttle 24.

[0020] Referring now to Figure 3, a routine is shown for determining whether output signals S1 and S2 of sensor 30 are in agreement. First, in step 310, first throttle position (θ_1) is determined based on signal S1 and the characteristics, or resistance, of track 210. In particular, as described later herein, first throttle position is determined based on a slope and offset of signal S1. Next, in step 312, second throttle position (θ_2) is measured and determined based on signal S2. In particular, the characteristics of track 212 are used. As described later herein, when measured voltage signal (S1) is less than a predetermined value, a first slope and first offset are used to convert signal S2 to θ_2. When the voltage is greater than said level, a second slope and offset are used to convert signal S2 to θ_2. Next, in step 314, a difference (e) is determined between first throttle position and second throttle position. In step 316, a determination is made as to whether first throttle position is less than a predetermined value D1. In other words, a determination is made in step 316 as to whether the throttle is operating in the region of the first segment of track 212 or in the region of the second segment of track 212. When the answer to step 316 is YES, a determination is made in step 318 as to whether the absolute value of the difference between the first and second throttle positions is greater than the threshold value E1. Otherwise, when the answer to step 316 is NO, a determination is made as to whether the absolute value of the difference is greater than threshold value E2. According to the present invention, different threshold levels are used depending on whether the throttle is operating in the first segment or second segment of track 212. In other words, since the signals have different sensitivity and resolution, different threshold values are used to account for this. In this way, it is possible to obtain higher sensitivity to disagreement in regions of low throttle position where a small change in throttle position produces a large change in engine torque, and lesser resolution in regions a large change of throttle position produces only a small change in engine torque. When the answer to either step 318 or 320 is YES, disagreement is indicated in step 322.

[0021] Referring now to Figure 4, a detailed graph showing the output characteristics of sensor 30 is shown. In particular, slope m1 and offset o1 are shown for the first segment of track 212, second slope m2 and second offset o2 are shown for the second segment of track 212. Also, slope $\bar{m}$, and offset $\bar{o}$, are shown for track 210. Three regions (circled 1, 2, and 3) are shown on the left-hand side of Figure 4. Region 2 represents the region of the transition between the first and second segments of track 212. Voltage levels VL1 and VL2 define region 2. Voltage levels VL1 and VL2 are predetermined values that represent physically determined limits due to manufacturing tolerance between which the transition resides. In addition, vertical dash lines show the close stop and open stop positions.

[0022] The following equations show how signals S1 and S2 are converted to throttle positions using the slopes and offsets.

For signal S1,

$$\theta_1 = \frac{S1-\bar{o}}{\bar{m}}$$

For signal S2 in the lower region,

$$\theta_2 = \frac{S2\text{-}o_1}{m_1}$$

For signal S2 in the upper region,

$$\theta_2 = \frac{S2\text{-}o_2}{m_2}$$

[0023] Referring now to Figure 5, a routine is described for learning the region of the transition between first and second segments of track 212. First, in step 510, a determination is made as to whether first signal S1 is varying. In other words, when learning both a slope and an offset from the given information, improved accuracy can be obtained if what is known as "persistence of excitation" to those skilled in the art is present. If only the offset is learned of signal S2 in the upper region, step 510 can be deleted. When the answer to step 510 is YES, the routine continues to step 512 and calculates the current measurement at step i of first and second throttle positions (θ^i_1,θ^i_2). Next, in step 514, the current value of the error signal (er^i) is calculated based on the measured throttle position as shown:

$$er^i = \theta^i_1 - \theta^i_2$$

[0024] Next, in step 516, a determination is made as to whether first voltage signal S1 is less than voltage limit VL1. When the answer to step 516 is YES, the routine continues to step 518 where the routine updates first slope and first offset (m1, o1). The following equations describe the updating of learning of the slope and the offset of the first segment of track 212:

$$m_1^{i+1} = f(er^i,\ m^i_1,\ o^i_1,\ \theta^i_1)$$

$$o_1^{i+1} = g(er^i, m^i_1, o^i_1, \theta^i_1)$$

[0025] In a preferred embodiment, functions *f,g* represent a recursive least squares algorithm. However, those skilled in the art will recognise, in view of this disclosure, that various other algorithms can be used drive error signal (er) to zero or to a minimum by adjusting the slopes and offsets. For example, a learning algorithm of the type described in U.S. Patent 5,464,000, could be adapted to co-operate with the present invention.

[0026] Otherwise, when the answer to step 516 is NO, a determination is made in step 520 as to whether first voltage signal S1 is greater than voltage limit 2. When the answer to step 520 is YES, the routine updates or learns the second slope and offset (m2, o2), in step 522:

$$m_2^{i+1} = f(er^i, m^i_2, o^i_2, \theta^i_1)$$

$$o^{i+1}{}_2 = g(er^i, m^i_2, o^i_2, \theta^i_1)$$

From either step 518 or 522, the routine continues to step 524 and updates transition voltage Vk. Transition voltage Vk is calculated according to the following equation:

$$V_k = m_1\ \frac{o_2 - o_1}{m_1 - m_2} + o_1$$

[0027] Thus, according to the present invention, it is possible to learn the region of the transition based on measurements of the first and second sensor. In this way, it is possible to use signal S2 for feedback control with high accuracy, despite the presence of the transition as described in Figure 6.

[0028] Referring now to Figure 6, a routine is described for controlling throttle 24. First, in step 606, a check for in-range signal readings is made. Then, in step 608, a determination is made as to whether both signals S1 and S2 are in-range. When the answer to step 608 is YES, the routine continues to step 610. Otherwise, the routine continues to step 609, where the throttle is controlled based on whichever signal is in-range. Next, in step 610, a check is made as to whether in-range disagreement is indicated in step 322. When agreement is indicated in step 610, the routine continues to step 611 where a determination is made as to whether signal S2 is less that voltage Vk minus tolerance amount (γ). When the answer to step 611 is YES, the routine continues to step 612 and controls throttle position based on first throttle position (θ1) which is based on signal S1. When the answer to step 612 is NO, the routine continues to step 613 and controls throttle position based on second throttle position (θ2) which is based on signal S2. In this way, increased control resolution can be obtained by using the sensor with the greater absolute value of gradient. In an alternative embodiment, the downward sloping signal can be used, regardless of the determination in step 611, as the default to provide closed loop feedback control of throttle position.

[0029] When the answer to step 610 is NO, the routine continues to step 614, where a determination is made as to whether signal S2 is greater than learned voltage (Vk) plus a small tolerance value (δ). In particular, in step 610, when sensors 1 and When the answer to step 614 is YES, it is determined that the throttle is operating in the first segment of track 212, and in step 616, second throttle position is calculated from first slope and first offset (m1,o1). Otherwise, when the answer to step 614 is NO, it is determined that the throttle is operating in the second segment of track 212 and second throttle position is calculated from the second slope and second offset (m2, o2). Then, in step 620, throttle position is controlled based on the greater of first throttle position and second throttle positions. In this way, a conservative approach is taken in that the greater of the throttle positions is selected so that feedback control will always tend to close the throttle in the event that one of the sensors indicates an incorrect value.

[0030] Because measured throttle position from either track 210 or 212 can be used for feedback control, it is important to know the region of the transition of track 212. In particular, since a system gain is changing, it is important that the correct slope and offset are used. This is also why a positive tolerance is used in step 614 so that the system errs on selecting the greater slope. In other words, if assumed sensor slope and actual sensor slope differ, then the actual system gain will be different than the actual. As described, the present invention selects a positive tolerance, thereby providing a conservative approach since the lower region of throttle position slope is greater than the upper region of throttle position slope. In other words, a tolerance range is given where the greater slope is selected, thereby giving lower system gain in the transition region, which is conservative.

[0031] In an alternative embodiment, only offset o2 is learned. In particular, due to the manufacturing process, the location of the transition will mostly affect offset o2. Thus, this parameter alone can be learned and used in the present invention.

[0032] Although several examples of embodiments which practice the invention have been described herein, there are numerous other examples which could also be described. The invention is therefore to be defined only in accordance with the following claims.

Claims

1. A method for an electronically controlled throttle including first and second position sensors, the second position sensor having a first characteristic in a first operating range and a second characteristic in a second operating range, comprising:

reading a first output of the first sensor;
reading a second output of the second sensor; and
learning a transition region between the first operating range and the second operating range based on said first output and said second output.

2. The method recited in Claim 1 wherein the characteristic is a sensor slope between output voltage and angular position.

3. The method recited in Claim 1 further comprising determining whether the throttle is operating in the first operating range based on said learned transition region.

4. The method recited in Claim 1 further comprising determining whether the throttle is operating in the second operating range based on said learned transition region.

5. The method recited in Claim 3 further comprising calculating a measured throttle position from said second sensor based on a first characteristic in response to said determination.

6. The method recited in Claim 4 further comprising calculating a measured throttle position from said second sensor based on a second characteristic in response to said determination.

7. The method recited in Claim 1 further comprising:

determining whether the throttle is operating in the first operating range based on said learned transition region;
determining whether the throttle is operating in the second operating range based on said learned transition region;
calculating a measured throttle position from said second sensor based on a first characteristic when operating in the first operating range;
calculating said measured throttle position from said second sensor based on a second characteristic when operating in the second operating range; and
controlling the throttle based on said measured throttle position.

8. The method recited in Claim 1 wherein said step of learning said transition region further comprises the steps of:

learning an offset of said second sensor in the second operating region; and
calculating said transition region based on said learned offset.

9. The method recited in Claim 8 wherein said learning further comprises learning said offset of said second sensor in the second operating region based on the first sensor output.

10. The method recited in Claim 1 wherein said step of learning said transition region further comprises the steps of:

learning a first slope and a first offset of said second sensor in the first operating region based on the first sensor output;
learning a second slope and a second offset of said second sensor in the second operating re-

gion based on the first sensor; and
calculating said transition region based on said learned first slope, said learned first offset, said learned second slope, and said learned second offset.

11. The method recited in Claim 1 wherein said transition region is a transition point.

12. A method for an electronically controlled throttle including first and second position sensors, the second position sensor having a first characteristic in a first operating range and a second characteristic in a second operating range, comprising:

reading a first output of the first sensor;
reading a second output of the second sensor, wherein the second position sensor has a substrate and a track on said substrate, wherein said track has a first resistivity in the first operating range and a second resistivity in the second operating range to produce said second output;
learning a transition region between the first operating range and the second operating range based on said first output and said second output.

13. The method recited in Claim 12 wherein said transition region is where resistivity of said second sensor changes.

14. The method recited in Claim 13 wherein said step of learning said transition region further comprises the steps of:

learning a second offset of said second sensor in the second operating region based on the first sensor; and
calculating said transition region based on a first slope of said second sensor in the first operating region, a second slope of said second sensor in the second operating region, a first offset of said second sensor in the first operating region, and said learned second offset.

15. The method recited in Claim 13 wherein said step of learning said transition region further comprises the steps of:

learning a second offset of said second sensor in the second operating region based on the first sensor; and
calculating said transition region based on said learned second offset.

16. The method recited in Claim 12 further comprising:

determining whether the throttle is operating in the first operating range based on said learned transition region;
determining whether the throttle is operating in the second operating range based on said learned transition region;
calculating a measured throttle position from said second sensor based on a first characteristic when operating in the first operating range;
calculating said measured throttle position from said second sensor based on a second characteristic when operating in the second operating range; and
controlling the throttle based on said measured throttle position.

17. A method for an electronically controlled throttle including first and second position sensors, the second position sensor having a first characteristic in a first operating range and a second characteristic in a second operating range, comprising:

reading a first output of the first sensor;
reading a second output of the second sensor;
calculating a first actual throttle position based on said first output;
calculating a second actual throttle position based on said second output and the first characteristic when said second output is greater than a predetermined value; and
calculating said second actual throttle position based on said second output and the second characteristic when said second output is less than said predetermined value.

18. The method recited in Claim 17 wherein said predetermined value is greater than a learned transition region between the first operating range and the second operating range.

19. The method recited in Claim 17 wherein said predetermined value is greater than a transition region between the first operating range and the second operating range.

20. A method for an electronically controlled throttle including first and second position sensors, the second position sensor having a first characteristic in a first operating range and a second characteristic in a second operating range, comprising:

reading a first output of the first sensor;
reading a second output of the second sensor;
learning said second characteristic of the second position sensor based on said first output and said second output.

21. The method recited in Claim 17 wherein said second characteristic is a linear relationship between position and voltage, wherein said learning further comprises learning an offset of said linear relationship.

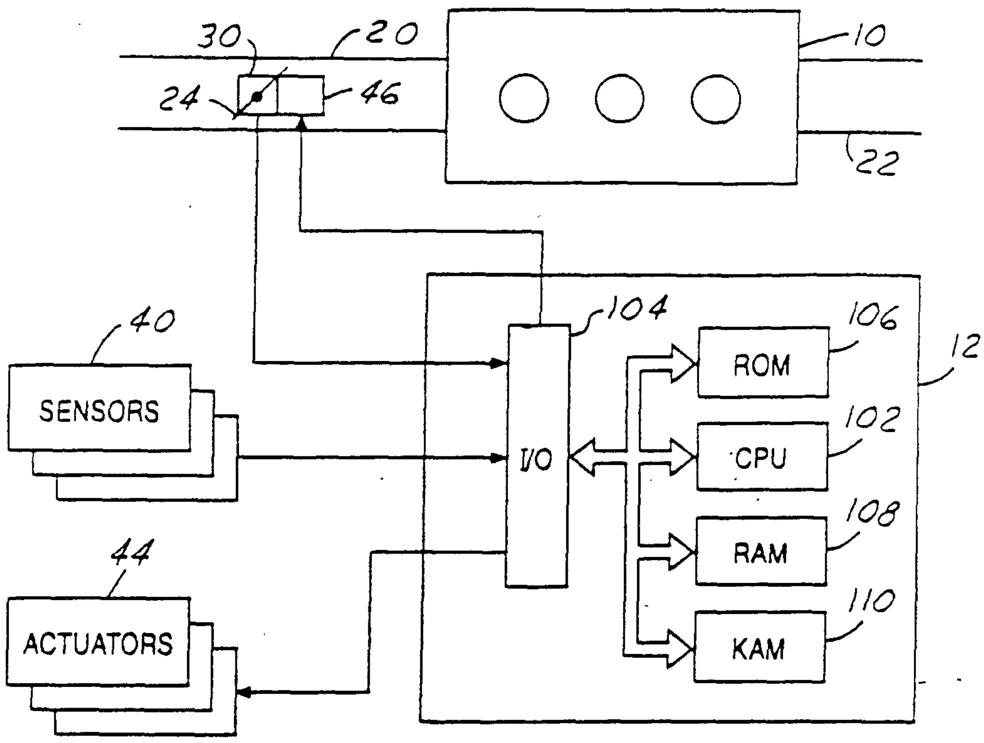

FIG. 1

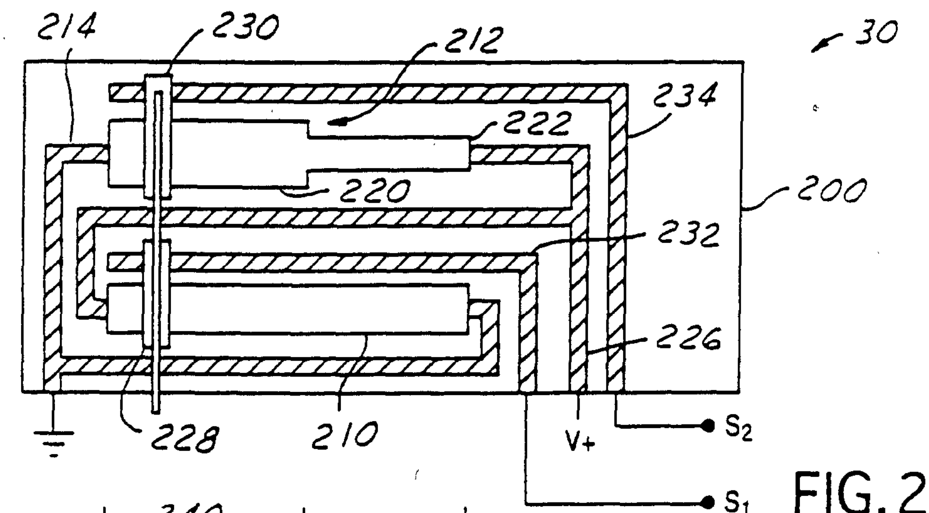

FIG. 2A

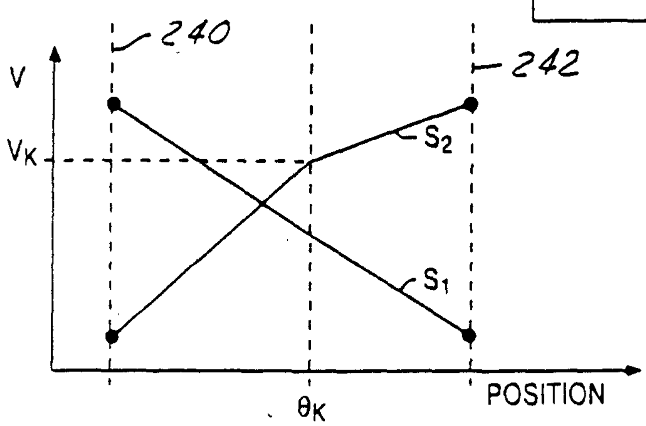

FIG. 2B

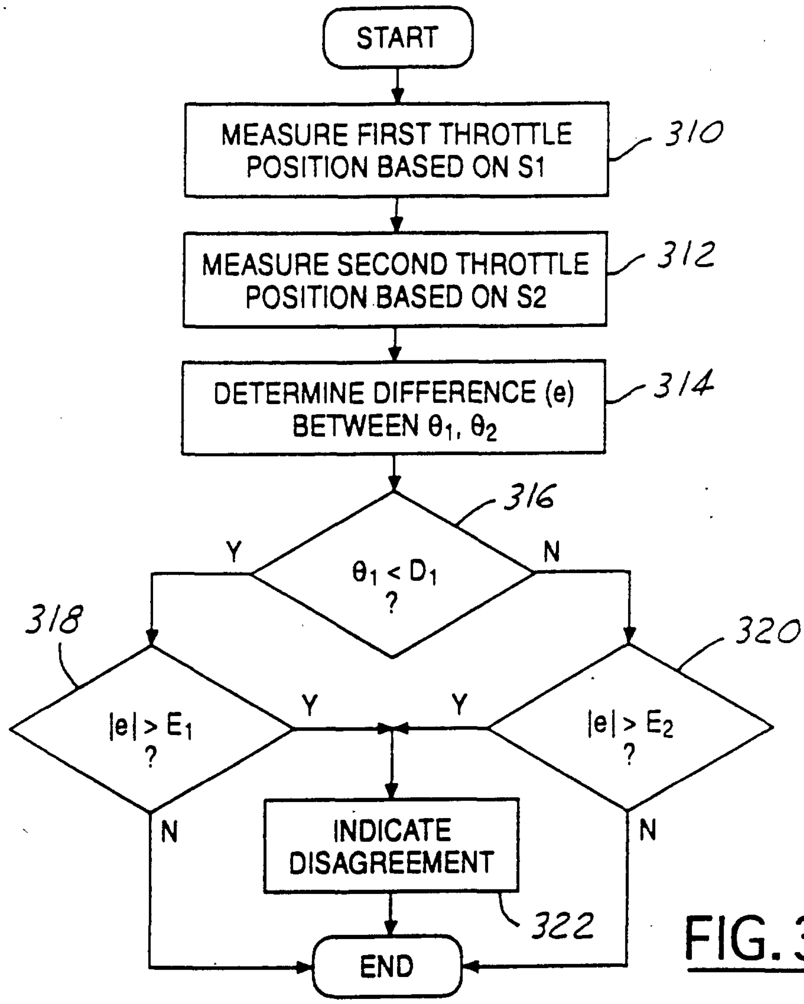
START
MEASURE FIRST THROTTLE POSITION BASED ON S1
310
MEASURE SECOND THROTTLE POSITION BASED ON S2
312
DETERMINE DIFFERENCE (e) BETWEEN θ_1, θ_2
314
316
$\theta_1 < D_1$?
Y
N
318
320
$|e| > E_1$?
$|e| > E_2$?
Y
Y
N
N
INDICATE DISAGREEMENT
322
END

FIG. 3

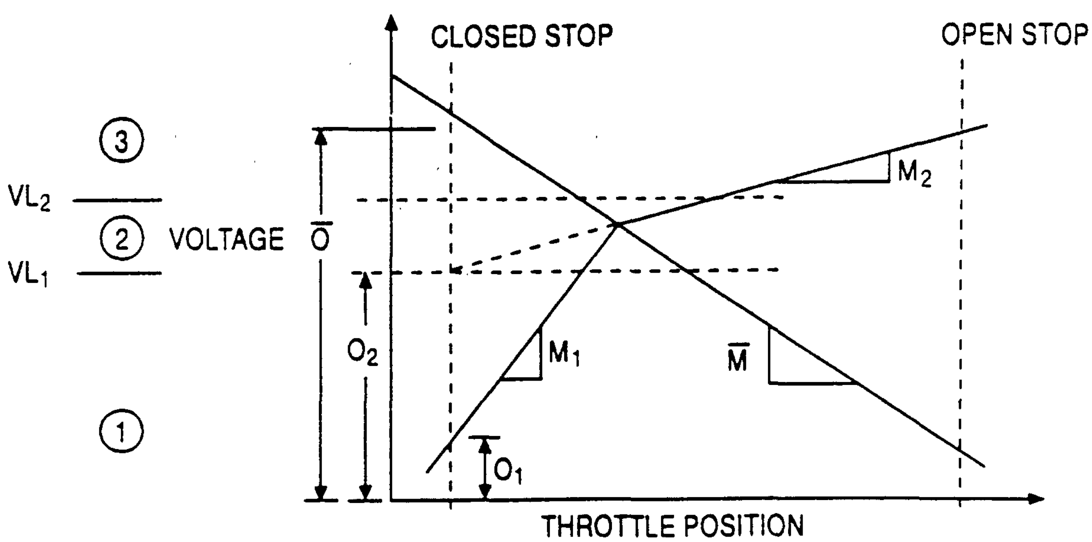
CLOSED STOP
OPEN STOP
3
VL_2
2
VOLTAGE
$\overline{O}$
VL_1
M_2
O_2
M_1
$\overline{M}$
1
O_1
THROTTLE POSITION

FIG. 4

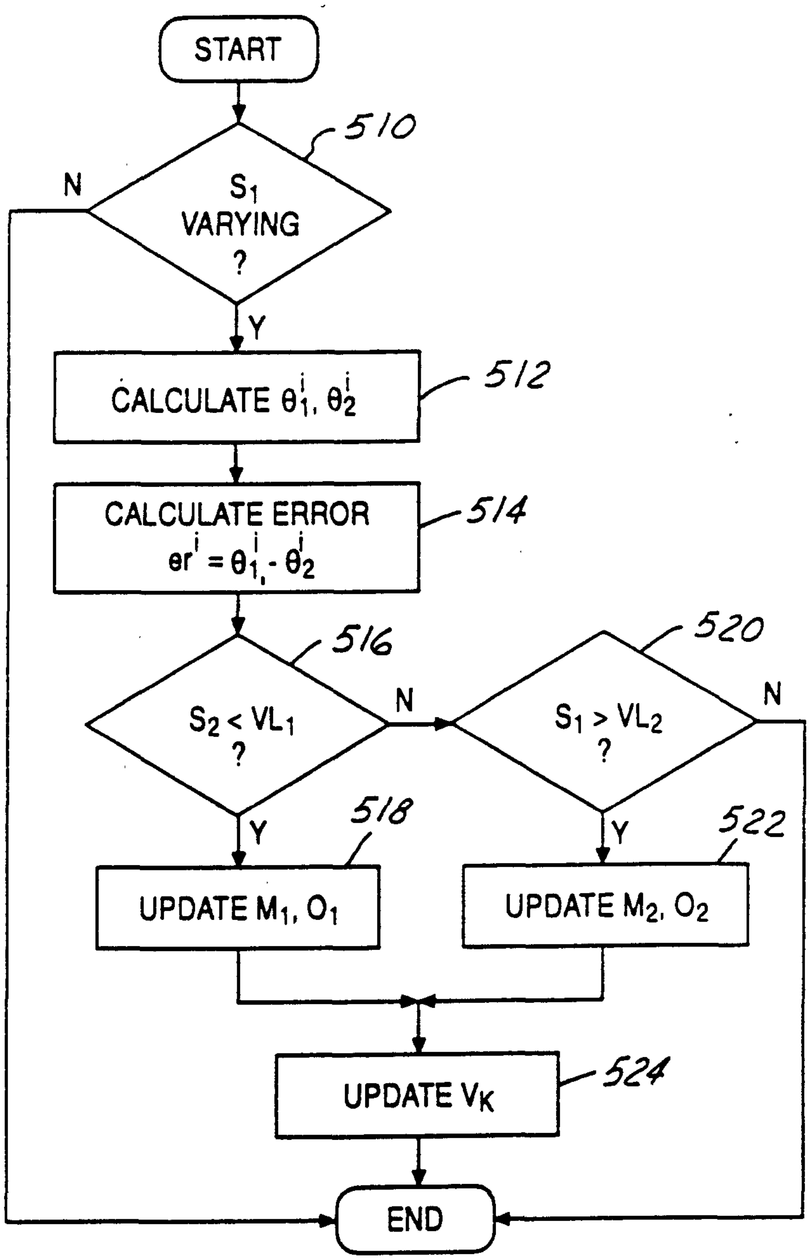
START
510
S_1 VARYING ?
N
Y
CALCULATE θ_1^i, θ_2^i
512
CALCULATE ERROR $er^i = \theta_1^i - \theta_2^i$
514
516
$S_2 < VL_1$?
N
520
$S_1 > VL_2$?
N
Y
518
Y
522
UPDATE M_1, O_1
UPDATE M_2, O_2
UPDATE V_K
524
END

FIG. 5

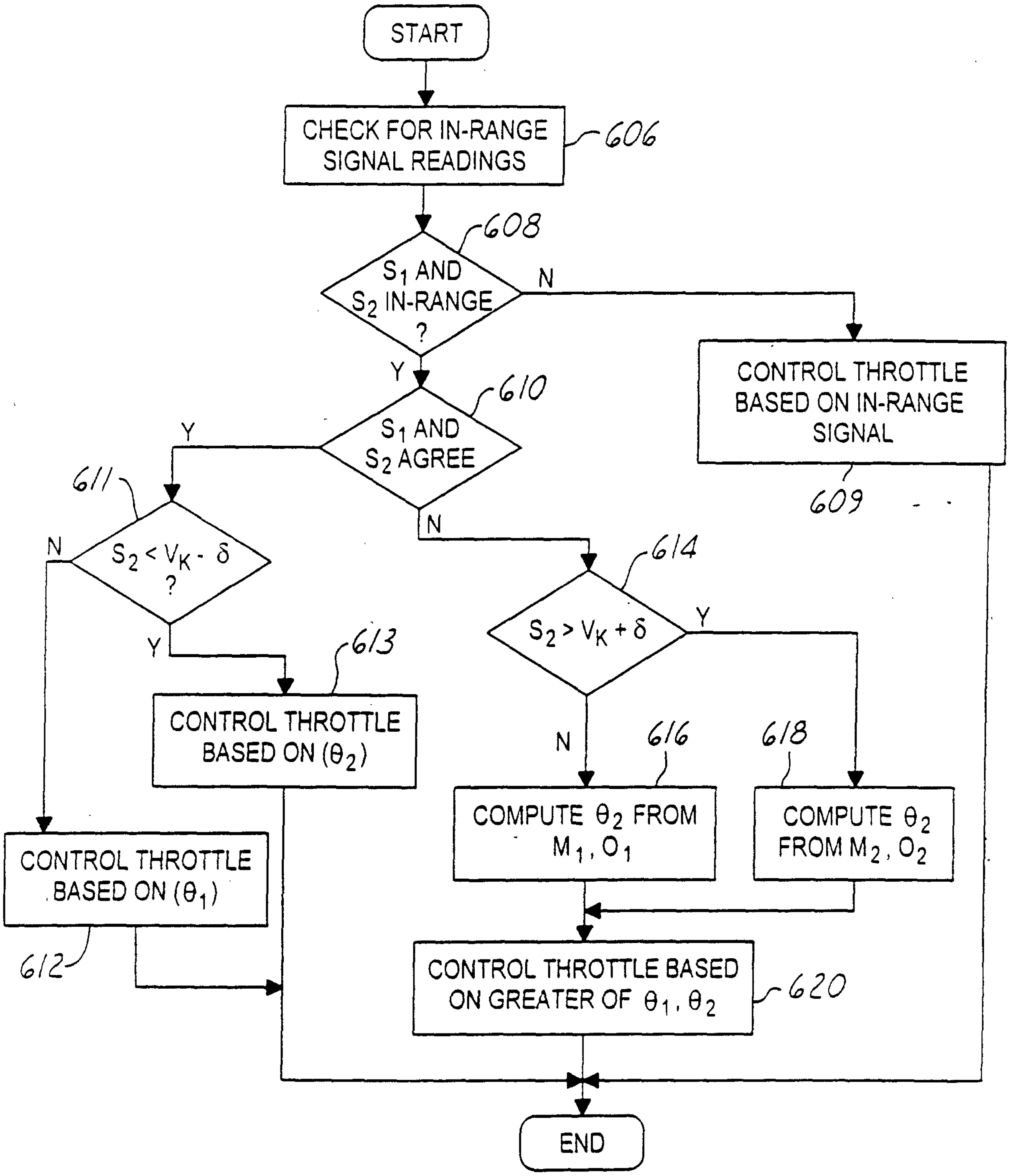
START
CHECK FOR IN-RANGE SIGNAL READINGS
606
608
S1 AND S2 IN-RANGE ?
N
Y
CONTROL THROTTLE BASED ON IN-RANGE SIGNAL
609
610
S1 AND S2 AGREE
Y
N
611
S2 < VK - δ ?
N
Y
613
CONTROL THROTTLE BASED ON (θ2)
614
S2 > VK + δ
Y
N
616
618
COMPUTE θ2 FROM M1, O1
COMPUTE θ2 FROM M2, O2
CONTROL THROTTLE BASED ON (θ1)
612
CONTROL THROTTLE BASED ON GREATER OF θ1, θ2
620
END

FIG. 6