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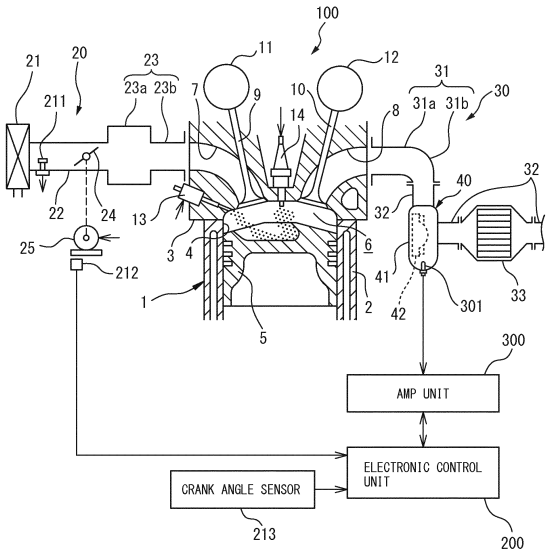
(54) COMBUSTION STATUS ESTIMATION DEVICE

(57) A combustion state estimating device 40 comprised of a rotor 42 rotatably housed inside a housing 41 provided on an exhaust path 32 of an engine body 1 having cylinders 4, having at least one blade 422, and driven to rotate by energy of exhaust discharged from each cylinder 4 of the engine body 1, a passage detection sensor 301 provided in the housing 41 and detecting a predetermined position inside the housing 41 being passed by a blade 422 of the rotor 42, and a processing system 300 configured to calculate an angular velocity of the rotor 42 based on the results of detection of the passage detection sensor 301 and to calculate at least one of the combustion energy or combustion interval of the cylinder 4 of the engine body 1 based on the angular velocity of the rotor 42.

FIG. 1



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Description

FIELD

[0001] The present invention relates to a combustion state estimating device.

BACKGROUND

[0002] JP2013-68130A discloses to use an in-cylinder pressure sensor provided at each cylinder of an internal combustion engine so as to detect an in-cylinder pressure of each cylinder.

SUMMARY

[0003] Here, as the method of estimation of the combustion state of a cylinder, the method of estimating the combustion state of a cylinder based on a detection value of an in-cylinder pressure sensor may be considered. However, in actuality, it is difficult to estimate a combustion state of a cylinder based on a detection value of an in-cylinder pressure sensor. A method of estimating a combustion state of a cylinder without using an in-cylinder pressure sensor is being sought.

[0004] The present invention was made focusing on this problem and has as its object to estimate a combustion state of a cylinder without using an in-cylinder pressure sensor.

[0005] To solve this problem, a combustion state estimating device according to one aspect of the present invention comprises a rotor rotatably housed inside a housing provided on an exhaust path of an engine body having a cylinder, having at least one blade, and driven to rotate by energy of exhaust discharged from the cylinder of the engine body, a passage detection sensor provided in the housing and detecting a predetermined position inside the housing being passed by a blade of the rotor, and a processing system configured to calculate an angular velocity of the rotor based on the results of detection of the passage detection sensor and to calculate at least one of the combustion energy or combustion interval of the cylinder of the engine body based on the angular velocity of the rotor.

[0006] According to the combustion state estimating device according to this aspect of the present invention, it is possible to provide a combustion state estimating device on the exhaust path so as to estimate a combustion state of a cylinder such as a combustion energy or combustion interval of a cylinder of an engine body. For this reason, it is possible to estimate a combustion state of a cylinder without using an in-cylinder pressure sensor.

BRIEF DESCRIPTION OF DRAWINGS

[0007]

[FIG. 1] FIG. 1 is a schematic view of a configuration of an internal combustion engine according to one embodiment of the present invention.

[FIG. 2A] FIG. 2A is a schematic cross-sectional view of a rotor and housing.

[FIG. 2B] FIG. 2B is a schematic plan view of a rotor.

[FIG. 3] FIG. 3 is a view for explaining a principle of detection of an eddy current sensor as a passage detection sensor.

[FIG. 4A] FIG. 4A is a view showing a trend in output value in the case of using an eddy current sensor as a passage detection sensor.

[FIG. 4B] FIG. 4B is a view showing a trend in output value in the case of using an eddy current sensor as a passage detection sensor.

[FIG. 5] FIG. 5 is a view showing one example of the results of calculation of an angular velocity of a compressor wheel in the case of making the rotor rotate by a constant angular velocity.

[FIG. 6] FIG. 6 is a schematic plan view of a rotor with blades in which shape error has occurred.

[FIG. 7] FIG. 7 is a view showing trends in angular velocity and kinetic energy of a rotor in one cycle of an internal combustion engine.

[FIG. 8] FIG. 8 is a view for explaining a method of calculation of a combustion energy of each cylinder and a combustion interval of each cylinder.

[FIG. 9] FIG. 9 is a flow chart for explaining control for calculation of an angular velocity of a rotor according to one embodiment of the present invention.

[FIG. 10] FIG. 10 is a flow chart for explaining control for estimation of the combustion energy of each cylinder of an engine body according to one embodiment of the present invention.

[FIG. 11] FIG. 11 is a flow chart for explaining control for estimation of the combustion interval of each cylinder of an engine body according to one embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

[0008] Below, referring to the drawings, embodiments of the present invention will be explained in detail. Note that, in the following explanation, similar component elements are assigned the same reference notations.

Overall Configuration

[0009] FIG. 1 is a schematic view of the configuration of an internal combustion engine 100 according to one embodiment of the present invention.

[0010] The internal combustion engine 100 comprises an engine body 1, intake system 20, exhaust system 30, and electronic control unit 200 for controlling the internal combustion engine 100. The internal combustion engine 100 is a so-called multicylinder internal combustion engine with an engine body 1 having a plurality of cylinders 4.

[0011] The engine body 1 burns fuel in a combustion

chamber 6 formed in each cylinder 4 to, for example, generate power for driving a vehicle etc. In the present embodiment, the engine body 1 has four cylinders 4, but the number of cylinders is not particularly limited. For example, it may also be one (single cylinder). Further, in the present embodiment, the engine body 1 burns fuel in a combustion chamber 6 by spark ignition, but the method of combustion of the fuel is also not particularly limited. It is also possible to burn fuel in a combustion chamber by compression ignition. Below, the configuration of the engine body 1 will be explained.

[0012] The engine body 1 comprises a cylinder block 2 and a cylinder head 3 fixed to a top surface of the cylinder block 2.

[0013] The cylinder block 2 is formed with a plurality of cylinders 4. Inside of each cylinder 4, a piston 5 is held receiving the combustion pressure and moving back and forth inside of the cylinder 4. The piston 5 is connected through a connecting rod to a crankshaft. Due to the crankshaft, the reciprocating movement of the piston 5 is converted to rotary motion. The space defined by the inner wall surface of the cylinder head 3, the inner wall surface of a cylinder 4, and the top surface of a piston forms a combustion chamber 6.

[0014] At the cylinder head 3, intake ports 7 opening at one side surface of the cylinder head 3 and opening at the combustion chambers 6 of the cylinders 4 and exhaust ports 8 opening at the other side surface of the cylinder head 3 and opening at the combustion chambers 6 of the cylinders 4 are formed.

[0015] Further, at the cylinder head 3, intake valves 9 for opening and closing openings of the combustion chambers 6 and intake ports 7, exhaust valves 10 for opening and closing openings of the combustion chambers 6 and exhaust ports 8, an intake camshaft 11 driving opening and closing of the intake valves 9, and an exhaust camshaft 12 driving opening and closing of the exhaust valves 10 are attached.

[0016] Further, at the cylinder head 3, fuel injectors 13 for injecting fuel into the combustion chambers 6 and spark plugs 14 for igniting the air-fuel mixtures of fuel and air injected from the fuel injectors 13 inside of the combustion chambers 6 are attached. Note that, the fuel injectors 13 may also be attached to inject fuel into the intake ports 7.

[0017] The intake system 20 is a system for guiding air to the insides of the cylinders 4 through the intake ports 7 and comprises an air cleaner 21, intake pipe 22, intake manifold 23, electronically controlled throttle valve 24, and air flow meter 211.

[0018] The air cleaner 21 removes sand and other foreign matter contained in the air.

[0019] The intake pipe 22 is connected at one end to the air cleaner 21 and is connected at the other end to a surge tank 23a of the intake manifold 23. Due to the intake pipe 22, air (intake air) flowing through the air cleaner 21 to the inside of the intake pipe 22 is guided to the surge tank 23a of the intake manifold 23.

[0020] The intake manifold 23 is comprised of the surge tank 23a and a plurality of intake runners 23b branched from the surge tank 23a and connected to openings of the intake ports 7 formed at the cylinder head side surfaces. The air introduced into the surge tank 23a is distributed evenly through the intake runners 23b to the insides of the cylinders 4.

[0021] The throttle valve 24 is provided inside the intake pipe 22. The throttle valve 24 is driven by a throttle actuator 25 and changes a passage cross-sectional area of the intake pipe 22 continuously or in stages. By using the throttle actuator 25 to adjust the opening degree of the throttle valve 24 (below, referred to as the "throttle opening degree"), the amount of intake taken into each cylinder 4 is adjusted. The throttle opening degree is detected by the throttle sensor 212.

[0022] The air flow meter 211 is provided inside the intake pipe 22 at the upstream side from the throttle valve 24. The air flow meter 211 detects the flow rate of air flowing through the inside of the intake pipe 22 (below, referred to as the "intake amount").

[0023] The exhaust system 30 is a system for purifying the combustion gas (exhaust) produced inside the combustion chambers 6 and discharging it to the outside air and is comprised of an exhaust manifold 31, exhaust pipe 32, and exhaust post-treatment device 33.

[0024] The exhaust manifold 31 is comprised of a plurality of exhaust runners 31a connected with the openings of the exhaust ports 8 formed at the side surface of the cylinder head and a header pipe 31b collecting the exhaust runners 31a and bundling them into one.

[0025] The exhaust pipe 32 is connected at one end to the header pipe 31b of the exhaust manifold 31 and opens at the other end to the outside air. The exhaust discharged from the cylinders 4 through the exhaust ports 8 to the exhaust manifold 31 flows through the exhaust pipe 32 and is discharged to the outside air.

[0026] The exhaust post treatment device 33 is a device for purifying the exhaust then discharging it to the outside air and is comprised of various types of catalysts removing the harmful substances and a filter for trapping harmful substances.

[0027] Further, the internal combustion engine 100 according to the present embodiment further comprises a combustion state estimating device 40 for estimating the combustion state of each cylinder 4 such as the combustion energy of each cylinder 4 or the combustion interval of each cylinder 4 of the engine body 1. The combustion state estimating device 40 comprises a housing 41 connected to the exhaust pipe 32, a rotor 42 arranged rotatably inside the housing 41, a passage detection sensor 301 attached to the housing 41, and an amp unit 300 configured to calculate the angular velocity of the rotor 42 based on the output results of the passage detection sensor 301 and to estimate the combustion state of each cylinder 4 such as the combustion energy of each cylinder 4 and the combustion interval of each cylinder 4 of the engine body 1 based on the angular velocity of the rotor

42. Details of the combustion state estimating device 40 will be explained later with reference to FIG. 2 on.

[0028] The electronic control unit 200 is comprised of a digital computer and is comprised of components connected to each other by a bidirectional bus such as a ROM (read only memory), RAM (random access memory), CPU (microprocessor), input port, and output port.

[0029] The electronic control unit 200 receives as input through the input port the output signals of the above-mentioned air flow meter 211 and throttle sensor 212 etc. and, as a signal for calculating the engine speed, an output signal of a crank angle sensor 213 generating an output pulse each time a crankshaft of the engine body 1 rotates by, for example, 15° etc. In this way, the electronic control unit 200 receives an input through the input port the output signals of various types of sensors required for controlling the internal combustion engine 100.

[0030] Further, the electronic control unit 200 is electrically connected to the fuel injectors 13, spark plugs 14, throttle actuators 25, and other control parts through the output port.

[0031] Further, the electronic control unit 200 is connected with the amp unit 300 by a CAN (Controller Area Network) communication line and is designed to send and receive data by CAN communication. In the present embodiment, the combustion state of each cylinder 4 of the engine body 1 estimated by the amp unit 300 is sent to the electronic control unit 200. Further the electronic control unit 200 according to the present embodiment is configured to be able to control a parameter relating to combustion in each cylinder 4, that is, the amount of fuel injection, the amount of intake air, the ignition timing, etc., in accordance with the combustion state of each cylinder 4 of the engine body 1 sent from the amp unit 300.

Constitution of Combustion State Estimating Device

[0032] FIG. 2A is a schematic cross-sectional view of the housing 41 and rotor 42. FIG. 2B is a schematic plan view of a rotor 42.

[0033] As shown in FIG. 2A, the rotor 42 is comprised of a center member 421 fixed to a shaft 423 rotatably supported by a roller bearing 424 and a plurality of blades 422 extending from the surface of the center member 421 in the radial direction and axial direction of the rotor 42. The center member 421 is fixed to the shaft 423 so that the axis L becomes coaxial with the axis of the shaft 423.

[0034] The rotor 42 is arranged inside of the housing 41 so as to be able to rotate about the axis L. Further, the rotor 42 is arranged inside the housing 41 so that when the rotor rotates, the radial direction end parts of the blades 422 move in the peripheral direction along the inside circumferential surface of the housing 41 in the state with a slight clearance from the inside circumferential surface.

[0035] Further, as shown in FIG. 2B, the rotor 42 according to the present embodiment has 12 blades 422 of the same shapes arranged at equal intervals. In FIG. 2B, to facilitate the explanation, the blades 422 are assigned identifying numbers of B1 to B12. Note that, the number of blades 422 is not limited to 12 and may be greater than 12 or less than 12. In the present embodiment, each blade 422 is configured to extend in the radial direction and axial direction of the rotor 42. However, the plurality of blades 422 may be any shapes such as curved shapes so long as able to drive rotation of the rotor 42 by exhaust flowing into the housing 41. Further, the blades 422 do not necessarily have to be arranged at equal intervals. Part or all of the blades 422 may be shapes different from the other blades.

[0036] Returning to FIG. 2A, the housing 41 has a center passage 411 extending through the center of the housing 41 and a ring-shaped passage 412 extending around the center passage 411 and through which exhaust flowing through the exhaust pipe flows. Around one end part of the center passage 411 (left side in figure), a ring-shaped passage 412 is arranged. At the inside of this ring-shaped passage 412, a rotor 42 is arranged inside the center passage 411. The other end part of the center passage 411 (right side in figure) is open and forms an outlet 413 from which the exhaust flows out. Therefore, the exhaust flowing through the exhaust pipe 32 flows through the ring-shaped passage 412 and out through the rotor 42 from the outlet 413 of the center passage 411.

[0037] Further, at the housing 41, to detect the passage of a blade 422 through a predetermined angular position (predetermined position) inside the housing 41, a passage detection sensor 301 is attached. The passage detection sensor 301 detects the passage of a blade 422 in front of the detecting part of the passage detection sensor 301. In the present embodiment, the passage detection sensor 301 is attached to the housing 41 so as to face the radial direction end faces 422a of the blades 422 of the rotor 42 and so as to become substantially parallel to the normal direction of the radial direction end faces 422a of the blades 422.

[0038] The amp unit 300 receives as input the output value of the passage detection sensor 301. The amp unit 300 is comprised of an amplifier amplifying the output value of the passage detection sensor 301 and a CPU (microprocessor) utilizing the output value amplified by the amplifier to calculate the angular velocity of the rotor 42 etc. joined together. In the present embodiment, the passage detection sensor 301 and the amp unit 300 are made separate members, but the passage detection sensor 301 may also house the amp unit 300, and the passage detection sensor 301 and amp unit 300 may be joined together.

[0039] Further, in the present embodiment, an eddy current sensor is used as the passage detection sensor 301. An eddy current sensor is a sensor outputting a voltage value corresponding to the distance between a sensor detecting part and a metal substance being measured. Below, referring to FIG. 3, the principle of detection of the eddy current sensor will be simply explained.

[0040] The eddy current sensor has a coil 301a generating a magnetic field by an AC excitation current at the detecting part. If a blade 422 passes through the magnetic field X generated by the coil 301a, an eddy current Y is generated at the blade 422 so as to cancel out the magnetic field generated by the coil 301a. The intensity of the magnetic field X changes due to the eddy current generated at the blade 422 and, as a result, the value of the current flowing through the coil 301a changes. Therefore, by detecting a change of the voltage value derived from the change of the current value flowing through the coil 301a by the eddy current sensor, it is possible to detect if a blade 422 has passed. Specifically, the time when the output value of the eddy current sensor has peaked can be judged as the time when a blade 422 has passed in front of the detecting part of the eddy current sensor 5 (that is, a predetermined angular position inside the housing 41).

[0041] Note that, as the passage detection sensor 301 for detecting passage of a blade 422, any sensor may be used so long as able to detect passage of the blade 422. As such a sensor, for example, a magnetic pickup (MPU) sensor may be mentioned. An MPU sensor is a sensor having a magnet and a detection coil in a detecting part. In such an MPU sensor, if the magnetic member of a blade approaches or moves away from the MPU sensor, the magnetic flux passing through the detection coil changes. Along with this, the induced electromotive force of the detection coil changes. Due to this, it is possible to detect the passage of a blade 422 at the front of the detecting part of the MPU sensor. In the following explanation, the case of use of an eddy current sensor as the passage detection sensor 301 will be explained.

[0042] FIG. 4A and FIG. 4B are views showing the trend in the output value (voltage value) of the passage detection sensor 301 in the case of using an eddy current sensor as the passage detection sensor 301. FIG. 4A shows the trend in the output value in the case where the angular velocity of the rotor 42 is relatively slow (for example, speed of rotor 42 is 200,000 rpm), while FIG. 4B shows the trend in the output value in the case where the angular velocity of the rotor 42 is relatively fast (for example, speed of rotor 42 is 400,000 rpm).

[0043] When using an eddy current sensor as the passage detection sensor 301, the shorter the distance between the detecting part of the passage detection sensor 301 and an object passing in front of it (in the present embodiment, a blade 422), the larger the output value. Therefore, if a blade 422 passes in front of the detecting part of the passage detection sensor 301, the output value of the passage detection sensor 301 rapidly increases. Accordingly, the output changing to a spike in FIG. 4A and FIG. 4B means the passage of a blade 422. Note that, Nos. B1 to B12 of FIG. 4A and FIG. 4B are identifying numbers of the blades 422 passing in front of the detecting part of the passage detection sensor 301.

[0044] As shown in FIG. 4A, if the angular velocity of the rotor 42 is relatively slow, along with the passage of a blade 422, the output value of the passage detection sensor 301 rapidly rises and falls and the time period between passages of two adjoining blades 422 is maintained constant at a low value.

[0045] On the other hand, as shown in FIG. 4B, if the angular velocity of the rotor 42 is relatively fast, before the output value of the passage detection sensor 301 which had risen along with the passage of one blade 422 falls to the lowest value, the output value of the passage detection sensor 301 starts to rise along with the passage of the next blade 422. Therefore, as shown in FIG. 4B, even in the time period between passages of two adjoining blades 422, the output value of the passage detection sensor 301 is not maintained constant. However, in this case as well, the timing where the output value of the passage detection sensor 301 becomes maximum shows the passage of a blade 422, so it is possible to accurately detect the passage of a blade 422 in front of the detecting part of the passage detection sensor 301.

One Example of Method of Calculation of Angular Velocity of Rotor Using Passage Detection Sensor

[0046] In this way, the passage detection sensor 301 can accurately detect the passage of a blade 422 in front of the detecting part of the passage detection sensor 301. For this reason, as one example of the method of calculation of the angular velocity of the rotor 42 using the passage detection sensor 301, the method of calculating the angular velocity of the rotor 42 each time a blade 422 passes in front of the passage detection sensor 301 based on the time interval from the passage of any one blade among the blades 422 (below, referred to as the "reference blade") in front of the passage detection sensor 301 to when the blade passing in front of the passage detection sensor 301 after the reference blade passes.

[0047] Below, referring to FIG. 4A, one example of the method of calculation of the angular velocity of the rotor 42 using this passage detection sensor 301 will be explained.

[0048] In the example shown in FIG. 4A, the time when the output value of the passage detection sensor 301 peaks due to a first blade B1 passing in front of the passage detection sensor 301 is made the time t1. Similarly, the times when the output value of the passage detection sensor 301 peaks due to a second blade B2, a third blade B3, and a fourth blade B4 passing in front of the passage detection sensor 301 are made the times t2, t3, and t4.

[0049] In this case, the time interval $\Delta t1$ from when the first blade B1 passes in front of the passage detection sensor 301 to when the second blade B2 passes becomes t2-t1. On the other hand, in the present embodiment, 12 blades are provided at equal intervals, so the angular interval between the first blade B1 and the second blade B2 basically becomes $(2\pi/12)$[rad]. Therefore, an instantaneous angular velocity $\omega 1$[rad/s] of the rotor 42 from when the first blade B1 passes in front of the passage detection sensor 301 to when the second blade

B2 passes (below, referred to as the "instantaneous angular velocity after passage of the first blade") becomes $2\pi/(12\times\Delta t1)$.

[0050] Similarly, the time interval $\Delta t2$ from when the second blade B2 passes in front of the passage detection sensor 301 to when the third blade B3 passes becomes t3-t2, while the time interval $\Delta t3$ from when the third blade B3 passes to when the fourth blade B4 passes becomes t4-t3. Therefore, the instantaneous angular velocity $\omega 2$ of the rotor 42 from when the second blade B2 passes in front of the passage detection sensor 301 to when the third blade B3 passes, that is, the instantaneous angular velocity $\omega 2$ after the passage of the second blade, becomes $2\pi/(12\times\Delta t2)$. Similarly, the instantaneous angular velocity $\omega 3$ of the rotor 42 from when the third blade B3 passes in front of the passage detection sensor 301 to when the fourth blade B4 passes, that is, the instantaneous angular velocity $\omega 3$ after the passage of the third blade, becomes $2\pi/(12\times\Delta t3)$.

[0051] Therefore, if representing the identifying number of the blades 422 by "i", if calculating the time interval Δti between passages of an adjoining pair of blades 422 (that is, the i-th blade Bi and (i+1)th blade B(i+1)) in front of the passage detection sensor 301 based on the output of the passage detection sensor 301, it is possible to calculate the instantaneous angular velocity coi after passage of the i-th blade Bi based on the time interval Δti and the angular interval between the adjoining pair of blades 422.

[0052] Specifically, by dividing the angular interval αi between the adjoining pair of blades 422 like in the following formula (1) by the time interval Δti of passage between these blades 422, it is possible to calculate the instantaneous angular velocity coi after passage of the i-th blade.

$$\omega i=\alpha i/\Delta ti \ldots(1)$$

[0053] Further, in the case, like the present embodiment, of the rotor 42 with blades 422 provided at equal intervals in the circumferential direction, if designating the total number of the blades 422 as "p", the angular interval αi becomes $(2\pi/p)$. Therefore, the instantaneous angular velocity ωi after passage of the i-th blade can be calculated by the following formula (2):

$$\omega i=2\pi/(p\times\Delta ti) \ldots (2)$$

[0054] In this regard, however, it will be understood that if using such a method of calculation to calculate the angular velocity of the rotor 42, that is, if calculating the angular velocity of the rotor 42 based on the time interval Δti from when the reference blade passes in front of the passage detection sensor 301 to when the blade passing in front of the passage detection sensor 301 after the reference blade passes, error arises between the actual angular velocity and the calculated angular velocity (calculation error).

Shape Error of Blades

[0055] FIG. 5 is a view showing one example of the results of calculation when calculating the angular velocity of the rotor 42 by the above-mentioned method of calculation if making the rotor 42 rotate by a certain angular velocity. In FIG. 5, the abscissa shows the identifying numbers of the blades 422, while the ordinate shows the instantaneous angular velocity of the rotor 42 after passage of the blade with the corresponding blade number.

[0056] In the example shown in FIG. 5, the rotor 42 is made to rotate by a certain angular velocity. Therefore, the instantaneous angular velocity of the rotor 42 calculated at this time should also become a constant value. However, in actuality, as shown in FIG. 5, the calculated instantaneous angular velocity of the rotor 42 will not necessarily become constant after passage of each blade 422. For example, in the example shown in FIG. 5, the instantaneous angular velocity of the rotor 42 after passage of the #2 blade becomes slower than the instantaneous angular velocity of the rotor 42 after passage of the #1 blade.

[0057] In this way, as one of the reasons why the calculated instantaneous angular velocity of the rotor 42 will not become a constant value, the shape error of the blades 422 of the rotor 42 (error within range of shape tolerance) may be mentioned. That is, sometimes shape error occurs in the blades 422 of the rotor 42 due to manufacturing error and aging. Due to this shape error, error arises when calculating the instantaneous angular velocity of the rotor 42. Below, referring to FIG. 6, the relationship between the calculated instantaneous angular velocity of the rotor 42 and the shape error of the blades 422 will be explained.

[0058] FIG. 6 is a schematic plan view of a rotor 42 in which shape error occurs in the blades 422. The broken line in FIG. 6 shows the shape of the blades 422 in the case where the blades 422 of the rotor 42 are formed as designed. In the example shown in FIG. 6, it will be understood that the second blade B2 and the 10th blade B10 have shape error with respect to the design blade shape. Specifically, the second blade B2 becomes a shape shifted to the first blade side in the circumferential direction with respect to the design shape. Further, the 10th blade B10 becomes a shape shifted to the outside in the radial direction with respect to the design shape.

[0059] If in this way error occurs in the blade shapes, the angular interval α between blades changes. In the example shown in FIG. 6, the shape of the second blade B2 becomes a shape shifted in the circumferential direction with respect to the design shape. As a result, in the region facing the passage detection sensor 301, the actual angular interval between the first blade B1 and the second blade B2 becomes $\alpha 1$ smaller than the design

value β1. Conversely, the actual angular interval between the second blade B2 and the third blade B3 becomes α2 larger than the design value β2. Therefore, the actual angular interval α1 between the first blade B1 and the second blade B2 becomes smaller than the actual angular interval α2 between the second blade B2 and the third blade B3.

[0060] On the other hand, in calculating the angular velocity, the design value is used rather than the actual angular intervals between blades. For this reason, even if the rotor 42 rotates by a constant angular velocity, the instantaneous angular velocity ω1 of the rotor 42 based on the time interval Δt1 from the first blade B1 to the second blade B2 is calculated as being faster than the instantaneous angular velocity ω2 of the rotor 42 based on the time interval Δt2 from the second blade B2 to the third blade B3. As a result, as shown in FIG. 5, the instantaneous angular velocity after passage of the first blade B1 is calculated as being faster than the instantaneous angular velocity after passage of the second blade B2.

[0061] Further, in the example shown in FIG. 6, the 10th blade BI0 becomes a shape shifted to the outside in the circumferential direction with respect to the design shape. As a result, the actual angular interval between the ninth blade B9 and the 10th blade B10 becomes α9 smaller than the design value β9. Further, the actual angular interval between the 10th blade B10 and the 11th blade B11 becomes α10 larger than the design value β10. As a result, even if the rotor 42 rotates by a certain angular velocity, the instantaneous angular velocity after passage of the ninth blade B9 is calculated as one faster than the instantaneous angular velocity after passage of the 10th blade B10.

[0062] Note that, FIG. 6 shows an example of shape error when the shapes of blades 422 are shifted overall in the circumferential direction or radial direction. However, the shape error arising at the blades 422 includes error in the axial direction of the rotor 42, error in the curved shapes of the blades, and various other error besides the above shape error. Further, if such shape error occurs in the blades 422, the angular velocity of the rotor 42 can no longer be accurately calculated.

Measures Against Calculation Error Occurring Due to Shape Error

[0063] Therefore, in the present embodiment, rather than, like with the above-mentioned method of calculation, calculating the angular velocity of the rotor 42 based on the time interval from when a reference blade passes in front of the passage detection sensor 301 to when the blade passing in front of the passage detection sensor 301 after the reference blade passes, that is, the time required for passage between adjoining blades, the angular velocity of the rotor 42 is calculated based on the time interval from when the reference blade passes in front of the passage detection sensor 301 to when the reference blade again passes in front of the passage detection sensor 301, that is, the time required for the rotor 42 to turn one time.

[0064] In this way, by calculating the angular velocity of the rotor 42 based on the time required for the rotor 42 to turn one time, even if shape error occurs in the blades 422, it is possible to calculate the angular velocity of the rotor 42 without being affected by the shape error. For example, if the reference blade is made the first blade B1, as shown in the example shown in FIG. 6, even if the actual angular interval α1 between the first blade B1 and the second blade B2 and the actual angular interval α9 between the ninth blade B9 and the 10th blade B10 respectively differ from the design values β1 and β9, the angular interval from the first blade B1 to the first blade B1 always becomes constant at 2π [rad]. Further, even if the first blade B1 itself changes in shape, the angular interval from the first blade B1 to the first blade B1 always becomes constant at 2π [rad].

[0065] For this reason, by calculating the angular velocity of the rotor 42 based on the time required for the rotor 42 to turn one time, it is possible to accurately calculate the angular velocity of the rotor 42 without being affected by shape error of the blades 422.

Utilization of Instantaneous Angular Velocity

[0066] Further, as a result of intensive research of the inventors, it was learned that if it is possible to accurately calculate the angular velocity of the rotor 42, it becomes possible to accurately estimate the combustion state of each cylinder 4 of the engine body 1 based on the calculated angular velocity of the rotor 42. Below, the method of estimating the combustion state of each cylinder 4 of the engine body 1 based on the angular velocity of the rotor 42 will be explained.

Calculation of Kinetic Energy of Rotor

[0067] Inside of the housing 41, the rotor 42 rotates, but the kinetic energy KE of the rotor 42 can be calculated by the following formula (3):

$$KE = I \times \omega^2 / 2 \quad \ldots (3)$$

[0068] In formula (3), "I" is the inertia moment of the rotor 42, while "ω" is the angular velocity of the rotor 42. The inertia moment I of the rotor 42 can be found by calculations in advance etc. from the shape and material of the rotor 42. Therefore, by finding the angular velocity of the rotor 42, it is possible to calculate the kinetic energy of the rotor 42 at the point of time of finding the angular velocity.

[0069] Therefore, in the present embodiment, during the operation of the internal combustion engine 100, the angular velocity co of the rotor 42 is calculated by the amp unit 300. Further, the kinetic energy of the rotor 42

is calculated by the amp unit 300 by formula (3). In the present embodiment, it is possible to accurately estimate the angular velocity ω of the rotor 42 without being affected by the shape error of the rotor 42, so it is possible to accurately calculate the kinetic energy of the rotor 42.

Estimation of Combustion State

[0070] If, in this way, it is possible to accurately calculate the kinetic energy of the rotor 42, based on the calculated kinetic energy, if the engine body 1 has a plurality of cylinders 4, it is possible to estimate the combustion state of each cylinder 4 such as the combustion energy generated when burning fuel in the combustion chamber 6 of each cylinder 4 or the combustion interval of the each cylinder 4. Further, if the engine body 1 has a single cylinder, it is possible to estimate the combustion state of the single cylinder such as the combustion energy generated when burning fuel in the combustion chamber of the single cylinder or the combustion interval. Below, the relationship between the kinetic energy of the rotor 42 and the combustion state of each cylinder 4 in the case where the engine body 1 has a plurality of cylinders 4 will be explained.

[0071] FIG. 7 is a view showing the trends in the angular velocity of the rotor 42 and the kinetic energy in one cycle of the internal combustion engine 100. The abscissa in the figure shows the crank angle of the engine body 1. The solid line in FIG. 7 shows the kinetic energy of the rotor 42, while the broken line shows the angular velocity of the rotor 42.

[0072] As shown in FIG. 7, the angular velocity of the rotor 42 changes according to the crank angle of the engine body 1. In the example shown in FIG. 7, first, if the exhaust valve of the #1 cylinder opens and exhaust flows out from the combustion chamber 6, the exhaust flowing into the ring-shaped passage 412 inside the housing 41 increases. For this reason, the angular velocity of the rotor 42 increases. Further, along with this, the kinetic energy of the rotor 42 also increases.

[0073] After that, at the end of the exhaust stroke of the #1 cylinder, the flow rate of exhaust flowing out from the combustion chamber 6 decreases. As a result, the angular velocity of the rotor 42 decreases. Further, along with this, the kinetic energy of the rotor 42 decreases.

[0074] Therefore, as will be understood from FIG. 7, during the exhaust stroke of the #1 cylinder, the angular velocity of the rotor 42 rises, then falls. Along with this, the kinetic energy of the rotor 42 increases, then decreases. Further, such angular velocity or kinetic energy trends in the same way in the exhaust stroke of other cylinders 4. Therefore, in a four-cylinder internal combustion engine 100, the angular velocity and kinetic energy of the rotor 42 greatly fluctuate up and down four times in one cycle of the internal combustion engine 100. That is, the angular velocity and kinetic energy of the rotor 42 fluctuate up and down several times in accordance with the number of cylinders of the internal combustion engine 100 during one cycle of the internal combustion engine 100.

[0075] Here, if considering the #4 cylinder as an example, the amount of rise of the kinetic energy of the rotor 42 during the exhaust stroke of the #4 cylinder (ΔKE in FIG. 7) is proportional to the exhaust energy of the exhaust discharged from the combustion chamber 6 of the #4 cylinder. Similarly, the amounts of rise of the kinetic energy of the rotor 42 during the exhaust strokes of the #1 cylinder, #3 cylinder, and #2 cylinder are proportional to the exhaust energies of the exhausts respectively discharged from the combustion chambers 6 of the #1 cylinder, #3 cylinder, and #2 cylinder. Here, the exhaust energy of the exhaust discharged from each cylinder 4 basically is proportional to the combustion energy generated when fuel is burned in the combustion chamber 6 of each cylinder 4, that is, the torque (combustion torque) generated due to combustion of fuel in the combustion chamber 6 of each cylinder 4.

[0076] Therefore, by comparing the amount of rise of the kinetic energy of the rotor 42 in the exhaust stroke of each cylinder 4 between cylinders, it is possible to detect the difference in combustion energy (combustion torque) between cylinders. Specifically, it is possible to detect the difference in combustion energy (combustion torque) between cylinders based on the difference (ΔKE) between the minimum value of the kinetic energy of the rotor 42 at the time of start of the exhaust stroke of each cylinder 4 and the maximum value of the kinetic energy of the rotor 42 during the exhaust stroke of the cylinder 4. A cylinder 4 with a large difference between these minimum value and maximum value can be judged as a cylinder 4 with a large combustion energy (combustion torque), while a cylinder 4 with a small difference between these minimum value and maximum value can be judged as a cylinder 4 with a small combustion energy (combustion torque).

[0077] Further, if considering the #4 cylinder as an example, the time interval from the time of start of the exhaust stroke of the #4 cylinder to the time of end of the exhaust stroke (Δtcom in FIG. 7), that is, the time period during which the rotor 42 is made to rotate by the exhaust discharged from the combustion chamber 6 of the #4 cylinder, corresponds to the combustion interval from the time of start of the combustion stroke of the #2 cylinder to the time of end of the combustion stroke. In the same way, the time intervals from the times of start of exhaust strokes of the #1 cylinder, #3 cylinder, and #2 cylinder to the times of end of the exhaust strokes respectively correspond to the combustion intervals from the times of start of the combustion strokes to the times of end of the combustion strokes of the #3 cylinder, #4 cylinder, and #1 cylinder.

[0078] Therefore, by comparing the time interval from the time of start of the exhaust stroke of each cylinder 4 to the time of end of the exhaust stroke between cylinders, it is possible to detect the difference in combustion intervals between cylinders.

[0079] If in this way it is possible to detect the difference in combustion energy (combustion torque) or the difference in combustion intervals between cylinders, for example, it would be possible to control the fuel injection amount, the amount of intake air, the ignition timing, and other parameters relating to combustion in each cylinder 4 by the electronic control unit 200 by feedback control or feed forward control. Due to this, it becomes possible to keep the difference in combustion energy (combustion torque) or the difference in combustion intervals between cylinders to the minimum extent. Further, if the engine body 1 has a single cylinder, by calculating at all times the combustion state of the single cylinder such as the combustion energy (combustion torque) or combustion interval of the single cylinder, for example even when for example a difference in combustion state arises in the steady state (state with no load fluctuations), it is possible to control the fuel injection amount, the amount of intake air, the ignition timing, or other parameter relating to combustion in each cylinder 4 by the electronic control unit 200 by feedback control or feed forward control so as to match the combustion state.

Method of Calculation of ΔKE and Δtcom

[0080] FIG. 8 is a view for explaining the method of calculation of the combustion energy ΔKE of each cylinder 4 and the combustion interval Δtcom of each cylinder 4. The abscissa in the figure shows the crank angle of the engine body 1. The solid line in FIG. 8 shows the kinetic energy of the rotor 42 while the broken line shows the angular velocity of the rotor 42.

[0081] To calculate the amount of rise of the kinetic energy of the rotor 42 during the exhaust stroke of each cylinder 4, that is, the combustion energy ΔKE generated when making fuel burn in the combustion chamber 6 of each cylinder 4, it is necessary to respectively calculate the minimum value of the kinetic energy of the rotor 42 at the time of start of the exhaust stroke of each cylinder 4 and the maximum value of the kinetic energy of the rotor 42 during the exhaust stroke of the cylinder 4.

[0082] Here, if using the #4 cylinder as an example and considering the differential value ω' of the angular velocity co of the rotor 42 (below, referred to as the "angular acceleration") (=dω/dt; slant of broken line of FIG. 8), as shown in FIG. 8, the angular acceleration ω' becomes 0 at the time of start of the exhaust stroke of each cylinder 4 where the kinetic energy of the rotor 42 becomes the minimum value (local minimum value). Further, the angular acceleration ω' becomes 0 even at a certain time during the exhaust stroke of each cylinder 4 where the kinetic energy of the rotor 42 becomes the maximum value (local maximum value).

[0083] Therefore, each time calculating the angular velocity ω of the rotor 42, the amp unit 300 according to present embodiment sets the angular velocity ω as the current angular velocity value ω_z of the rotor 42 and calculates the differential value of the current angular velocity value ω_z as the current angular acceleration value ω_z'. Further the amp unit 300 sets the current angular velocity value ω_z of when the absolute value of the current angular acceleration value ω_z' becomes the preset close to 0 value of the extremal value judgment threshold or less as the angular velocity ωL at the time of start of the exhaust stroke of each cylinder 4 (below, referred to as the "local minimum angular velocity") or as the angular velocity ωH at the time during the exhaust stroke of each cylinder 4 where the kinetic energy of the rotor 42 becomes the maximum value (local maximum value) (below, referred to as the "local maximum angular velocity").

[0084] Note that, regarding the current angular velocity value ω_z when the absolute value of the current angular acceleration value ω_z' becomes the extremal value judgment threshold or less, whether the current angular velocity value ω_z is the local minimum angular velocity ωL or the local maximum angular velocity ωH can be judged by judging if the immediately preceding calculated previous angular acceleration value ω_{z-1}' is a positive value.

[0085] Specifically, if the previous angular acceleration value ω_{z-1}' is a negative value, that is, if the slant of the broken line in FIG. 8 is negative, it can be judged that the angular velocity has turned from a fall to a rise. Therefore, the amp unit 300 according to present embodiment, in this case, sets the current angular velocity value ω_z of when the absolute value of the current angular acceleration value ω_z' becomes the extremal value judgment threshold or less as the local minimum angular velocity ωL. On the other hand, if the previous angular acceleration value ω_{z-1}' is a positive value, that is, if the slant of the broken line of FIG. 8 is positive, it can be judged that this is a time when the angular velocity ω turns from a rise to a fall. Therefore, the amp unit 300 according to present embodiment, in this case, sets the current angular velocity value ω_z of when the absolute value of the current angular acceleration value ω_z' becomes an extremal value judgment threshold or less as the local maximum angular velocity ωH.

[0086] If entering the thus set local minimum angular velocity ωL and local maximum angular velocity ωH into formula (3), it is possible to calculate the minimum value of the kinetic energy of the rotor 42 at the time of start of the exhaust stroke of each cylinder 4 and the maximum value of the kinetic energy of the rotor 42 during the exhaust stroke of the cylinder 4. Further, if subtracting from the thus calculated maximum value of the kinetic energy the minimum value, it is possible to calculate the combustion energy ΔKE generated when making fuel burn in the combustion chamber 6 of each cylinder 4.

[0087] Further, the combustion interval Δtcom of each cylinder 4, as explained above, corresponds to the time interval from the start of the exhaust stroke of each cylinder 4 to the end of the exhaust stroke. Therefore, the combustion interval Δtcom of each cylinder 4 matches the time from when the local minimum angular velocity ωL is set to when the local minimum angular velocity ωL is next set. Therefore, the amp unit 300 according to

present embodiment measures the time from when the local minimum angular velocity ωL is set to when the local minimum angular velocity ωL is next set so as to calculate the combustion interval of each cylinder 4.

[0088] Note that, aside from this as well, for example, it is also possible to count the time from when calculating the minimum value of the kinetic energy of the rotor 42 to when next calculating the minimum value of the kinetic energy of the rotor 42 so as to calculate the combustion interval Δtcom of each cylinder 4.

Flow Chart of Control for Estimation of Combustion State

[0089] Below, the control for estimation of the combustion energy of each cylinder 4 and the combustion interval of each cylinder 4 of the engine body 1 utilizing the output value of the passage detection sensor 301 according to the present embodiment will be explained.

[0090] First, referring to FIG. 9, control for calculation of the angular velocity of the rotor 42 which the amp unit 300 performs will be explained. The amp unit 300 repeatedly performs this routine by a predetermined processing period (=sampling period t_{smp}).

[0091] At step S1, the amp unit 300 reads the output value of the passage detection sensor 301.

[0092] At step S2, the amp unit 300 judges if the elapsed time counting start flag F1 has been set to "0". The elapsed time counting start flag F1 is a flag with an initial value which is set to "0". When the elapsed time counting start flag F1 is set to "0", it is set to "1" if passage of a blade 422 is detected by the passage detection sensor 301. Further, if the angular velocity and speed of the rotor 42 are estimated, the flag is again returned to "0". The amp unit 300 proceeds to the processing of step S2 if the elapsed time counting start flag F1 is set to "0". On the other hand, the amp unit 300 proceeds to the processing of step S5 if the elapsed time counting start flag F1 is set to "1".

[0093] At step S3, the amp unit 300 judges if passage of a blade 422 has been detected. The blade 422 for which passage was detected at this step S3 becomes any one blade of the plurality of blades, that is, a reference blade. The amp unit 300 proceeds to the processing of step S4 if passage of a blade 422 is detected. On the other hand, the amp unit 300 ends the current processing if passage of a blade 422 is not detected.

[0094] At step S4, the amp unit 300 sets the elapsed time counting start flag F1 to "1" and starts the counting of the elapsed time t_{e1} from when the reference blade passes in front of the detecting part of the passage detection sensor 301.

[0095] At step S5, the amp unit 300 calculates the previous value of the elapsed time t_{e1} plus the sampling period t_{smp} as the elapsed time t_{e1}. Note that, the initial value of the elapsed time t_e is 0.

[0096] At step S6, the amp unit 300 judges if passage of a blade 422 has been detected by the passage detection sensor 301. The amp unit 300 proceeds to the processing of step S7 if passage of a blade 422 is detected by the passage detection sensor 301. On the other hand, the amp unit 300 ends the current processing if passage of a blade 422 is not detected by the passage detection sensor 301.

[0097] At step S7, the amp unit 300 calculates the number of times "i" of blade passage from when the reference blade passed in front of the detecting part of the passage detection sensor 301. Specifically, the amp unit 300 calculates the previous value of the number of times "i" of blade passage plus 1 as the number of times "i" of blade passage. Note that, the initial value of the number of times "i" of blade passage is 0.

[0098] At step S8, the amp unit 300 judges if the blade 422 for which passage was detected at step S6 is the reference blade. Specifically, the amp unit 300 judges if the number of times "i" of blade passage has become a value found by multiplying the total number of blades (in the present embodiment, 12) by a positive integer "n".

[0099] If setting the positive integer "n" to for, example, "1", it is possible to judge at step S8 if the rotor 42 has turned one time, while if setting it to, for example, "2", it is possible to judge at step S8 if the rotor 42 has turned two times. That is, it is possible to adjust the timing of estimation of the angular velocity of the rotor 42 in accordance with the positive integer "n" and possible to adjust the number of estimated data of the angular velocity of the rotor 42 per unit time. In the present embodiment, the positive integer "n" is set to "1", but the positive integer "n" may also be set to a value larger than "1" in accordance with the processing capacity etc. of the CPU of the amp unit 300.

[0100] The amp unit 300 proceeds to the processing of step S9 if the blade 422 for which passage was detected at step S6 is the reference blade. On the other hand, the amp unit 300 ends the current processing if the blade 422 for which passage was detected at step S6 is not the reference blade.

[0101] At step S9, the amp unit 300 sets the elapsed time t_{e1} calculated at step S5 as the reference blade passing time t_m. That is, the amp unit 300 sets the positive integer "n" of the present embodiment as "1", so sets the time period from when detecting a first passage of the reference blade in front of the detecting part of the passage detection sensor 301 until when detecting the next passage of the reference blade in front of the detecting part of the passage detection sensor 301 (time required for the rotor 42 to turn once) as the reference blade passing time t_m.

[0102] At step S10, the amp unit 300 calculates the angular velocity of the rotor 42 based on the reference blade passing time t_m. Specifically, the amp unit 300 enters the reference blade passing time t_m into the following formula (4) to calculate the angular velocity ω of the rotor 42. Note that, at step S10, it is also possible to enter the reference blade passing time t_m into the following formula (5) to also calculate the speed N of the rotor 42.

$$\omega=2\pi/t_m \ldots (4)$$

$$N=60/t_m \ldots (5)$$

[0103] At step S11, the amp unit 300 returns the elapsed time t_{e1}, the number of times "i" of blade passage, and the elapsed time counting start flag F1 to the initial value 0.

[0104] Next, referring to FIG. 10, the control for estimation of the combustion energy of each cylinder 4 of the engine body 1 which the amp unit 300 performs will be explained. The amp unit 300 repeatedly performs this routine by a predetermined processing period (=sampling period t_{smp}).

[0105] At step S21, the amp unit 300 judges if the angular velocity ω of the rotor 42 is newly calculated by the control for calculation of the angular velocity of the above-mentioned rotor 42. The amp unit 300 proceeds to the processing of step S22 if the angular velocity ω of the rotor 42 is newly calculated. On the other hand, the amp unit 300 ends the current processing if the angular velocity co of the rotor 42 is not newly calculated.

[0106] At step S22, the amp unit 300 reads the newly calculated angular velocity ω of the rotor 42 and the reference blade passing time t_m used for the calculation.

[0107] At step S23, the amp unit 300 judges if there are two points or more of data of the angular velocity co of the rotor 42 read up to then. The amp unit 300 proceeds to the processing of step S24 if there are two points or more of data of the angular velocity ω of the rotor 42 read up to then. On the other hand, the amp unit 300 ends the current processing if there are not two points or more of data of the angular velocity ω of the rotor 42 read up to then.

[0108] At step S24, the amp unit 300 calculates the current angular acceleration value ω_z' of the rotor 42. Specifically, the amp unit 300 calculates the current newly read angular velocity ω of the rotor 42 as the current angular velocity value ω_z of the rotor 42 and calculates the one previously read angular velocity ω of the rotor 42 as the previous angular velocity value ω_{z-1} of the rotor 42. Further, the amp unit 300 enters into the following formula (6) the current angular velocity value ω_z, the previous angular velocity value ω_{z-1}, and the reference blade passing time t_m read at step S22 to calculate the current angular acceleration value ω_z' of the rotor 42.

$$\omega_Z' = (\omega_Z-\omega_{Z-1})/t_m \ldots (6)$$

[0109] At step S25, the amp unit 300 judges if the absolute value of the current angular acceleration value ω_z' of the rotor 42 is the extremal value judgment threshold or less. The amp unit 300 proceeds to the processing of step S26 if the current angular acceleration value ω_z' of the rotor 42 is the extremal value judgment threshold or less. On the other hand, the amp unit 300 ends the current processing if the current angular acceleration value ω_z' of the rotor 42 becomes larger than the extremal value judgment threshold.

[0110] At step S26, the amp unit 300 judges if the previous angular acceleration value ω_{z-1}' of the rotor 42 is a negative value. The amp unit 300 proceeds to the processing of step S27 if the previous angular acceleration value ω_{z-1}' of the rotor 42 is a negative value. On the other hand, the amp unit 300 proceeds to the processing of step S29 if the previous angular acceleration value ω_{z-1}' of the rotor 42 is a positive value.

[0111] At step S27, the amp unit 300 sets the current angular velocity value ω_z of the rotor 42 set at step S24 as the local minimum angular velocity ωL.

[0112] At step S28, the amp unit 300 sets the flag F2 at "1". The flag F2 is a flag with an initial value set at "0".

[0113] At step S29, the amp unit 300 judges if the flag F2 has been set to "1". The amp unit 300 proceeds to the processing of step S30 if the flag F2 has been set to "1". On the other hand, it ends the current processing if the flag F2 has been set to "0".

[0114] At step S30, the amp unit 300 sets the current angular velocity value ω_z of the rotor 42 set at step S24 as the local maximum angular velocity ωH.

[0115] At step S31, the amp unit 300 enters into the following formula (7) the local minimum angular velocity ωL and local maximum angular velocity ωH set at step S27 and step S30 to calculate the amount of rise ΔKE of the kinetic energy of the rotor 42, that is, the combustion energy generated when burning fuel in a combustion chamber 6 of a cylinder 4 during the current exhaust stroke:

$$\Delta KE=I\times\{(\omega H^2-\omega L^2)/2\} \ldots (7)$$

[0116] At step S32, the amp unit 300 returns the flag F2 to the initial value of "0".

[0117] Next, referring to FIG. 11, the control for estimation of the combustion interval of each cylinder 4 of the engine body 1 performed by the amp unit 300 during the operation of the internal combustion engine 100 will be explained. The amp unit 300 repeatedly performs this routine by a predetermined processing period (=sampling period t_{smp}).

[0118] At step S41, the amp unit 300 judges if the flag F3 has been set to 0. The flag F3 is a flag with an initial value (value at start of operation of the internal combustion engine 100) set to "0". It is set to "1" when the local minimum angular velocity ωL is first set after the start of the operation of the internal combustion engine 100. The flag F3 is returned to "0" at the time of stopping the operation of the internal combustion engine or the time of starting the operation. The amp unit 300 proceeds to the processing of step S42 if the flag F3 is set to "0". On the other hand, the amp unit 300 proceeds to the processing of step S44 if the flag F3 is set to "1".

[0119] At step S42, the amp unit 300 judges if the local minimum angular velocity ωL has first been set from the start of the operation of the internal combustion engine 100. Specifically, the amp unit 300 judges if the local minimum angular velocity ωL has been set after first proceeding to step S27 of the above-mentioned control for estimation of the combustion energy after the start of the operation of the internal combustion engine 100. The amp unit 300 proceeds to the processing of step S43 if the local minimum angular velocity ωL has been set after first proceeding to step S27 of the above-mentioned control for estimation of the combustion energy after the start of the operation of the internal combustion engine 100. On the other hand, the amp unit 300 ends the current processing if it does not proceed to step S27 of the above-mentioned control for estimation of the combustion energy after start of the operation of the internal combustion engine 100 and the local minimum angular velocity ωL is still not set.

[0120] At step S43, the amp unit 300 sets the flag F3 at "1" and starts counting the elapsed time t_{e2} from when the angular velocity of the rotor 42 becomes the local minimum angular velocity.

[0121] At step S44, the amp unit 300 calculates the cumulative value of the previous value of the elapsed time t_{e2} plus the sampling period t_{smp} as the elapsed time t_{e2}. Note that, the initial value of the elapsed time t_{e2} is 0.

[0122] At step S45, the amp unit 300 judges if the local minimum angular velocity ωL has been changed. The amp unit 300 proceeds to the processing of step S46 if the local minimum angular velocity ωL has been changed. On the other hand, the amp unit 300 ends the current processing if the local minimum angular velocity ωL is not updated.

[0123] At step S46, the amp unit 300 calculates the elapsed time t_{e2} calculated at step S44 as the combustion interval Δtcom.

[0124] At step 47, the amp unit 300 returns the elapsed time t_{e2} to the initial value 0 and again starts to count the elapsed time t_{e2} from when the angular velocity of the rotor 42 becomes the local minimum angular velocity.

[0125] The combustion state estimating device 40 according to the present embodiment explained above comprises a rotor 42 housed rotatably inside a housing 41 provided on an exhaust pipe 32 (exhaust path) of the engine body 1 having a cylinder 4, having at least one blade 422, and driven to rotate by the energy of the exhaust discharged from each cylinder 4 of the engine body 1, a passage detection sensor 301 provided at the housing 41 and detecting a predetermined position inside the housing 41 being passed by a blade 422 of the rotor 42, and an amp unit 300 (processing system) configured to calculate an angular velocity of the rotor 42 based on the results of detection of the passage detection sensor 301 and calculate at least one of a combustion energy or combustion interval of a cylinder 4 of the engine body 1 based on the angular velocity of the rotor 42.

[0126] Therefore, according to the present embodiment, it is possible to calculate at least one of a combustion energy or combustion interval of a cylinder 4 of an engine body 1 even without providing an in-cylinder pressure sensor by just providing a combustion state estimating device 40 comprised of a housing 41, rotor 42, passage detection sensor 301, and amp unit 300 in an exhaust pipe 32.

[0127] Further, as the method of estimating the combustion energy of each cylinder 4, for example, there is the method of providing each cylinder 4 with an in-cylinder pressure sensor for detecting a pressure in a combustion chamber 6 and calculating the combustion energy of each cylinder 4 based on the detected value of the in-cylinder pressure sensor. However, in this case, the same number of in-cylinder pressure sensors as the number of cylinders is necessary. For this reason, due to the variation in individual in-cylinder pressure sensors, the precision of estimation of the combustion energy of each cylinder 4 falls. Furthermore, the degree of deterioration along with time of each in-cylinder pressure sensor is liable to differ. This being so, the precision of estimation of the combustion energy of each cylinder 4 falls along with the elapse of time.

[0128] As opposed to this, according to the present embodiment, as explained above, by just providing one combustion state estimating device 40 at the exhaust pipe 32, it is possible to estimate the combustion state of each cylinder such as the combustion energy of each cylinder 4 of the engine body 1 or the combustion interval of each cylinder 4. For this reason, it is possible to suppress a drop in the precision of estimation of the combustion state of each cylinder 4 due to individual variations or aging and precisely estimate the combustion state of each cylinder 4.

[0129] Further, the amp unit 300 according to present embodiment is configured to calculate the elapsed time from when any one blade 422 among the blades 422 passes a predetermined position one time as the reference blade passing time each time that any one blade passes the predetermined position a predetermined number of times and to calculate the angular velocity of the rotor 42 based on the reference blade passing time and the number of times any one blade 422 passes a predetermined position during the reference blade passing time.

[0130] For this reason, it is possible to precisely calculate the angular velocity of the rotor 42 without being affected by shape error of the blades 422 or aging. Therefore, it is possible to more precisely calculate the combustion energy of each cylinder 4 or the combustion interval of each cylinder 4 of the engine body 1 calculated based on the angular velocity of the rotor 42.

[0131] Further, the amp unit 300 according to present embodiment is configured to calculate the differential value of the angular velocity, that is, the angular acceleration, based on the angular velocity of the rotor 42 and to calculate the combustion energy of the cylinder 4 during the exhaust stroke based on the angular velocity of the

rotor 42 when the absolute value of the angular acceleration becomes a predetermined extremal value judgment threshold or less. More specifically, the amp unit 300 according to present embodiment is configured to set the angular velocity of the rotor 42 when the absolute value of the angular acceleration becomes the predetermined extremal value judgment threshold or less as the local minimum angular velocity if the previous value of the angular acceleration is a negative value, to set the angular velocity of the rotor 42 when the absolute value of the angular acceleration becomes the predetermined extremal value judgment threshold or less as the local maximum angular velocity if the previous value of the angular acceleration is a positive value, and to calculate the combustion energy of the cylinder 4 during the exhaust stroke based on the local minimum angular velocity and the local maximum angular velocity.

[0132] Due to this, according to the present embodiment, it is possible to precisely calculate the combustion energy of each cylinder 4 from the angular velocity of the rotor 42 calculated by the amp unit 300.

[0133] Further, the amp unit 300 according to present embodiment is configured to calculate the combustion interval of each cylinder 4 based on the time period from when the local minimum angular velocity is set to when the local minimum angular velocity is updated.

[0134] Due to this, according to the present embodiment, it is possible to precisely calculate the combustion interval of each cylinder 4 from the angular velocity of the rotor 42 calculated by the amp unit 300.

[0135] Above, embodiments of the present invention were explained, but the above embodiments only shown some of the examples of application of the present invention and are not intended to limit the technical scope of the present invention to the specific constitutions of the embodiments.

[0136] Note that, in the above embodiments, the housing 41 of the combustion state estimating device 40 was provided at the upstream side in the direction of flow of exhaust compared with the exhaust post treatment device 33, but it may also be provided at the downstream side.

[0137] Further, in the above embodiments, the internal combustion engine 100 was not provided with a forced induction system (supercharger or turbocharger), but an internal combustion engine provided with a forced induction system may also be provided with the combustion state estimating device 40 and the combustion state of each cylinder of the internal combustion engine may be estimated.

REFERENCE SIGNS LIST

[0138]

100. internal combustion engine
1. engine body
41. housing
42. rotor
422. blade
300. amp unit (processing system)
301. passage detection sensor

Claims

1. A combustion state estimating device comprising:

a rotor rotatably housed inside a housing provided on an exhaust path of an engine body having a cylinder, having at least one blade, and driven to rotate by energy of exhaust discharged from the cylinder of the engine body,
a passage detection sensor provided in the housing and detecting a predetermined position inside the housing being passed by a blade of the rotor, and
a processing system configured to calculate an angular velocity of the rotor based on the results of detection of the passage detection sensor and to calculate at least one of the combustion energy or combustion interval of the cylinder of the engine body based on the angular velocity of the rotor.

2. The combustion state estimating device according to claim 1, wherein

the processing system is configured to:

calculate a differential value of the angular velocity of angular acceleration based on the angular velocity of the rotor and
calculate the combustion energy of the cylinder during the exhaust stroke based on the angular velocity of the rotor when the absolute value of the angular acceleration becomes a predetermined extremal value judgment threshold or less.

3. The combustion state estimating device according to claim 2, wherein

the processing system is configured to:

set the angular velocity of the rotor when an absolute value of the angular acceleration becomes a predetermined extremal value judgment threshold or less as a local minimum angular velocity if the previous value of the angular acceleration is a negative value,
set the angular velocity of the rotor when an absolute value of the angular acceleration becomes a predetermined extremal value judgment threshold or less as a local max-

imum angular velocity if the previous value of the angular acceleration is a positive value, and

calculate a combustion energy of the cylinder during the exhaust stroke based on the local minimum angular velocity and the local maximum angular velocity.

4. The combustion state estimating device according to claim 3, wherein

the processing system is configured to calculate the combustion interval of the cylinder based on the time period from when the local minimum angular velocity is set to when the local minimum angular velocity is updated.

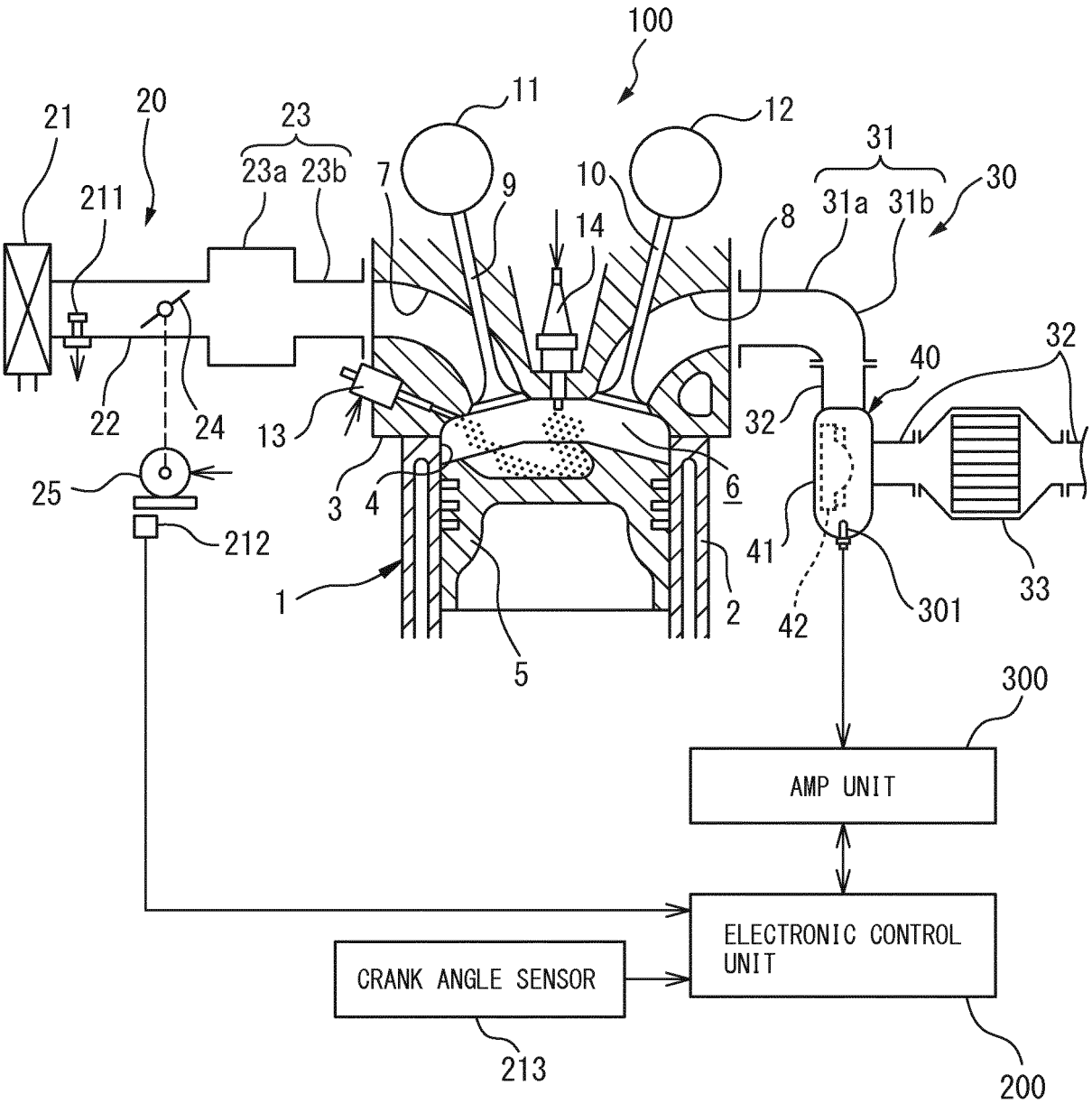
5. The combustion state estimating device according to any one of claim 1 to claim 4, wherein

the processing system is configured to:

calculate an elapsed time from when any one blade among the blades passes a predetermined position once as a reference blade passing time each time the any one blade passes the predetermined position a predetermined number of times and

calculate the angular velocity of the rotor based on the reference blade passing time and the number of times the any one blade passes the predetermined position during the reference blade passing time.

FIG. 1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2
5
300
AMP UNIT
ELECTRONIC CONTROL UNIT
CRANK ANGLE SENSOR
213
200

FIG. 2A

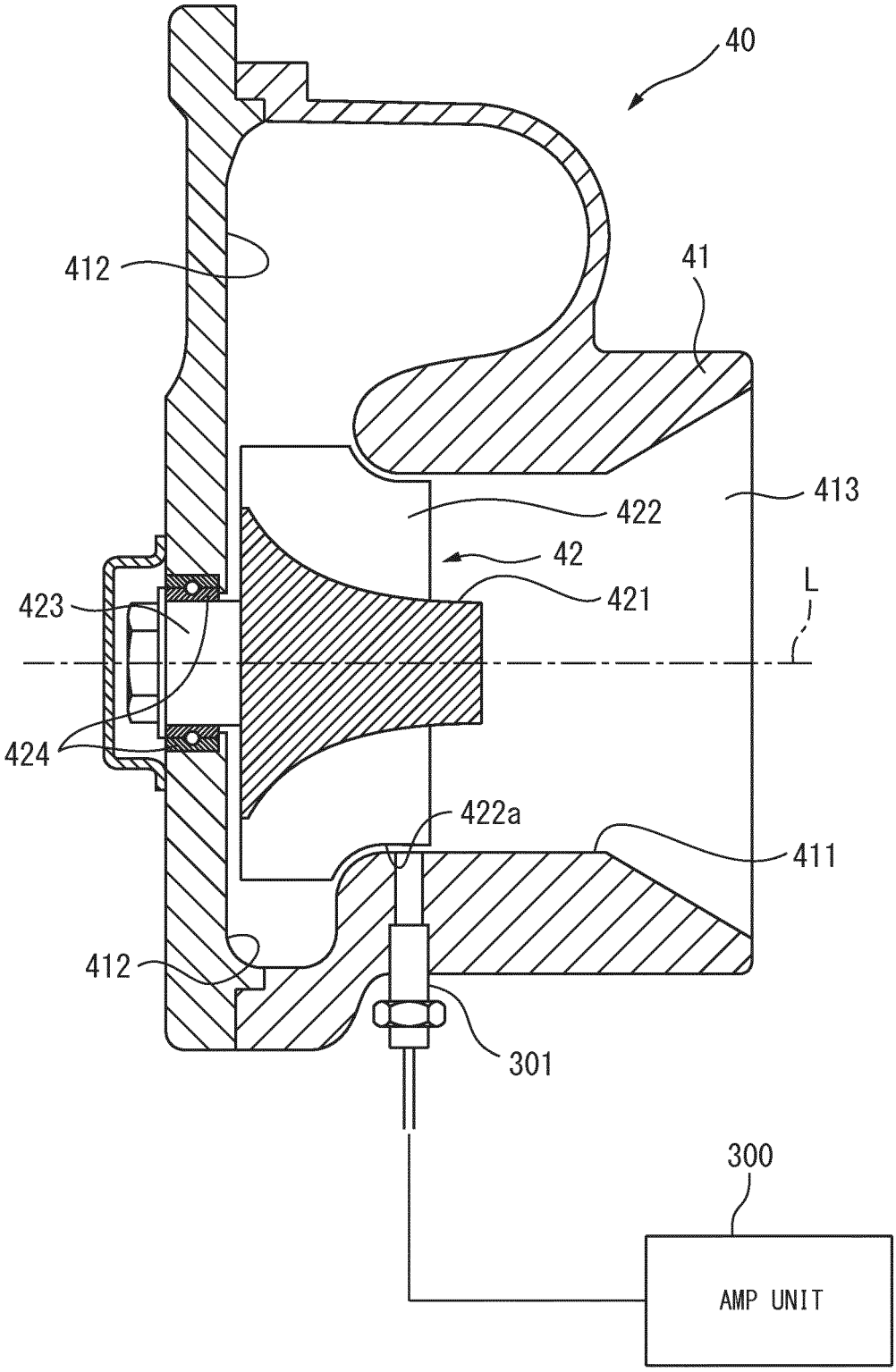


FIG. 2B

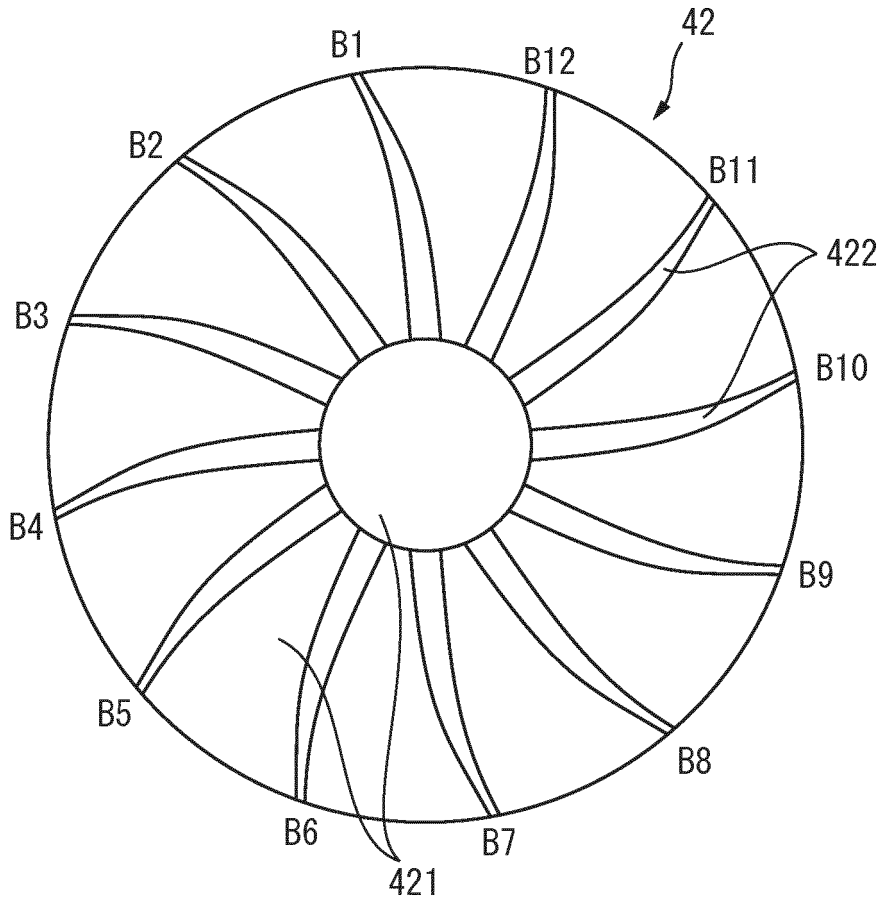


FIG. 3

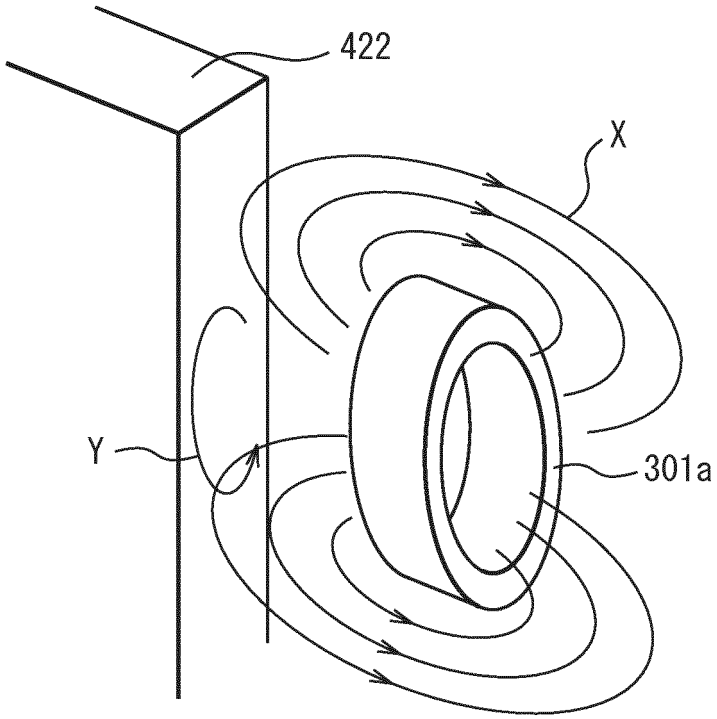


FIG. 4A

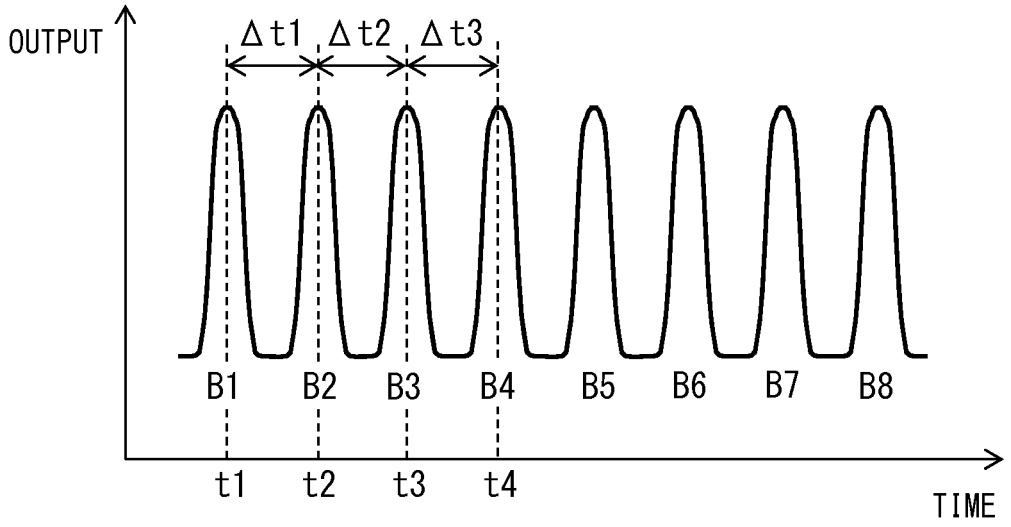

OUTPUT
Δt1
Δt2
Δt3
B1
B2
B3
B4
B5
B6
B7
B8
t1
t2
t3
t4
TIME

FIG. 4B

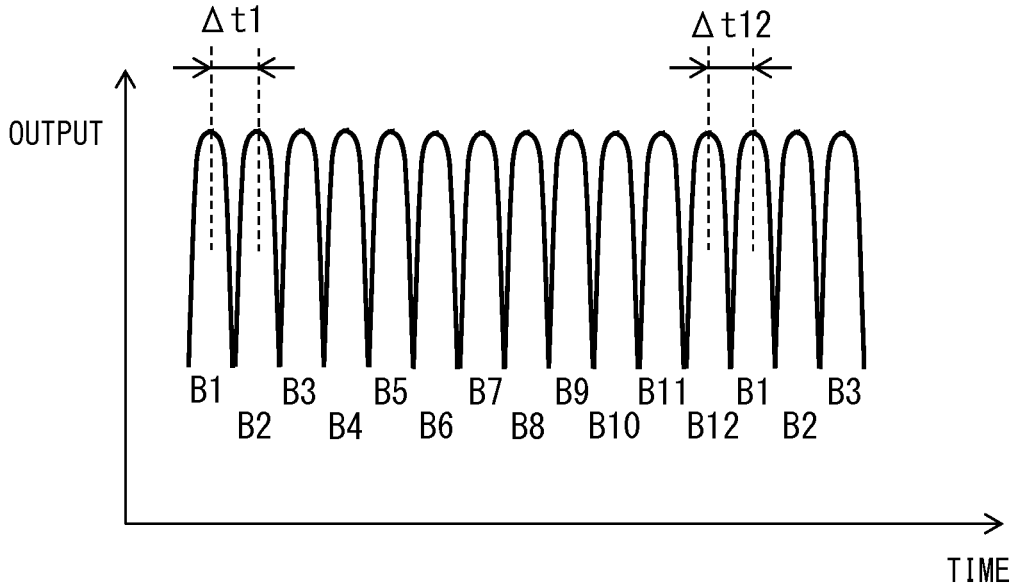

Δt1
Δt12
OUTPUT
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B1
B2
B3
TIME

FIG. 5

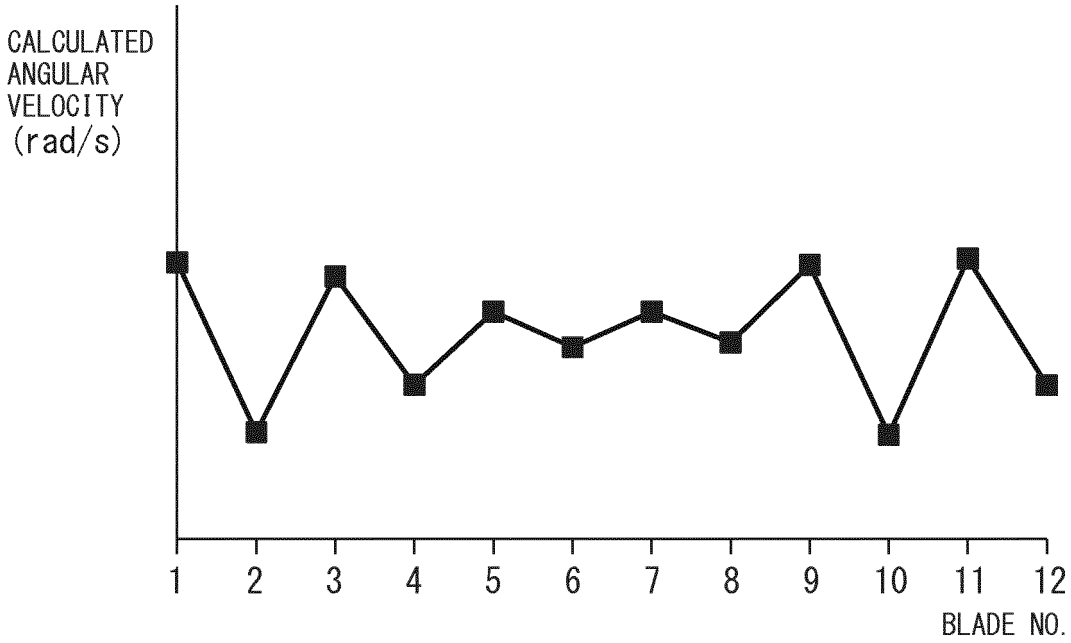

CALCULATED
ANGULAR
VELOCITY
(rad/s)
1
2
3
4
5
6
7
8
9
10
11
12
BLADE NO.

FIG. 6

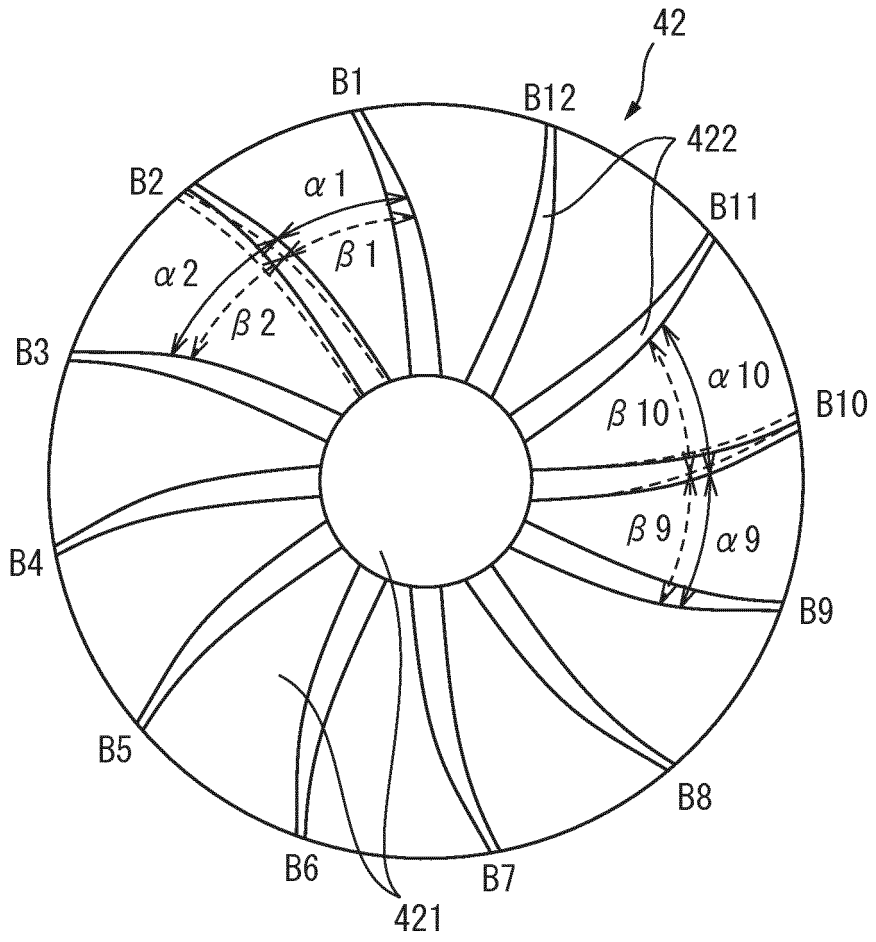

42
B1
B12
422
B2
α1
B11
β1
α2
β2
B3
α10
β10
B10
β9
α9
B4
B9
B5
B8
B6
B7
421

FIG. 7

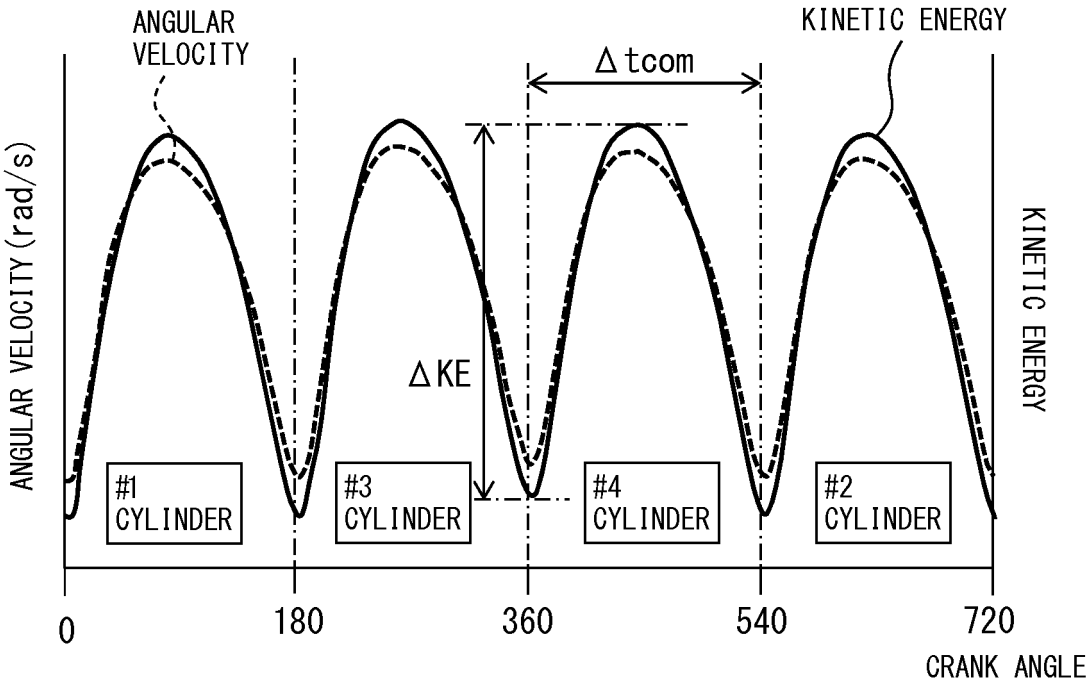

ANGULAR VELOCITY
KINETIC ENERGY
Δtcom
ΔKE
ANGULAR VELOCITY (rad/s)
KINETIC ENERGY
#1 CYLINDER
#3 CYLINDER
#4 CYLINDER
#2 CYLINDER
0
180
360
540
720
CRANK ANGLE

FIG. 8

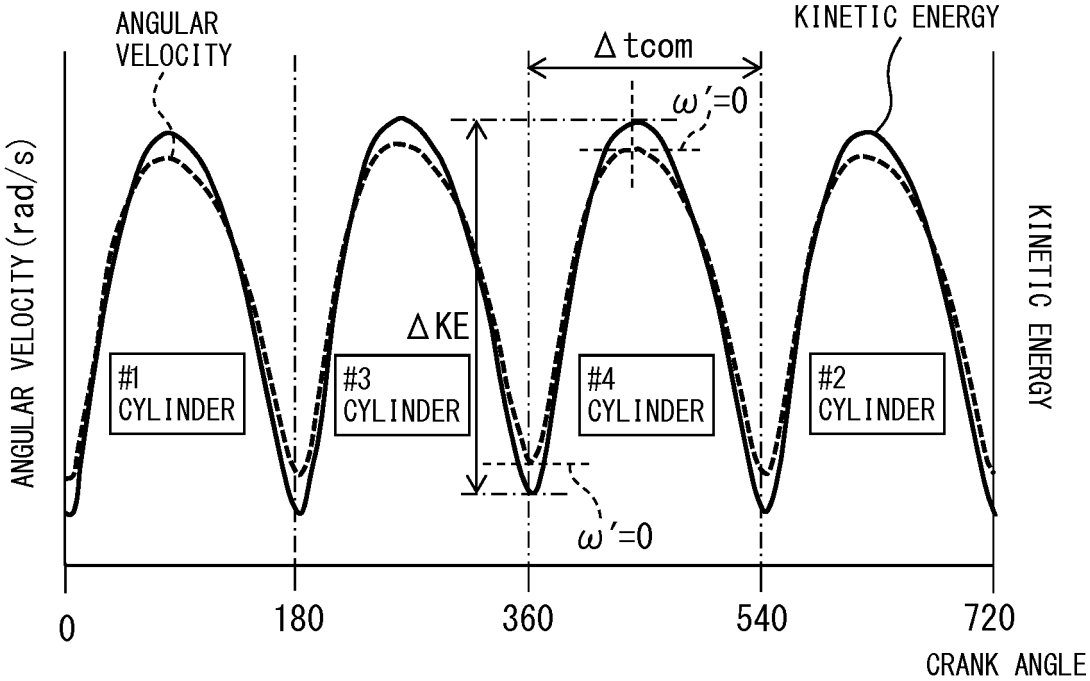

ANGULAR VELOCITY
KINETIC ENERGY
Δtcom
ω'=0
ΔKE
ω'=0
ANGULAR VELOCITY (rad/s)
KINETIC ENERGY
#1 CYLINDER
#3 CYLINDER
#4 CYLINDER
#2 CYLINDER
0
180
360
540
720
CRANK ANGLE

FIG. 9

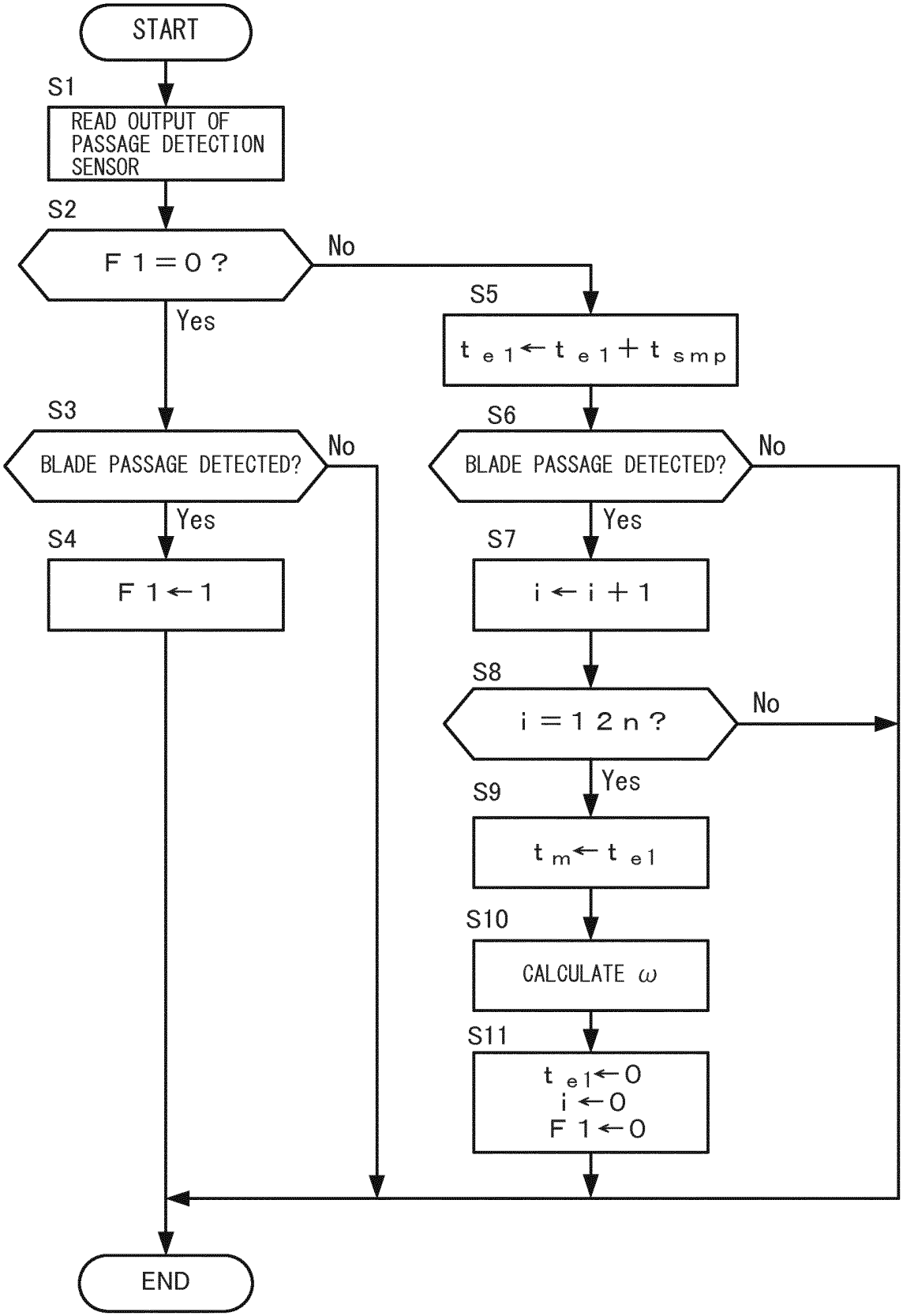

START
S1
READ OUTPUT OF PASSAGE DETECTION SENSOR
S2
F 1 = 0 ?
No
Yes
S3
BLADE PASSAGE DETECTED?
No
Yes
S4
F 1 ← 1
S5
t e 1 ← t e 1 + t smp
S6
BLADE PASSAGE DETECTED?
No
Yes
S7
i ← i + 1
S8
i = 1 2 n ?
No
Yes
S9
t m ← t e 1
S10
CALCULATE ω
S11
t e 1 ← 0
i ← 0
F 1 ← 0
END

FIG. 10

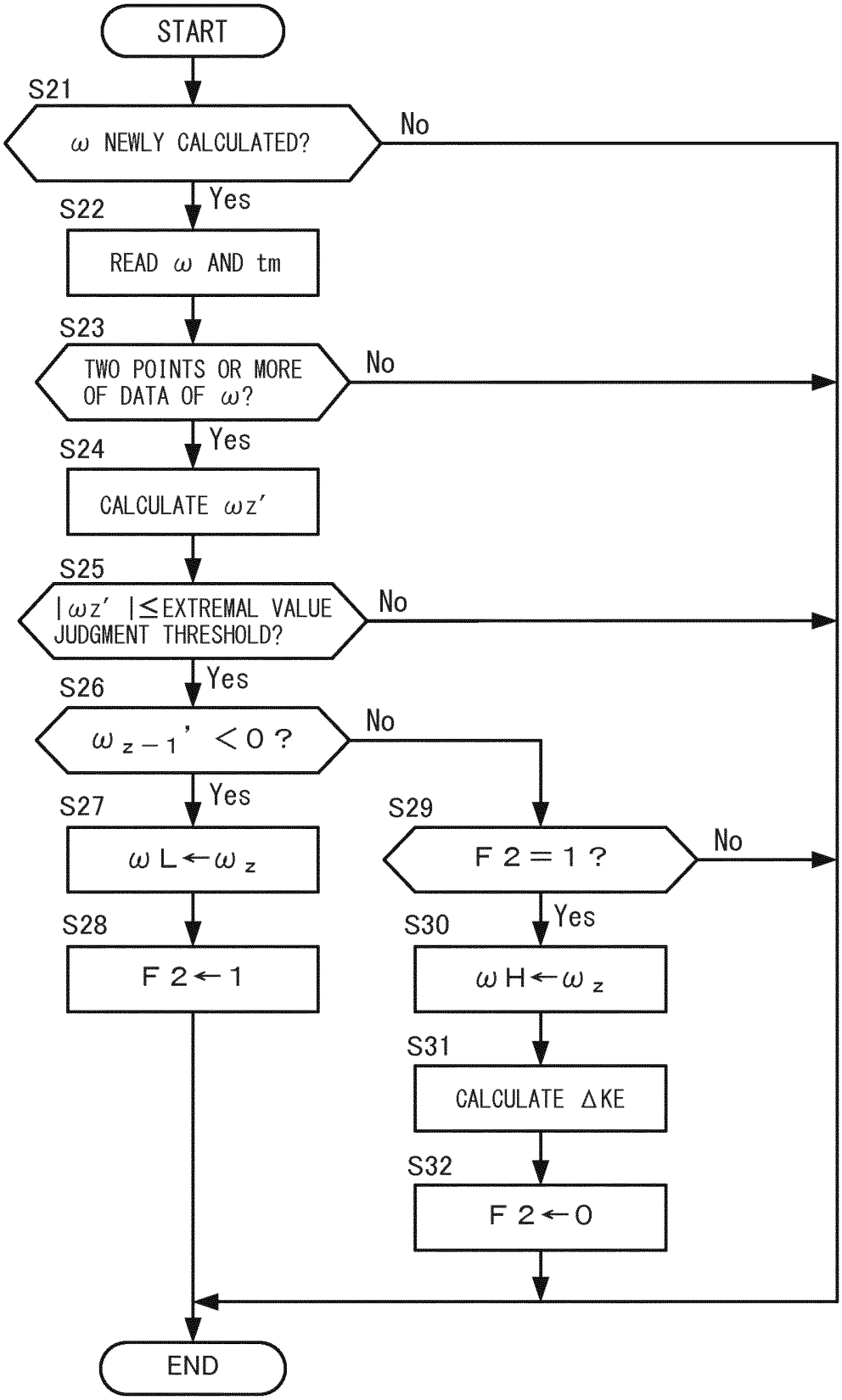
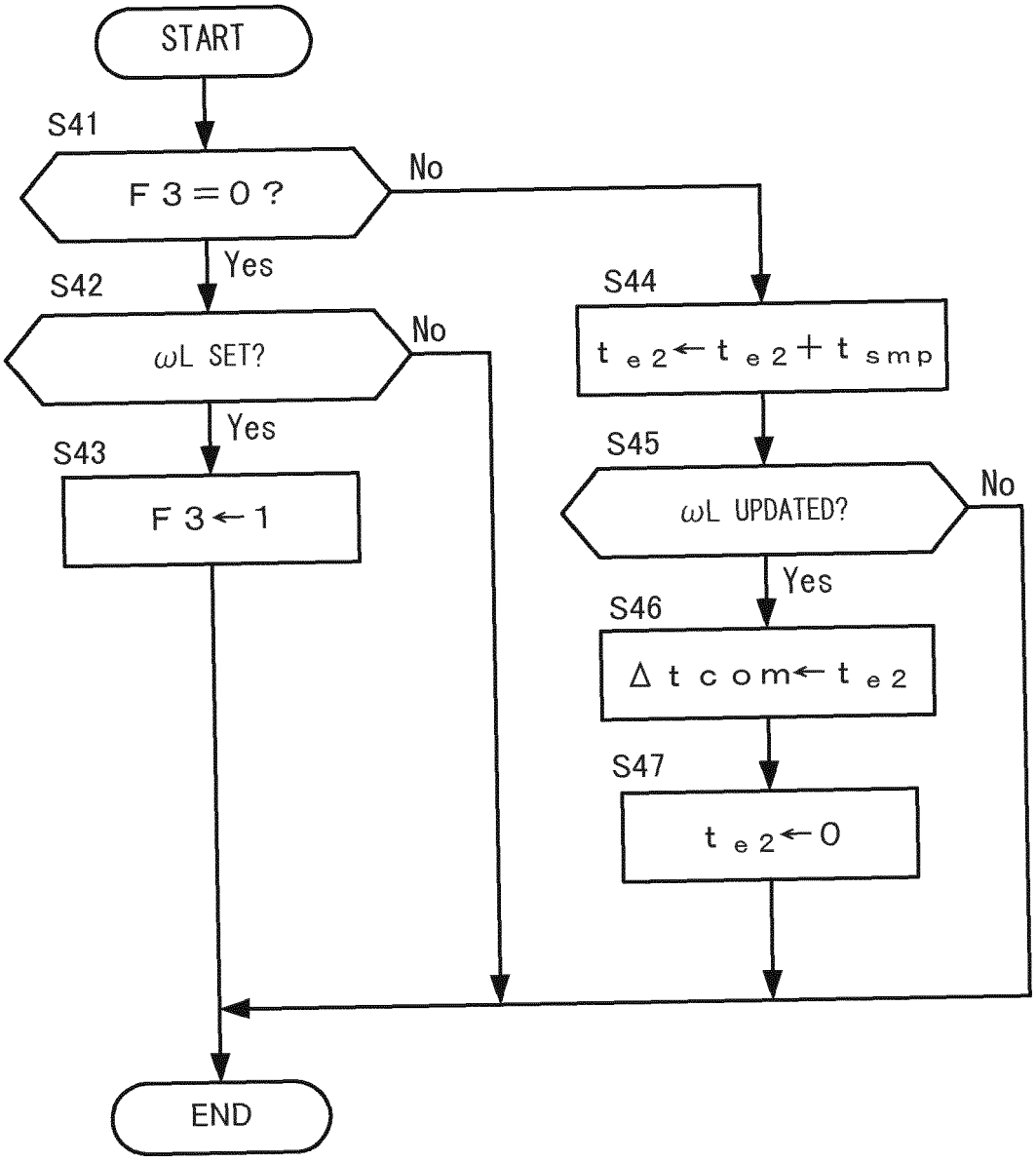

START
S21
ω NEWLY CALCULATED?
No
Yes
S22
READ ω AND tm
S23
TWO POINTS OR MORE OF DATA OF ω?
No
Yes
S24
CALCULATE ωz'
S25
|ωz'|≤EXTREMAL VALUE JUDGMENT THRESHOLD?
No
Yes
S26
ωz-1' < 0 ?
No
Yes
S27
ωL←ωz
S28
F2←1
S29
F2=1?
No
Yes
S30
ωH←ωz
S31
CALCULATE ΔKE
S32
F2←0
END

FIG. 11


START
S41
F 3 = 0 ?
No
Yes
S42
ωL SET?
No
Yes
S43
F 3 ← 1
S44
t e 2 ← t e 2 + t smp
S45
ωL UPDATED?
No
Yes
S46
Δ t com ← t e 2
S47
t e 2 ← 0
END

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/085256

A. CLASSIFICATION OF SUBJECT MATTER
F02D45/00(2006.01)i, *F02D23/00*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02D45/00, F02D23/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2015-197074 A (Toyota Motor Corp.), 09 November 2015 (09.11.2015), paragraphs [0011] to [0029]; fig. 1 to 6 (Family: none)	1-3,5 4
Y	JP 2008-14656 A (Denso Corp.), 24 January 2008 (24.01.2008), paragraph [0020] (Family: none)	1-3,5
Y	JP 2002-98584 A (Mitsubishi Heavy Industries, Ltd.), 05 April 2002 (05.04.2002), paragraph [0028] (Family: none)	5

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 February 2016 (08.02.16)	16 February 2016 (16.02.16)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/085256

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-132423 A (Toyota Motor Corp.), 12 July 2012 (12.07.2012), paragraphs [0018] to [0044]; fig. 1 to 4 (Family: none)	1-5

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2013068130 A **[0002]**