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### Diagnostic apparatus and diagnostic method for rotational angle sensor, and control apparatus for actuator

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#### Abstract

A diagnostic apparatus for a rotational angle sensor that outputs two correlated signals, corresponding to the rotational angle, obtains a reference value from the two correlated signals. Thereafter, the diagnostic apparatus for the rotational angle sensor diagnoses whether or not a failure has occurred in the rotational angle sensor based on whether or not a numerical value obtained from the two correlated signals is within a predetermined range including the reference value.

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## **Background/Summary**

### TECHNICAL FIELD

(1) The present invention relates to a diagnostic apparatus and a diagnostic method for a rotational angle sensor, and a control apparatus for an actuator.

### BACKGROUND ART

(2) Regarding a rotational angle sensor, as disclosed in JP 2012-145488 A (Patent Document 1), a technique for diagnosing a failure in the rotational angle sensor based on whether or not a sum of a square of a sine wave signal ( $\sin \theta$ ) and a square of a cosine wave signal ( $\cos \theta$ ) corresponding to a rotational angle  $\theta$  of a rotating body (i.e.,  $\sin^2 \theta + \cos^2 \theta$ ) is within a normal range, has been proposed.

### REFERENCE DOCUMENT LIST

Patent Document

(3) Patent Document 1: JP 2012-145488 A

### SUMMARY OF THE INVENTION

#### Problem to be Solved by the Invention

(4) However, a generating circuit and a processing circuit of a sine wave signal and a cosine wave signal of a rotational angle sensor include variation, which is inherent in each circuit, and therefore, the sum of squares of the sine and cosine wave signals does not always give a unique value ( $\sin^2 \theta + \cos^2 \theta = 1$ ), even when the rotational angle sensor operates normally. Therefore, an upper threshold and a lower threshold defining the normal range, are set to values so as not to yield incorrect diagnosis considering the variations in the generating circuit and the processing circuit, and thus, the accuracy of failure diagnosis has not been good.

(5) Thus, an object of the present invention is to provide a diagnostic apparatus and a diagnostic method for a rotational angle sensor, and to provide a control apparatus for an actuator, which improve accuracy of failure diagnosis.

#### Means for Solving the Problem

(6) Therefore, according to the present invention, a diagnostic apparatus for a rotational angle sensor that outputs two correlated signals, corresponding to the rotational angle, obtains a reference

value from the two correlated signals. Thereafter, the diagnostic apparatus for the rotational angle sensor diagnoses whether or not a failure has occurred in the rotational angle sensor based on whether or not a numerical value obtained from the two correlated signals is within a predetermined range including the reference value.

(7) Moreover, according to the present invention, a control apparatus for an actuator that rotates a rotating body, the control apparatus controlling the actuator so that an output value of a rotational angle sensor that outputs two correlated signals, corresponding to a rotational angle of the rotating body, converges to a target angle, the control apparatus obtaining a reference value from the two correlated signals. Thereafter, the control apparatus for the actuator diagnoses whether or not a failure has occurred in the rotational angle sensor based on whether or not a numerical value obtained from the two correlated signals is within a predetermined range including the reference value.

Effects of the Invention

(8) According to the present invention, it is possible to increase the accuracy of failure diagnosis of a rotational angle sensor.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a system diagram illustrating an example of an internal combustion engine for use in a vehicle.

(2) FIG. 2 is a partial enlarged view illustrating an example of a stopper mechanism.

(3) FIG. 3 is an explanatory view illustrating an example of a resolver output.

(4) FIG. 4 is a configuration view illustrating a generating circuit and a processing circuit of a sine wave signal and a cosine wave signal.

(5) FIG. 5 is an explanatory view of variations included in a sum of squares of the sine and cosine wave signals.

(6) FIG. 6 is a flowchart illustrating an example of learning processing of a reference value.

(7) FIG. 7 is an explanatory view of a table storing the sum of squares of the sine and cosine wave signals.

(8) FIG. 8 is a timing chart illustrating an example of learning processing.

(9) FIG. 9 is a flowchart illustrating an example of a failure diagnosis process.

(10) FIG. 10 is an explanatory view of a threshold value for diagnosing a failure of an absolute angle sensor.

(11) FIG. 11 is an explanatory view of the sum of squares when a sine wave signal becomes abnormal.

### MODE FOR CARRYING OUT THE INVENTION

(12) Hereinbelow, an embodiment for implementing the present invention is described in detail with reference to the accompanying drawings.

(13) FIG. 1 illustrates an example of an internal combustion engine for use in a vehicle.

(14) An internal combustion engine **100** includes a cylinder block **110**, a piston **120** reciprocatably fitted in a cylinder bore **112** of cylinder block **110**, a cylinder head **130** in which an intake port **130A** and an exhaust port **130B** are formed, and an intake valve **132** and an exhaust valve **134** that open and close opening ends of intake port **130A** and exhaust port **130B**.

(15) Piston **120** is coupled to a crankshaft **140** via a con-rod (connecting rod) **150** including a lower link **150A** and an upper link **150B**. A combustion chamber **160** is formed between a top surface **120A** of piston **120** and a lower surface of cylinder head **130**. A spark plug **170** that ignites a mixture of fuel and air is attached to the approximate center of cylinder head **130** defining combustion chamber **160**.

(16) Furthermore, internal combustion engine **100** is provided with a variable valve timing (valve timing control, VTC) mechanism **180** that makes variable the phase of the open period of intake valve **132** relative to crankshaft **140**, and a variable compression ratio (VCR) mechanism **190** that makes the compression ratio variable by changing the volume of combustion chamber **160**.

(17) For example, by changing the phase of an intake camshaft **200** relative to crankshaft **140** using an actuator, such as an electric motor, VTC mechanism **180** advances or retards the center phase of the operating angle of intake valve **132** while keeping the operating angle of intake valve **132** constant. But it is not limited to the phase of intake valve **132**, and VTC mechanism **180** may make variable the phase of at least one of intake valve **132** and exhaust valve **134**.

(18) By changing the volume of combustion chamber **160** using a multi-link mechanism, for example, like one disclosed in JP 2002-276446 A, VCR mechanism **190** makes the compression ratio of internal combustion engine **100** variable. Hereinbelow, an example of VCR mechanism **190** will be described.

(19) Crankshaft **140** includes a plurality of journal portions **140A** and a plurality of crank pin portions **140B**. Journal portions **140A** are rotatably supported by a main bearing (not illustrated) of cylinder block **110**. Crank pin portions **140B** are eccentric from journal portions **140A**, and lower link **150A** is rotatably coupled to each of crank pin portions **140B**. Upper link **150B** has a lower end side pivotally coupled to one end of lower link **150A** by a coupling pin **152** and has an upper end side pivotally coupled to piston **120** by a piston pin **154**. A control link **192** has an upper end side pivotally coupled to the other end of lower link **150A** by a coupling pin **194** and has a lower end side pivotally coupled to a lower portion of cylinder block **110** via a control shaft **196**.

Specifically, control shaft **196** is rotatably supported by the engine body (cylinder block **110**) and has an eccentric cam portion **196A** that is eccentric from the rotation center of control shaft **196**, while a lower end side of control link **192** is rotatably fitted on eccentric cam portion **196A**. The rotational position of control shaft **196** is controlled by a compression ratio control actuator **198** that uses an electric motor.

(20) In VCR mechanism **190** using such a multi-link mechanism, when control shaft **196** is rotated by compression ratio control actuator **198**, the center position of eccentric cam portion **196A**, that is, the relative position to an engine body (cylinder block **110**), changes. When the pivotal support position of the lower end of control link **192** is changed by this, the position of piston **120** at the piston top dead center (TDC) becomes higher or lower, so that the volume of combustion chamber **160** increases or decreases, to change the compression ratio of internal combustion engine **100**. In this event, when the operation of compression ratio control actuator **198** is stopped, control link **192** is rotated relative to eccentric cam portion **196A** of control shaft **196** by reciprocating motion of piston **120**, so that the compression ratio shifts to the low compression ratio side.

(21) As illustrated in FIG. 2, a stopper mechanism **210**, which restricts the displacement (rotation) of control shaft **196** when control shaft **196** is rotated beyond a normal control range, is attached to VCR mechanism **190**. Stopper mechanism **210** includes a substantially fan-shaped first member **210A**, the pivot portion of which is secured to control shaft **196**, and a plate-shaped second member **210B** secured to cylinder block **110**. First member **210A** rotates integrally with control shaft **196**. When control shaft **196** rotates beyond a maximum compression ratio (upper limit) or a minimum compression ratio (lower limit), defining the normal control range, second member **210B** comes in contact with one of two sides defining the central angle of first member **210A**, so as to restrict the displacement of control shaft **196**, which is one example of a mechanism member.

Herein, since stopper mechanism **210** functions when control shaft **196** has exceeded the normal control range, first member **210A** and second member **210B** do not come in contact with each other in normal control, so that, for example, it is possible to reduce the occurrence of abnormal noise or the like. Stopper mechanism **210** may be used not only for restricting the displacement of control shaft **196**, but also for learning a reference position of control shaft **196**.

(22) Stopper mechanism **210** is sufficient if it can restrict the displacement on at least one of the

maximum compression ratio side and the minimum compression ratio side with respect to the rotation of control shaft **196**. Furthermore, stopper mechanism **210** is sufficient if it can restrict the displacement of control shaft **196** by at least two members, and such two members are not limited to substantially fan-shaped first member **210A** and plate-shaped second member **210B**, and may have other shapes.

(23) VTC mechanism **180** and VCR mechanism **190** are electronically controlled by a VTC controller **220** and a VCR controller **230**, respectively, each incorporating a processor such as a microcomputer. VTC controller **220** and VCR controller **230** are connected to an engine controller **250**, incorporating a processor such as a microcomputer and configured to electronically control internal combustion engine **100**, via, for example, a controller area network (CAN) **240** being one example of an in-vehicle network. Therefore, freely chosen data can be sent and received via CAN **240** between VTC controller **220**, VCR controller **230**, and engine controller **250**. The in-vehicle network is not limited to CAN **240**, and any known network such as FlexRay (registered trademark) may be used.

(24) To engine controller **250**, output signals of a rotation speed sensor **260** that measures rotational speed  $N_e$  of internal combustion engine **100**, and a load sensor **270** that measures load  $Q$  of internal combustion engine **100** are input, as examples of operating states of internal combustion engine **100**. Herein, as load  $Q$  of internal combustion engine **100**, a state quantity closely related to the torque, such as intake negative pressure, intake flow rate, supercharging pressure, accelerator opening degree, throttle opening degree, or the like, may be used. For example, engine controller **250** refers to maps in which target values matching rotational speeds and loads are set, and calculates a target angle of VTC mechanism **180** and a target compression ratio of VCR mechanism **190** corresponding to rotational speed  $N_e$  and load  $Q$  of internal combustion engine **100**, respectively. Then, engine controller **250** sends the target angle and the target compression ratio to VTC controller **220** and VCR controller **230**, respectively, via CAN **240**. Output signals read by engine controller **250** are not limited to the output signals of rotation speed sensor **260** and load sensor **270**, and engine controller **250** may read rotational speed  $N_e$  and load  $Q$  of internal combustion engine **100** from an additional controller (not illustrated) connected via CAN **240**.

(25) VTC controller **220** having received the target angle performs feedback control of a drive current to be output to an actuator of VTC mechanism **180** such that a real angle (actual angle) measured by a sensor (not illustrated) converges to the target angle. VCR controller **230** having received the target compression ratio performs feedback control of a drive current to be output to compression ratio control actuator **198** of VCR mechanism **190** such that a real compression ratio (actual compression ratio) that is measured by a compression ratio sensor described below converges to the target compression ratio. By doing this, VTC mechanism **180** and VCR mechanism **190** are controlled to the target values corresponding to the operation state of internal combustion engine **100**.

(26) The compression ratio sensor that measures an actual compression ratio of internal combustion engine **100** includes: a relative angle sensor **280** that measures a relative angle of an output shaft of compression ratio control actuator **198**; and an absolute angle sensor **290** that measures an absolute angle of control shaft **196** coupled to the output shaft of compression ratio control actuator **198** via a speed reducer **198A**. Using an output value of absolute angle sensor **290** at the start-up of the engine as a reference point, VCR controller **230** obtains a rotational angle of control shaft **196**, that is, the compression ratio of internal combustion engine **100**, from an output value of relative angle sensor **280**. This is because relative angle sensor **280** has high resolution whereas, for example, it cannot distinguish between  $0^\circ$  and  $360^\circ$  of the same phase, and absolute angle sensor **290** can obtain an absolute angle of control shaft **196**, although it has low resolution.

(27) Each of relative angle sensor **280** and absolute angle sensor **290** includes a resolver, or the like, that outputs two correlated signals, corresponding to a rotational angle of a rotating body, more specifically, outputs a sine wave signal and a cosine wave signal. For example, the resolver

includes a rotor that integrally rotates with the rotating body, and a stator with one phase of an exciting coil wound thereon and two phases of output coils wound thereon. When an alternating voltage is applied to the exciting coil of the stator, a two-phase voltage with a sine wave signal and a cosine wave signal, which change in response to the rotational angle (electric angle) of the rotating body, is generated in each output coil, as illustrated in FIG. 3. VCR controller **230** can obtain the rotational angle of the rotating body by calculating an arctangent of the sine and cosine wave signals output from the resolver. In the following description, the rotational angle obtained from the two signals of relative angle sensor **280** is referred to as “output value of relative angle sensor **280**” and the rotational angle obtained from the two signals of absolute angle sensor **290** is referred to as “output value of absolute angle sensor **290**”.

(28) Herein, variations in the generating circuit and the processing circuit of the sine wave signal and the cosine wave signal of the resolver will be described.

(29) VCR controller **230** has an excitation signal generator **230A**, an exciting circuit **230B**, a sine wave circuit **230C**, a cosine wave circuit **230D**, and an A/D converter **230E** as illustrated in FIG. 4. Excitation signal generator **230A** generates an excitation signal containing a sine wave (alternating) of a predetermined frequency, for example. Exciting circuit **230B** amplifies the excitation signal from excitation signal generator **230A**, and then applies the amplified excitation signal to the exciting coil of a resolver Res. Sine wave circuit **230C** shapes the sine wave signal output from the output coil of resolver Res, and then outputs the shaped sine wave signal to A/D converter **230E**. Cosine wave circuit **230D** shapes the cosine wave signal output from the output coil of resolver Res, and then outputs the shaped cosine wave signal to A/D converter **230E**. A/D converter **230E** converts the sine wave signal and the cosine wave signal output from sine wave circuit **230C** and cosine wave circuit **230D** into digital signals.

(30) Then, VCR controller **230** reads the sine wave signal and the cosine wave signal, which have been converted into the digital signals by A/D converter **230E**, and then calculates the arctangent thereof to thereby obtain the rotational angle of the rotating body and also diagnoses whether or not a failure has occurred in resolver Res based on the sum of squares of these two signals. At this time, the sum of squares of the sine and cosine wave signals include a variation of excitation signal generator **230A**, a variation of exciting circuit **230B**, a variation of resolver Res, variations of sine wave circuit **230C** and cosine wave circuit **230D**, and a variation of A/D converter **230E** as individual variations. Moreover, the sum of squares of the sine and cosine wave signals includes a variation due to the temperature characteristics in each circuit, an eccentric variation due to degradation and wear of the rotor, and the like, as non-reproducible variations, for example.

(31) When “individual variation+non-reproducible variation” is compared with “individual variation” as illustrated in FIG. 5 with respect to the variations of the sum of squares of the sine and cosine wave signals, the “individual variation” occupies the largest part of the variations. Therefore, when the sum of squares of the sine and cosine wave signals output from the resolver is calculated as an initialization process of VCR controller **230**, a reference value (learning value) including only the individual variation can be obtained. Then, by considering the non-reproducible variation to the reference value, the threshold values (upper threshold and lower threshold) for failure diagnosis can be obtained.

(32) For example, VCR controller **230** learns each of the reference values for failure diagnosis after a learning flag to be output from a diagnostic tool connected to CAN **240** changes from LOW to HI in a vehicle assembling factory. More specifically, VCR controller **230** changes the compression ratio of internal combustion engine **100** to the low compression ratio side, and control shaft **196** is brought into a state in which the displacement to the low compression ratio side is restricted by stopper mechanism **210**. Then, VCR controller **230** changes the compression ratio of internal combustion engine **100** to the high compression ratio side, and then learns the sum of squares of the sine and cosine wave signals output from resolver Res as the reference value at each predetermined angle  $\theta_{sub.0}$  until the displacement of control shaft **196** to the high compression

ratio side is restricted by stopper mechanism **210**. The reference values may be referred to in the subsequent control, and therefore may be written in a table in a nonvolatile memory, such as flash ROM (read only memory).

(33) FIG. **6** illustrates an example of a learning process of a reference value executed by the processor of VCR controller **230** according to a control program stored in a nonvolatile memory. The learning process can also be executed during self shutdown after a vehicle travels for a predetermined time or for a predetermined distance, for example, as well as after the learning flag of a diagnostic tool changes from LOW to HI. Although the following description is given provided that a failure of absolute angle sensor **290** is diagnosed, a failure of relative angle sensor **280** may also be diagnosed by the same process.

(34) In step **1** (abbreviated as “S1” in FIG. **6**; the same applies hereinafter), the processor of VCR controller **230** outputs a drive signal to compression ratio control actuator **198** of VCR mechanism **190**, for example, to thereby rotate compression ratio control actuator **198** so that the compression ratio of internal combustion engine **100** is changed to the low compression ratio side. At this time, the processor of VCR controller **230** controls the rotation of compression ratio control actuator **198** by speed feedback control, for example (the same applies hereinafter).

(35) In step **2**, the processor of VCR controller **230** determines whether or not compression ratio control actuator **198** has stopped based on whether or not an output value of relative angle sensor **280** has changed, for example. When compression ratio control actuator **198** has stopped, first member **210A** of stopper mechanism **210** comes in contact with second member **210B**, so that the displacement of control shaft **196** to the low compression ratio side is restricted. Then, when the processor of VCR controller **230** determines that compression ratio control actuator **198** has stopped, the process proceeds to step **3** (Yes), whereas when the processor of VCR controller **230** determines that compression ratio control actuator **198** does not stop, the process returns to step **1** (No).

(36) In step **3**, the processor of VCR controller **230** determines whether or not first predetermined time has passed after compression ratio control actuator **198** has stopped utilizing a built-in timer function, for example. Herein, the first predetermined time is time for securing time until the displacement of control shaft **196** to the low compression ratio side is certainly restricted and can be set as appropriate based on the output characteristics of compression ratio control actuator **198**, the reduction ratio of decelerator **198A**, and the like. Then, when the processor of VCR controller **230** determines that the first predetermined time has passed, the process proceeds to step **4** (Yes), whereas when the processor of VCR controller **230** determines that the first predetermined time does not pass, the process waits (No).

(37) In step **4**, the processor of VCR controller **230** obtains the sum of squares of a sine wave signal and a cosine wave signal output from absolute angle sensor **290**. Then, the processor of VCR controller **230** writes the sum of squares in association with the output value (rotational angle) of absolute angle sensor **290** in the table in the nonvolatile memory as illustrated in FIG. **7**. In short, the processor of VCR controller **230** stores (learns) the rotational angle at which the displacement of control shaft **196** to the low compression ratio side is restricted and the sum of squares in association.

(38) In step **5**, the processor of VCR controller **230** outputs a drive signal to compression ratio control actuator **198** of VCR mechanism **190**, for example, whereby compression ratio control actuator **198** is rotated so that the compression ratio of internal combustion engine **100** is changed to the high compression ratio side.

(39) In step **6**, the processor of VCR controller **230** reads an output value of absolute angle sensor **290**, for example, and then determines whether or not control shaft **196** has rotated by a multiple of the predetermined angle  $\theta_{sub.0}$  based on the state in which the displacement of control shaft **196** to the low compression ratio side is restricted. Herein, the predetermined angle  $\theta_{sub.0}$  can be set as appropriate based on the output characteristics of absolute angle sensor **290**, the demanded



accuracy, and the like, for example. Then, when the processor of VCR controller **230** determines that control shaft **196** has rotated by a multiple of the predetermined angle  $\theta_{sub.0}$ , the process proceeds to step **7** (Yes), whereas when the processor of VCR controller **230** determines that control shaft **196** does not rotate by a multiple of the predetermined angle  $\theta_{sub.0}$ , the process proceeds to step **8** (No).

(40) In step **7**, the processor of VCR controller **230** obtains the sum of squares of the sine and cosine wave signals output from absolute angle sensor **290**. Then, the processor of VCR controller **230** successively writes the sum of squares in association with the output value (rotational angle) of absolute angle sensor **290** in the table in a nonvolatile memory as illustrated in FIG. **7**. In short, the processor of VCR controller **230** stores (learns) the rotational angle of control shaft **196** and the sum of squares in association at each predetermined angle from the state in which the displacement of control shaft **196** to the low compression ratio side is restricted.

(41) In step **8**, the processor of VCR controller **230** determines whether or not compression ratio control actuator **198** has stopped based on whether or not an output value of relative angle sensor **280** has changed, for example. When compression ratio control actuator **198** has stopped, first member **210A** of stopper mechanism **210** comes in contact with second member **210B**, so that the displacement of control shaft **196** to the high compression ratio side is restricted. Then, when the processor of VCR controller **230** determines that compression ratio control actuator **198** has stopped, the process proceeds to step **9** (Yes), whereas when the processor of VCR controller **230** determines that compression ratio control actuator **198** does not stop, the process returns to step **5** (No).

(42) In step **9**, the processor of VCR controller **230** determines whether or not second predetermined time has passed after compression ratio control actuator **198** has stopped utilizing a built-in timer function, for example. Herein, the second predetermined time is time for securing time until the displacement of control shaft **196** to the high compression ratio side is certainly restricted and can be set as appropriate based on the output characteristics of compression ratio control actuator **198**, the reduction ratio of decelerator **198A**, and the like. The second predetermined time may be the same as the first predetermined time, or alternatively, may be different from the first predetermined time. Then, when the processor of VCR controller **230** determines that the second predetermined time has passed, the process proceeds to step **10** (Yes), whereas when the processor of VCR controller **230** determines that the second predetermined time does not pass, the process waits (No).

(43) Since the restricted position to the high compression ratio side may not be a multiple of the predetermined angle, the output value (rotational angle) of absolute angle sensor **290** and the sum of squares may be written in the table in the nonvolatile memory in the state in which the displacement of control shaft **196** to the high compression ratio side is restricted. Moreover, when the table in the nonvolatile memory has free space, the output value of absolute angle sensor **290** and the sum of squares which are finally stored may be written.

(44) In step **10**, the processor of VCR controller **230** sets the operation range defined by the state in which the displacement to the low compression ratio side is restricted and the state in which the displacement to the high compression ratio is restricted as the operation range of control shaft **196**, and then the processor writes the same in the nonvolatile memory. The operation range can prevent control shaft **196** from rotating beyond the operation range, for example, and can contribute to a reduction in heat generation amount, power consumption, and the like of compression ratio control actuator **198**.

(45) As illustrated in FIG. **8**, according to such a learning process, when the learning flag output from a diagnostic tool changes from LOW to HI, control shaft **196** of VCR mechanism **190** rotates to the low compression ratio side, and then the output value of each of relative angle sensor **280** and absolute angle sensor **290** begins to gradually change toward the restricted position on the low compression ratio side. When the first predetermined time has passed in a state in which, as a result

of the fact that control shaft **196** has changed toward the restricted position on the low compression ratio side, first member **210A** of stopper mechanism **210** comes in contact with second member **210B**, so that the displacement to the low compression ratio side is restricted, control shaft **196** of VCR mechanism **190** begins to rotate to the high compression ratio side.

(46) Then, the output value of each of relative angle sensor **280** and absolute angle sensor **290** begins to gradually change toward the restricted position on the high compression ratio side with the rotation of control shaft **196**. In the process of changing from the restricted position on the low compression ratio side to the restricted position on the high compression ratio side, the sum of squares of the sine and cosine wave signals output from absolute angle sensor **290** is obtained whenever control shaft **196** rotates at a predetermined angle, and then stored in the table in the nonvolatile memory in a state of being associated with the output value of absolute angle sensor **290**. When second predetermined time has passed in a state in which, as a result of the fact that control shaft **196** has changed toward the restricted position on the high compression ratio side, first member **210A** of stopper mechanism **210** comes in contact with second member **210B**, so that the displacement to the high compression ratio side is restricted, the operation range of compression ratio control actuator **198** is set.

(47) In the table in the nonvolatile memory, the rotational angle and the sum of squares are written in association in response to directions from the outside at a vehicle assembling factory, and the like. Therefore, it is thought that, when the environments of a vehicle assembling factory and the like are uniformly managed, only the individual variations of absolute angle sensor **290** are included in the sum of squares to be written in the table. Therefore, a failure can be diagnosed referring to the table in the nonvolatile memory based on the sum of squares stored therein as the reference value.

(48) FIG. **9** illustrates an example of a failure diagnosis process of absolute angle sensor **290** to be executed by the processor of VCR controller **230** according to a control program stored in the nonvolatile memory after the learning process has been completed.

(49) In step **11**, the processor of VCR controller **230** reads a sine wave signal and a cosine wave signal from absolute angle sensor **290**.

(50) In step **12**, the processor of VCR controller **230** calculates a sum of squares of the sine and cosine wave signals.

(51) In step **13**, the processor of VCR controller **230** obtains the rotational angle of control shaft **196** by calculating the arctangent of the sine wave signal and the cosine wave signal.

(52) In step **14**, the processor of VCR controller **230** sets the upper threshold and the lower threshold for diagnosing a failure referring to the table in the nonvolatile memory. More specifically, the processor of VCR controller **230** obtains the sum of squares (reference value) associated with the rotational angle of control shaft **196** referring to the table in the nonvolatile memory. Then, the processor of VCR controller **230** calculates a predetermined ratio (for example, 15%) of the sum of squares, sets the same as a predetermined value, and then adds to or subtracts from the sum of squares the predetermined value to thereby set the upper threshold and the lower threshold. The processor of VCR controller **230** may be set the upper threshold and the lower threshold by multiplying the sum of squares by different predetermined ratios (for example, 1.15 and 0.85) or adding to or subtracting from the sum of squares a constant value (fixed value). In short, the processor of VCR controller **230** sets the predetermined range including the sum of squares considering the non-reproducible variations.

(53) In step **15**, the processor of VCR controller **230** determines whether or not the sum of squares is greater than or equal to the lower threshold and less than or equal to the upper threshold, in short, whether or not the sum of squares is within the normal range (predetermined range). Then, when the processor of VCR controller **230** determines that the sum of squares is greater than or equal to the lower threshold and less than or equal to the upper threshold, the process proceeds to step **16** (Yes), whereas when the processor of VCR controller **230** determines that the sum of squares is not

greater than or equal to the lower threshold or not less than or equal to the upper threshold, the process proceeds to step 17 (No).

(54) In step 16, the processor of VCR controller 230 determines that absolute angle sensor 290 is normal.

(55) In step 17, the processor of VCR controller 230 determines that absolute angle sensor 290 has failed.

(56) According to the failure diagnosis process, the threshold value for diagnosing a failure of absolute angle sensor 290 is obtained by considering the non-reproducible variations to the reference value which includes only the individual variations. Therefore, as illustrated in FIG. 10, the lower threshold for diagnosing a failure of absolute angle sensor 290 becomes greater than a value set so as not to cause wrong diagnosis and the frequency of diagnosing that a failure has occurred in absolute angle sensor 290 can be increased. The same applies to the upper threshold for diagnosing a failure of absolute angle sensor 290. Then, when the sum of squares of the sine and cosine wave signals output from absolute angle sensor 290 exceeds the threshold value, it is diagnosed that a failure has occurred in absolute angle sensor 290. On the other hand, unless the sum of squares of the sine and cosine wave signals output from absolute angle sensor 290 exceeds the threshold value, it is diagnosed that absolute angle sensor 290 is normal. Therefore, the accuracy of failure diagnosis of absolute angle sensor 290 can be improved.

(57) In absolute angle sensor 290, when the output coil outputting a sine wave signal develops a short circuit, the sine wave signal always represents zero, as illustrated in FIG. 11. In this case, the sum of squares of the sine and cosine wave signals appears to be a cosine wave form that changes in half the period of the cosine wave signal, as illustrated in FIG. 11. Since the range of the threshold value defined by the upper threshold and the lower threshold is narrowed, even when the output coil outputting a sine wave signal develops a short circuit, the short circuit can be diagnosed at an early stage. Moreover, even when it is erroneously diagnosed that a failure has occurred due to overlapping of noise or the like, then it is diagnosed that absolute angle sensor 290 is normal at an early stage. Therefore, for example, a fail-safe operation transited due to the occurrence of a failure can be canceled and the function of VCR mechanism 190 which is a control target system can be demonstrated.

(58) When diagnosing that a failure has occurred in absolute angle sensor 290, the processor of VCR controller 230 may output a control signal to compression ratio control actuator 198 of VCR mechanism 190, to cause the transition to a fail-safe operation, in which the compression ratio of an internal combustion engine is changed to the lowest compression ratio. Moreover, when diagnosing that a failure has occurred in absolute angle sensor 290, the processor of VCR controller 230 may shift an output value of absolute angle sensor 290 into the range defined by the upper threshold and the lower threshold at a freely chosen timing (for example, while the engine is stopped).

(59) Although, in the above embodiment, a method of diagnosing a failure of relative angle sensor 280 and absolute angle sensor 290, serving as a rotational angle sensor, has been described, the rotational angle sensor may be any angle sensor that uses a resolver or the like. Furthermore, although the processor of VCR controller 230 plays a major role in diagnosing a failure of the rotational angle sensor, this is not limited thereto, and any processor for failure diagnosis, any processor of another controller, a dedicated circuit, or the like, may be used.

#### REFERENCE SYMBOL LIST

(60) 230 VCR controller 280 Relative angle sensor 290 Absolute angle sensor Res Resolver

## Claims

1. A diagnostic apparatus comprising: a processor operatively coupled to a rotational angle sensor and that outputs two correlated signals, corresponding to a rotational angle, wherein the processor is configured to diagnose whether or not a failure has occurred in the rotational angle sensor based

on whether or not a numerical value obtained from the two correlated signals is within a predetermined range including a reference value obtained from the two correlated signals beforehand, and the reference value is obtained during a learning process, during which multiple values of the reference value are measured, the multiple values including a lowermost value and an uppermost value, the lowermost value and the uppermost value defining the predetermined range, wherein the reference value is obtained at each predetermined angle during the learning process, the lowermost value is smaller than the uppermost value, the predetermined range is obtained by taking a variation due to temperature characteristics, or a variation due to degradation into account, and the processor is configured to diagnose that the rotational angle sensor is normal when the numerical value is within the predetermined range, whereas processor diagnoses that a failure has occurred in the rotational angle sensor when the numerical value is out of the predetermined range.

2. The diagnostic apparatus for the rotational angle sensor, according to claim 1, wherein the two correlated signals are a sine wave signal and a cosine wave signal.
3. The diagnostic apparatus for the rotational angle sensor, according to claim 2, wherein each of the reference value and the numerical value is a sum of squares of the sine and cosine wave signals.
4. The diagnostic apparatus for the rotational angle sensor, according to claim 1, wherein the predetermined range has a width that is a predetermined ratio of the reference value.
5. The diagnostic apparatus for the rotational angle sensor, according to claim 1, wherein the rotational angle sensor measures a rotational angle of a control shaft or an actuator of a variable compression ratio mechanism that makes a compression ratio of an internal combustion engine variable.
6. The diagnostic apparatus for the rotational angle sensor, according to claim 1, wherein the rotational angle sensor is a resolver comprising a rotor that rotates integrally with a rotating body, and a stator with one phase of an exciting coil and two phases of output coils.
7. The diagnostic apparatus for the rotational angle sensor according to claim 1, wherein the reference value is obtained at each predetermined angle during a learning process, such that the reference value is variable based on the angle.
8. A diagnostic method of a rotational angle sensor, comprising the steps of: operatively coupling a processor to a rotational angle sensor; obtaining, with the processor two correlated signals, corresponding to a rotational angle, a reference value from the two correlated signals; and then diagnosing, with the processor, whether or not a failure has occurred in the rotational angle sensor based on whether or not a numerical value obtained from the two signals is within a predetermined range including the reference value, wherein the reference value is obtained during a learning process, during which multiple values of the reference value are measured, the multiple values including a lowermost value and an uppermost value, the lowermost value and the uppermost value defining the predetermined range, the reference value is obtained at each predetermined angle during the learning process, the lowermost value is smaller than the uppermost value, the predetermined range is obtained by taking a variation due to temperature characteristics, or a variation due to degradation into account, and the processor is configured to diagnose that the rotational angle sensor is normal when the numerical value is within the predetermined range, whereas processor diagnoses that a failure has occurred in the rotational angle sensor when the numerical value is out of the predetermined range.
9. The diagnostic method of the rotational angle sensor, according to claim 8, wherein the two signals are a sine wave signal and a cosine wave signal.
10. The diagnostic method of the rotational angle sensor, according to claim 9, wherein each of the reference value and the numerical value is a sum of squares of the sine and cosine wave signals.
11. A system comprising: an actuator; a rotational angle sensor; and a processor operatively coupled to the rotational angle sensor and to the actuator, wherein the actuator is configured to rotate a rotating body, the processor is configured to control the actuator so that an output value of the rotational angle sensor that outputs two correlated signals, corresponding to a rotational angle

of the rotating body, converges to a target angle, wherein the processor is configured to diagnose whether or not a failure has occurred in the rotational angle sensor based on whether or not a numerical value obtained from the two correlated signals is within a predetermined range including a reference value obtained from the two correlated signals beforehand, wherein the reference value is obtained during a learning process, during which multiple values of the reference value are measured, the multiple values including a lowermost value and an uppermost value, the lowermost value and the uppermost value defining the predetermined range, the reference value is obtained at each predetermined angle during the learning process, the lowermost value is smaller than the uppermost value, the predetermined range is obtained by taking a variation due to temperature characteristics, or a variation due to degradation into account, and the processor is configured to diagnose that the rotational angle sensor is normal when the numerical value is within the predetermined range, whereas processor diagnoses that a failure has occurred in the rotational angle sensor when the numerical value is out of the predetermined range.

12. The control apparatus for the actuator, according to claim 11, wherein the processor is configured to switch the actuator to a fail-safe operation when the processor diagnoses that a failure has occurred in the rotational angle sensor.

13. The control apparatus for the actuator, according to claim 11, wherein the processor is configured to shift an output value of the rotational angle sensor into the predetermined range at a freely chosen timing when the processor diagnoses that a failure has occurred in the rotational angle sensor.

14. The control apparatus for the actuator, according to claim 11, wherein the rotating body is a control shaft of a variable compression ratio mechanism that makes a compression ratio of an internal combustion engine variable.

15. The control apparatus for the actuator, according to claim 14, wherein the reference value is obtained in an operation range of a stopper mechanism that restricts rotation to a low compression ratio side and to a high compression ratio side of the control shaft.

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