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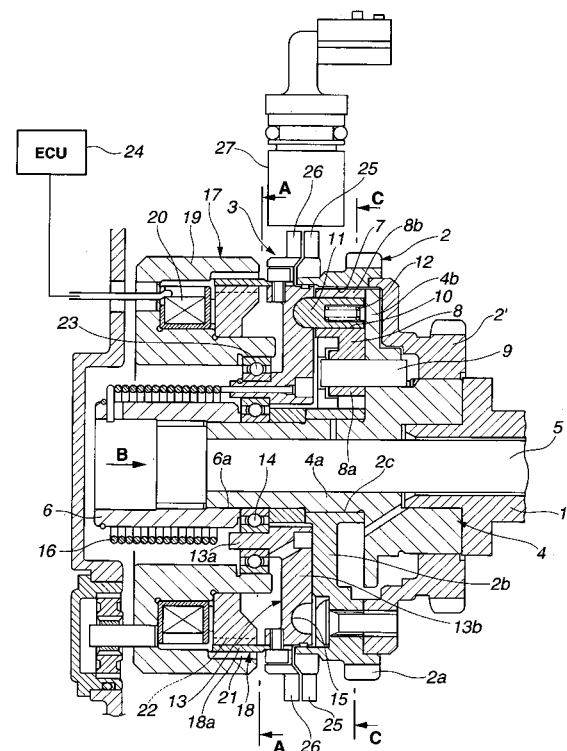
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(54) **Phase angle detection apparatus and variable valve timing control apparatus using the phase angle detection apparatus for internal combustion engine**

(57) A phase angle detection apparatus includes an intermediate rotary member changing an operating angle of a driven member that is driven by a driving member, a detection unit detecting a rotational angle of the intermediate rotary member, which corresponds to the operating angle of the driven member, and outputting the rotational angle as a detection pulse signal, a controller receiving the detection pulse signal and calculating a pulse rising time difference between the detection pulse signal and a pre-set reference pulse signal. The controller detects, based on the pulse rising time difference, a pre-determined middle angle position of the driven member from all the operating angles of the driven member.

FIG.1



Description**BACKGROUND OF THE INVENTION**

5 **[0001]** The present invention relates to a phase angle detection apparatus that detects a rotational phase difference between at least two rotary members, and more particularly to a phase angle detection apparatus which is used for a variable valve timing control apparatus of an internal combustion engine, which variably controls open/close timing of an intake-side or exhaust-side valve of the internal combustion engine according to an engine operating condition.

10 **[0002]** In recent years, there have been proposed and developed various variable valve timing control apparatuses. One such variable valve timing control apparatus has been disclosed in Japanese Patent Provisional Publication No. 2005-180307 (hereinafter is referred to as "JP2005-180307") corresponding to US7143730 (B2).

15 **[0003]** The variable valve timing control apparatus disclosed in JP2005-180307 includes a timing sprocket to which a torque (turning force) is transferred from a crankshaft of an engine, a camshaft relatively rotatably supported within a predetermined angular range with respect to the timing sprocket, a sleeve fixedly connected to the camshaft, and a rotational phase control mechanism (or a relative angular phase control or shift mechanism) provided between the timing sprocket and the sleeve so as to control or shift a rotational phase of the camshaft relative to the timing sprocket in accordance with an engine operation condition.

20 **[0004]** The rotational phase control mechanism includes a radial direction guide window formed in the timing sprocket, a spiral guide (a spiral guide groove) formed on a surface of a spiral guide disk, a link member having two end portions: a base end portion pivotally provided and a top end portion slidably supported in the radial direction guide window so that the top end portion can slide in a radial direction along the radial direction guide window, an engagement portion which is provided at the top end portion of the link member and whose top end (a spherical portion or a semi-spherical protrusion) is engaged with the spiral guide, and a hysteresis brake applying a braking force to the spiral guide disk according to the engine operating condition.

25 **[0005]** When energizing an electromagnetic coil of the hysteresis brake, an electromagnetic brake acts on the spiral guide disk via a hysteresis member. By this braking action, the engagement portion (the top end portion) of the link member moves or slides in the radial direction along the radial direction guide window while being guided by the spiral guide. The sleeve (also the camshaft) can therefore be rotated relative to the timing sprocket within the predetermined angular range. With this, the open/close timing of the intake valve is variably controlled in accordance with the engine operating condition.

SUMMARY OF THE INVENTION

35 **[0006]** In the variable valve timing control apparatus in JP2005-180307, regarding a way of detecting the relative rotational angle or phase between the timing sprocket and the camshaft, cam angle information from a cam angle sensor that detects a cam rotational angle of the camshaft and crank angle information from a crank angle sensor that detects a rotational angle of the crankshaft are input into a controller, the controller, then, calculates the above two input information and obtains the phase difference of the cam rotational angle of the camshaft with respect to the crank rotational angle of the crankshaft.

40 **[0007]** Further, in the electromagnetic brake type variable valve timing control apparatus, the spiral guide disk is normally controlled to be rotated to a most-retarded rotational angle side by way of a spring force in an engine stop state. And after an engine start-up, the spiral guide disk is controlled to be rotated to an advanced rotational angle side by way of the application of the electromagnetic brake with increase in an engine rpm.

45 **[0008]** However, in order to improve the engine startability at the engine start-up, a curvature of the spiral guide of the spiral guide disk is changed around the most-retarded rotational angle side. That is, an outer end side of the spiral guide is slightly bent or curved inwardly so that the rotational phase of the camshaft becomes a slightly advanced phase with respect to the rotational phase of the crankshaft at the engine start-up. Therefore, the outer end side of the spiral guide is formed so that the rotational phase of the camshaft shifts from the slightly advanced phase to the most-retarded phase by the electromagnetic brake application after the engine start-up. Furthermore, the rest of the spiral guide is formed so that the rotational phase of the camshaft shifts to a most-advanced phase from the most-retarded phase by further application of the same electromagnetic brake.

50 **[0009]** In this case where the curvature of the outer end side of the spiral guide is changed around the most-retarded rotational angle side, when the electromagnetic brake is applied from the engine start-up, since both a retardation control and an advancement control are continuously carried out, it is difficult to detect the relative rotational phase difference by the cam angle sensor and the crank angle sensor. That is to say, since the rotational phase of the camshaft shifts to different directions, i.e. in the retarded phase direction and the advanced phase direction, by way of the same electromagnetic brake application by the energization, it is difficult to precisely execute the phase-control by only the cam angle and crank angle sensors.

[0010] In other words, in the case where the phase-control is executed by only the respective information detected by the cam angle and crank angle sensors, the accuracy of the controlled variable for the electromagnetic brake type variable valve timing control apparatus is not sufficient, thus the valve timing control can not be executed precisely.

[0011] It is therefore an object of the present invention to provide a phase angle detection apparatus which is capable of detecting the rotational phase difference between at least two rotary members with high precision.

[0012] According to one aspect of the present invention, a phase angle detection apparatus comprises: an intermediate rotary member changing an operating angle of a driven member that is driven by a driving member; a detection unit detecting a rotational angle of the intermediate rotary member, which corresponds to the operating angle of the driven member, and outputting the rotational angle as a detection pulse signal; a controller receiving the detection pulse signal and calculating a pulse rising time difference between the detection pulse signal and a pre-set reference pulse signal, and the controller detects, based on the pulse rising time difference, a predetermined middle angle position of the driven member from all the operating angles of the driven member.

[0013] According to another aspect of the present invention, a phase angle detection apparatus comprises: a drive rotary member rotated by an engine crankshaft in synchronization with the engine crankshaft; a driven rotary member connected with a camshaft having a cam that opens/closes an engine valve, and driven by the drive rotary member; a phase-change mechanism having an intermediate rotary member and relatively changing a rotational phase angle of the driven rotary member with respect to the drive rotary member by changing a rotational angle of the intermediate rotary member; a detection unit detecting the rotational angle of the intermediate rotary member and outputting the rotational angle as a detection pulse signal; a controller calculating a pulse rising time difference between the detection pulse signal and a reference pulse signal corresponding to the rotational angle of the drive rotary member, and the controller detects, based on the pulse rising time difference, a predetermined middle angle position of the driven rotary member from all the rotational phase angles of the driven rotary member.

[0014] According to a further aspect of the invention, a variable valve timing control apparatus of an internal combustion engine, which controls an open/close timing of an engine valve in accordance with an engine operating condition, comprises: a drive rotary member that is rotated by an engine crankshaft in synchronization with the engine crankshaft; a driven rotary member that is connected with a camshaft provided with a cam for opening/closing the engine valve, and is driven by the drive rotary member; a phase-change mechanism that has an intermediate rotary member relatively shifting a rotational phase angle of the driven rotary member with respect to the drive rotary member, and changes a rotational phase angle of the cam by controlling a rotational angle of the intermediate rotary member; a detection system that detects the rotational angles of the intermediate rotary member and the drive rotary member; a controller that calculates a rotational phase difference between the intermediate rotary member and the drive rotary member; and the controller detects, based on the rotational phase difference, a middle angle position of the driven rotary member from all the rotational phase angles of the driven rotary member, which corresponds to a middle point between retarded and advanced direction control areas of the engine valve open/close timing.

[0015] The other objects and features of this invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a longitudinal cross section of a variable valve timing control apparatus of an internal combustion engine, to which a phase angle detection apparatus according to the present invention is applied.

[0017] FIG. 2 is a perspective exploded view of the variable valve timing control apparatus, when viewed from a direction of the rear side.

[0018] FIG. 3 is a perspective exploded view of the variable valve timing control apparatus, when viewed from a direction of the front side.

[0019] FIG. 4 is a sectional view of the variable valve timing control apparatus, when taken along a line A-A of FIG. 1.

[0020] FIG. 5 is a drawing showing first and second target protrusions, when viewed from an arrow B of FIG. 1.

[0021] FIG. 6 is a schematic view showing a location relationship between the first and second target protrusions and a spiral guide groove that guides an engaging pin.

[0022] FIG. 7 is a sectional view of the variable valve timing control apparatus, when taken along a line A-A of FIG. 1.

[0023] FIG. 8 is a sectional view of the variable valve timing control apparatus, when taken along a line C-C of FIG. 1, under the condition that the rotational phase between drive and driven rotary members is shifted to a most-retarded phase position.

[0024] FIG. 9 is a sectional view of the variable valve timing control apparatus, when taken along a line C-C of FIG. 1, under the condition that the rotational phase between drive and driven rotary members is shifted to a most-advanced phase position.

[0025] FIG. 10 is a graph showing a relationship between a rotational angle of a spiral guide disk and a position of the spiral guide groove from a center of the spiral guide disk and a cam phase.

[0026] FIGS. 11A, 11B and 11C show pulse signals of the first and second target protrusions at an engine start-up (FIG. 11A), at the most-retarded phase position (FIG. 11B), at the most-advanced phase position (FIG. 11C).
[0027] FIG. 12 is a flow chart showing a way of a phase detection by a controller according to the present invention.
[0028] FIG. 13 is a control flow chart by the controller.

DETAILED DESCRIPTION OF THE INVENTION

[0029] Embodiments of a phase angle detection apparatus applied to a variable valve timing control apparatus of an internal combustion engine will be explained below with reference to the drawings. In the following description, the terms "front" and "rear" are used for purposes of locating one element relative to another and are not to be construed as limiting terms. And in Figs. 2 and 3, "front side" is a side of a torsion spring 16 (described later), and "rear side" is a side of a cam 1a (also described later). Further, although each embodiment below is applied to control of open/close timing of an intake valve for the internal combustion engine, it can also be applied to control of open/close timing of an exhaust valve.

[0030] Firstly, the variable valve timing control apparatus using the phase angle detection apparatus will be explained with reference to Figs. 1 to 9. The variable valve timing control apparatus includes a camshaft 1 rotatably supported on a cylinder head (not shown) of the engine, a timing sprocket 2 (as a drive rotary member or driving member) rotatably disposed at front side of the camshaft 1, and a relative angular phase control mechanism (simply, a phase converter or a phase-change mechanism) 3 disposed inside the timing sprocket 2 so as to change or control a relative rotational phase (or simply, a relative phase) between the camshaft 1 and timing sprocket 2.

[0031] The camshaft 1 has two cams 1a, 1a for each cylinder, which are disposed on an outer peripheral surface of the camshaft 1 to actuate respective intake valves, a driven rotary member (driven shaft member, or driven member) 4 connected with a front end of the camshaft 1 by a cam bolt 5 so that the driven rotary member 4 and the camshaft 1 are coaxially aligned with each other, and a sleeve 6 which screws on and is fixed to a front end portion of the driven rotary member 4.

[0032] The driven rotary member 4 has a cylindrical-shaped shaft portion 4a and a large-diameter stepped flange portion 4b. The shaft portion 4a is provided with a hole for receiving therethrough the cam bolt 5. And further, the shaft portion 4a is formed with a male screw thread on an outer peripheral surface thereof at a front end portion thereof in order for the sleeve 6 to screw on. The flange portion 4b is integrally formed with the shaft portion 4a at a rear end portion of the shaft portion 4a (in a position axially corresponding to the front end of the camshaft 1).

[0033] The sleeve 6 is formed with a female screw thread 6a on an inner peripheral surface thereof at a rear end portion thereof in order for the shaft portion 4a to be screwed in. Moreover, the sleeve 6 is caulked by an annular caulker so as to prevent the sleeve 6 turning after the sleeve 6 screws onto the shaft portion 4a fully and tightly and is fixed to the shaft portion 4a.

[0034] Regarding the timing sprocket 2, a plurality of sprocket teeth 2a are integrally formed with an outer circumference of the timing sprocket 2 in the circumferential direction. And then, the timing sprocket 2 with this ring-shaped sprocket teeth 2a is linked to an engine crankshaft (not shown) and turns via a timing chain (not shown). Further, the timing sprocket 2 has a plate member 2b, which is substantially disciform in shape, inside the sprocket teeth 2a. The plate member 2b is provided with a hole 2c at a center thereof for receiving therethrough the shaft portion 4a of the driven rotary member 4. The plate member 2b (the timing sprocket 2) is therefore rotatably supported by the outer peripheral surface of the shaft portion 4a of the driven rotary member 4. In a rear end (an end at the side of the camshaft 1) of the timing sprocket 2, a second sprocket 2' (not shown) for drive an auxiliary equipment is linked with the timing sprocket 2 with a bolt.

[0035] In addition, the plate member 2b is provided with two radial direction guide windows 7, 7 (as a radial guide) formed by parallel-opposed side walls respectively. More specifically, each of the radial direction guide windows 7, 7 is formed through the plate member 2b (that is, the radial direction guide windows 7, 7 penetrate the plate member 2b) such that each of the radial direction guide windows 7, 7 is arranged in a direction of a diameter of the timing sprocket 2. Further, two guide holes 2d, 2d are provided in the plate member 2b between the radial direction guide windows 7, 7 respectively (the two guide holes 2d, 2d also penetrate the plate member 2b). These radial direction guide window 7 and guide hole 2d are provided for receiving therethrough a top end portion 8b (described later) and a base end portion 8a (also described later) of a link member 8 (a follower portion, also described later), and therefore the top end portion 8b and the base end portion 8a can move or slide along the radial direction guide window 7 and the guide hole 2d respectively.

[0036] Each of the guide holes 2d, 2d is formed into arc-shape along a circumferential direction radially outside the hole 2c. And, a length in the circumferential direction of the guide hole 2d is set or dimensioned to a length corresponding to a movable range of the base end portion 8a (in other words, the length of the guide hole 2d is set to a length corresponding to a phase-shift range of relative rotational phase between the camshaft 1 and timing sprocket 2).

[0037] Each of the two link members 8, 8 (as a movable member) is formed into arc-shape, and has the above two end portions: the base end portion 8a and the top end portion 8b, at a front side of the flange portion 4b of the driven

rotary member 4. The base end portion 8a and top end portion 8b are both formed into cylindrical-shape, and protrude toward the plate member 2b respectively. On the other hand, at a rear side of the flange portion 4b (at the side of camshaft 1), two lever protrusions 4p, 4p, which radially protrude, are formed. And further, a hole 4h is provided at each of the lever protrusion 4p through the lever protrusion 4p and the flange portion 4b. The base end portion 8a is, then, supported and rotatably or pivotally fixed to the driven rotary member 4 by pin 9. And, one end portion of pin 9 is press-fitted in the above hole 4h.

[0038] As mentioned above, the top end portion 8b of the link member 8 is slidably engaged in the radial direction guide window 7. The top end portion 8b is formed with a retaining hole 10 opening toward the front direction. And further, in this retaining hole 10, an engaging pin 11 (as an engaged portion) having a spherical-shaped end at front end thereof and a coil spring 12 biasing the engaging pin 11 toward the front direction (toward a spiral guide groove or spiral groove 15 (described later)) through the radial direction guide window 7, are provided. Spherical-shaped end of the engaging pin 11 is slidably engaged in the spiral guide groove 15 (described later) of a spiral guide disk 13 (or spiral disk, also described later), and therefore the top end portion 8b moves or slides radially in and along the radial direction guide window 7 while being guided along the spiral guide groove 15.

[0039] More specifically, the top end portion 8b is slidably engaged with the radial direction guide window 7, and the base end portion 8a is rotatably fixed to the driven rotary member 4 by the pin 9. With this setting or configuration, when the top end portion 8b moves or slides radially in and along the radial direction guide window 7 by an external force which results from the engaging pin 11 guided by the spiral guide groove 15, the base end portion 8a moves or slides in and along the guide hole 2d. The driven rotary member 4 consequently rotates relative to the timing sprocket 2 in a circumferential direction corresponding to a radial movement direction of the top end portion 8b by a certain degree corresponding to a displacement of the top end portion 8b. (That is, an operating angle of the driven rotary member 4 is shifted by the rotation of the spiral guide disk 13)

[0040] As for the spiral guide disk 13 facing to a front side of the plate member 2b, as illustrated in Fig. 1, the spiral guide disk 13 includes a cylindrical portion 13a having a ball bearing 14 and a disk portion 13b integrally formed with the cylindrical portion 13a at rear end of the cylindrical portion 13a. The spiral guide disk 13 is, then, rotatably supported on the shaft portion 4a of the driven rotary member 4 by means of the ball bearing 14. Each of the two spiral guide grooves 15, 15 is formed on a rear surface of the spiral guide disk 13 (that is, at the side of the camshaft 1). The spiral guide groove 15 serving as a spiral guide is semi-circular in cross section. The spherical-shaped end 11a of the engaging pin 11 of the link member 8 is slidably engaged with the spiral guide groove 15, and thereby being guided along the spiral guide groove 15.

[0041] The spiral guide disk 13 is formed by way of high density sintered process (high density sintered process : after pressure forming of powder metal molded into an intermediate rotary member and preliminary sintering (preliminary sintering process), the preliminarily sintered compact of intermediate rotary member is pressurized at high pressure (repressing process)). Accordingly, the spiral guide groove 15 is also formed simultaneously when forming sintered alloy or sintered metal of the spiral guide disk 13 by the high density sintered process, and then the intermediate rotary member is formed.

[0042] As can be seen from Figs. 6, 8 and 9, each of the spiral guide grooves 15, 15 is arranged separately from each other. And further, each spiral guide groove 15 is formed such that its spiral radius gradually reduces along a direction of rotation of the timing sprocket 2. More specifically, an outermost groove section 15a (that is, a section from an inflexion point 15c up to the top end) located at the outermost portion of the spiral guide groove 15 is formed to be bent inwardly at the inflexion point 15c at a given angle. Furthermore, the outermost groove section 15a is slightly inwardly bent further by a small angle around a central portion of longitudinal length of the outermost groove section 15a.

[0043] That is to say, the spiral guide groove 15 has two sections: the outermost groove section 15a and a normal section 15b except outermost groove section 15a. A rate of change of spiral (rate of change of rotational phase) of the normal section 15b (or a convergence rate of the normal section 15b) is constant. In other words, the spiral radius of the normal section 15b gradually reduces along the direction of rotation of the timing sprocket 2. On the other hand, the convergence rate of the outermost groove section 15a is small as compared with that of the normal section 15b. That is, the outermost groove section 15a is formed in a substantially straight line along a tangent line of the spiral guide disk 13, and a length L of the outermost groove section 15a is set to be relatively long.

[0044] Put another way, a speed reducer or speed reduction mechanism is configured by the above spiral guide disk 13, spiral guide groove 15, link member 8, engaging pin 11 and others, as illustrated in Fig. 10, a relative rotational phase-shift angle θ_1 (or a conversion angle θ_1) between the camshaft 1 and timing sprocket 2, corresponding to a cam phase with respect to a phase of the timing sprocket 2, varies according to a rotation of the spiral guide disk 13. More specifically, a rate of change of the conversion angle θ_1 with respect to a rotational angle θ of the spiral guide disk 13 (called a speed-reduction ratio) differs between the A and B sections, which correspond to the outermost groove section 15a and the normal section 15b respectively. In this embodiment, the speed-reduction ratio corresponding to the outermost groove section 15a is set to be greater than that of the normal section 15b, and the speed-reduction ratio corresponding to the outermost groove section 15a is set to be greater than or equal to 6 (at least, $\theta:\theta_1 = 1:6$).

[0045] When the spiral guide disk 13 relatively rotates in a retarding direction with respect to the timing sprocket 2 with the engaging pin 11 being engaged with the spiral guide groove 15, the top end portion 8b of the link member 8 moves in a radially inward direction in and along the radial direction guide window 7 while being guided by the spiral guide groove 15. At this time, the camshaft 1 is rotated in an advancing direction. Fig. 9 shows a most-advanced phase position (state). On the other hand, when the spiral guide disk 13 relatively rotates in an advancing direction with respect to the timing sprocket 2, the top end portion 8b moves in a radially outward direction. Here, when the engaging pin 11 (also the top end portion 8b) comes to the inflexion point 15c while being guided, the camshaft 1 is most retarded. Fig. 8 shows a most-retarded phase position (state).

[0046] And further, when the spiral guide disk 13 is controlled to be rotated further, the engaging pin 11 (also the top end portion 8b) is guided and positioned at the outermost groove section 15a. At this time, a phase of the camshaft 1 is slightly shifted from the above most-retarded phase position (Fig. 8) to a slightly advanced phase position suitable for an engine starting (simply, an engine start-up phase).

[0047] The above-mentioned spiral guide disk 13 is provided with a relative operating turning force with respect to the camshaft 1 by way of a control force or operating force application mechanism (described later). When provided with the operating turning force, the top end portion 8b of the link member 8 is radially displaced in and along the radial direction guide window 7 by the operating force via the spherical-shaped end 11a of the engaging pin 11 guided by the spiral guide groove 15. At this time, by way of motion-conversion mechanism or working of the link member 8, the driven rotary member 4 is displaced in the direction of rotation thereof or is relatively rotated with respect to the timing sprocket 2 by the turning force. That is, the link member 8 slidably engaged in the radial direction guide window 7 and the spiral guide groove 15 serves to convert the radial displacement of the top end portion 8b along the radial direction guide window 7 into the circumferential displacement of the base end portion 8a along the guide hole 2d. In other words, the link member 8 rockably linked to both of the radial direction guide window 7 and the spiral guide groove 15 acts as a motion converter, and therefore the driven rotary member 4 is rotated.

[0048] As illustrated in Fig. 1, the operating force application mechanism includes a torsion spring 16 (as a biasing device, as a means for forcing) permanently forcing the spiral guide disk 13 in the direction of rotation of the timing sprocket 2 via the sleeve 6, a hysteresis brake 17 (an electromagnetic brake) that selectively generates a braking force against a force of the torsion spring 16 to force the spiral guide disk 13 in the reverse direction to the rotation of the timing sprocket 2, and an controller 24 (ECU: electrical control unit, output section) that controls the braking force of the hysteresis brake 17 according to the engine operating condition. By way of controlling the braking force of the hysteresis brake 17 appropriately by the controller 24 in accordance with the engine operating condition, the spiral guide disk 13 is relatively rotated with respect to the timing sprocket 2, or these rotational positions are held or maintained.

[0049] As can be seen from Fig. 1, the torsion spring 16 is disposed outside the sleeve 6. And a first end portion 16a of the torsion spring 16 is radially inserted into a hole formed at a front end portion of the sleeve 6 and is fixed to the sleeve 6. On the other hand, a second end portion 16b of the torsion spring 16 is inserted into a hole formed at a front side of the cylindrical portion 13a in an axial direction and is fixed to the cylindrical portion 13a. The torsion spring 16 serves to force and turn the spiral guide disk 13 in a direction of a starting rotational phase after the engine has stopped.

[0050] With respect to the hysteresis brake 17, the hysteresis brake 17 includes a hysteresis ring 18 integrally connected and fixed to a front outer periphery of the spiral guide disk 13, an annular coil yoke 19 arranged at a front side of the hysteresis ring 18, and an electromagnetic coil 20 circumferentially surrounded with the coil yoke 19 to induce magnetic flux in the coil yoke 19. The controller 24 precisely controls an application of current to the electromagnetic coil 20 according to the engine operating condition, a relatively large magnetic flux is therefore generated.

[0051] The hysteresis ring 18 is made of a magnetically semi-hardened material (i.e. a hysteresis material) having a characteristic showing a change of magnetic flux with phase lag behind a change of external magnetic field. As illustrated in Fig. 4, a top end portion 18a of the hysteresis ring 18 is disposed such that the top end portion 18a is in a cylindrical air gap between circumferentially-opposed pole teeth 21, 22 (described later) formed on inner and outer peripheral surfaces of the coil yoke 19 apart from the opposed pole teeth (with the top end portion 18a in non-contact with the pole teeth 21, 22). The hysteresis ring 18 thus receives a braking action by the coil yoke 19.

[0052] The coil yoke 19 is formed into a substantially cylindrical such that the coil yoke 19 circumferentially surrounds the electromagnetic coil 20. Further, the coil yoke 19 is held unrotatably by an engine cover (not shown) through a rattle or lash-absorption mechanism (or a lash eliminator). And also, the coil yoke 19 is supported on the cylindrical portion 13a of the spiral guide disk 13 via a ball bearing 23 provided at a cylindrical inner surface of the coil yoke 19 such that spiral guide disk 13 rotates relative to the coil yoke 19.

[0053] As will be explained in detail about the pole teeth 21, 22, as can be seen from Figs. 2 to 4, the coil yoke 19 includes a ring yoke portion 19a in an interior space portion thereof at a rear side thereof (at a side of the spiral guide disk 13), and a plurality of the opposed pole teeth 21, 22 arranged circumferentially at regular intervals on inner peripheral surface of the interior space portion of the coil yoke 19 and outer peripheral surface of the ring yoke portion 19a. More specifically, each of the pole teeth 21, 22 formed in projected shape and serving to generate magnetic field (as a magnetic field generating portion) is arranged circumferentially in a staggered configuration. That is, each recessed portion between

each tooth of the pole teeth 21, 22 and each projected portion of the pole teeth 21, 22 is placed on opposite sides of the circumferential air gap. Thus, upon energization of the electromagnetic coil 20, magnetic field is generated between the opposed adjacent projected portions. That is, the magnetic field is generated at a certain angle relative to a circumferential direction of the hysteresis ring 18. As described above, the top end portion 18a of the hysteresis ring 18 is located in the cylindrical air gap between the circumferentially-opposed pole teeth 21, 22 with the top end portion 18a in the non-contact with the pole teeth 21, 22. More specifically, an air gap between an outer peripheral surface of the top end portion 18a and the pole teeth 21, and an air gap between an inner peripheral surface of the top end portion 18a and the pole teeth 22 are set to infinitesimally small distances respectively to obtain a large magnetic force.

[0054] When the electromagnetic coil 20 induces magnetic flux in the coil yoke 19 and the hysteresis ring 18 rotates and is displaced in the magnetic field between the opposed pole teeth 21, 22, the braking force is generated due to a difference between a direction of magnetic flux in the hysteresis ring 18 and a direction of the magnetic field. As a result, the hysteresis brake 17 acts to brake the hysteresis ring 18 or to stop the rotation of the hysteresis ring 18. A strength of the braking force is independent of a rotational speed of the hysteresis ring 18 (i.e. a relative speed between the hysteresis ring 18 and opposed pole teeth 21, 22), but is substantially proportional to an intensity of the magnetic field (i.e. an amount of magnetizing current supplied to the electromagnetic coil 20). That is, if the amount of magnetizing current supplied to the electromagnetic coil 20 is constant, the strength of the braking force is also constant.

[0055] The relative angular phase control mechanism 3 has the radial direction guide window 7 of the timing sprocket 2, the link member 8, the engaging pin 11, the lever protrusion 4p, the spiral guide disk 13, the spiral guide groove 15, the operating force application mechanism and others.

[0056] As illustrated in Figs. 1, 2, 5 and 6, four first target protrusions 25 are fixedly provided on an outer peripheral surface opposite to the sprocket teeth 2a of the timing sprocket 2. The four first target protrusions 25 are disposed at regular intervals (90° angle) in the circumferential direction. This first target protrusion 25 is provided for detecting the rotational angle of the timing sprocket 2 (the crankshaft) by a rotational angle detection sensor 27 (detection section, described later). That is, the rotational angle detection sensor 27 picks up the rotational angle (or rotational position) of the timing sprocket 2, and obtains a base or reference pulse signal.

[0057] On the other hand, four second target protrusions 26 are fixedly provided on the outer peripheral surface of the spiral guide disk 13 so that the second target protrusion 26 faces the first target protrusion 25 in the direction of the camshaft 1 in a close position to the first target protrusion 25. The four second target protrusions 26 are disposed at regular intervals (90° angle) in the circumferential direction. This second target protrusion 26 is provided for detecting the rotational angle of the spiral guide disk 13 by the rotational angle detection sensor 27. That is, the rotational angle detection sensor 27 picks up also the rotational angle (or rotational position) of the spiral guide disk 13, and obtains a pulse signal. Here, regarding a relationship between positions of the first and second target protrusions 25, 26, as can be seen in Figs. 5, 6 and 11A, in an initial position under the engine stop state, the second target protrusion 26 is spaced apart from the first target protrusion 25 in a direction opposite to the rotational direction of the timing sprocket 2 (the rotational direction of the engine) by 20° angle (deg). This is for prevention of an overlap of the pulse signals of the first and second target protrusions 25, 26 in the A section or area from the initial position to the inflexion point 15c in Fig. 10.

[0058] Further, the reason why the four target protrusions for each first and second target protrusion 25, 26 are provided is because the rotational angle detection sensor 27 can detect the rotational angles of the timing sprocket 2 and the spiral guide disk 13 in real time, and also the above overlap and passing of the pulse in the A section can be prevented.

[0059] Furthermore, in order for the rotational angle detection sensor 27 to distinguish or recognize the respective target protrusions, a width "W" in the circumferential direction of the first target protrusion 25 is set to be greater (larger) than a width "W1" of the second target protrusion 26. (That is, the pulse width of the reference pulse signal corresponding to the rotational angle of the crankshaft and the pulse width of the detection pulse signal corresponding to the rotational angle of the spiral guide disk 13 are different from each other. Here, to recognize the respective rotational angles, shapes of the target protrusions could differ from each other, instead of the different protrusion's width.)

[0060] The rotational angle detection sensor 27 is used also as a normal crank angle sensor that detects an engine rpm. This rotational angle detection sensor 27 uses a normal Hall element, and a top end portion of the sensor 27 is positioned at close to edges of the first and second target protrusions 25, 26. The rotational angle detection sensor 27, then, detects the first and second target protrusions 25, 26 by a Hall IC, and outputs the respective pulse voltages into the controller 24. Here, a detection unit or system is configured by the first and second target protrusions 25, 26 and the rotational angle detection sensor 27.

[0061] The controller 24 detects a current engine operating condition based on input information from the rotational angle detection sensor 27 detecting the engine speed (engine rpm) as the crank angle sensor, a cam angle sensor detecting a rotational angle of the camshaft 1, an airflow meter detecting an engine load from an intake-air quantity, a throttle valve opening sensor, an engine temperature sensor and others (these are not shown), and then outputs a signal of control current supplied to the electromagnetic coil 20 according to the engine operating condition.

[0062] In addition, the controller 24 detects, based on the input pulse signal from the rotational angle detection sensor 27, a rotational phase difference between the timing sprocket 2 and the spiral guide disk 13 from the respective rotational

angles.

[0063] In the following, an operation of the relative angular phase control mechanism 3 and the operating force application mechanism will be explained in detail. When the electromagnetic coil 20 of the hysteresis brake 17 is de-energized in the engine stop state with an ignition key turned off, the spiral guide disk 13 is rotated fully in the rotational direction of the engine with respect to the timing sprocket 2 by way of the force of the torsion spring 16. At this time, as shown in Fig. 6, the spherical-shaped end 11a of the engaging pin 11 is shifted and positioned at the top end portion of the outermost groove section 15a of the spiral guide groove 15, and therefore the rotational phase of the camshaft 1 relative to the engine crankshaft is shifted to the engine start-up phase, which is a slightly advanced phase position as compared with the most-retarded phase position, and is maintained at this position. That is to say, engine valve open and closure timings at the engine start-up are set to suitable timings for the engine start-up. As described above, with respect to the location relationship between the first and second target protrusions 25, 26 at this time, the second target protrusion 26 is positioned apart from the first target protrusion 25 in the direction opposite to the rotational direction of the timing sprocket 2 by 20° angle (deg).

[0064] In addition to this, when turning the ignition on for the engine starting, there is a possibility that the spiral guide disk 13 will be unintentionally rotated owing to occurrence or generation of a disturbing force such as an alternate torque or positive and/or negative torque fluctuations while cranking the engine. In more detail, the positive and/or negative torque fluctuations occur during the engine starting, and are transferred to the spiral guide disk 13. And thus, there is a risk that the spiral guide disk 13 may be unintentionally rotated against the force of the torsion spring 16. However, as described above, since the engaging pin 11 (the spherical-shaped end 11a) is kept or maintained at a top end 15d of the outermost groove section 15a with stability, the rotational phase of the camshaft 1 relative to the engine crankshaft is maintained at the phase position suitable for the engine starting. Accordingly, this can improve engine startability.

[0065] Further, in this embodiment, the outermost groove section 15a of the spiral guide groove 15 is bent inwardly, and the speed-reduction ratio thereof is set to be greater than or equal to 6. Consequently, since an operating or working resistance of the engaging pin 11 positioned at the outermost groove section 15a (the top end 15d) against outermost groove section 15a becomes great, the spiral guide disk 13 is held there with stability. The unintentional rotation of spiral guide disk 13 is therefore avoided, and the rotational phase of camshaft 1 is maintained with stability at the engine start-up and the good engine startability is ensured.

[0066] After the engine starts, during the engine operating at low-rpm such as idling conditions, when the control current is supplied to the electromagnetic coil 20 by the controller 24, the magnetic force generated at the hysteresis brake 17 acts as braking force against the force of the torsion spring 16 on the spiral guide disk 13. At this time, the electromagnetic coil 20 is supplied with a relatively larger control current than normal in order for the guided engaging pin 11 to rapidly move from a side of the top end 15d toward the inflexion point 15c. As explained in more detail about this, as can be seen from Fig. 8, as this control current is supplied and the braking force acts on the spiral guide disk 13, the spiral guide disk 13 relatively rotates in the reverse direction to the rotation of the timing sprocket 2. Meanwhile, the timing sprocket 2 keeps turning while engaging the top end portion 8b (also the engaging pin 11 guided by the spiral guide groove 15) in the radial direction guide window 7. The engaging pin 11 therefore moves toward the inflexion point 15c in the spiral guide groove 15 rapidly, and also the top end portion 8b moves in the radially outward direction in and along the radial direction guide window 7 by the above supplied control current. Thus, a rotational phase of the driven rotary member 4 relative to the timing sprocket 2 is shifted toward the most-retarded phase position via the motion-conversion mechanism or working of the link member 8. As a result, the rotational phase of the camshaft 1 relative to the engine crankshaft (i.e. the rotational phase between the camshaft 1 and the engine crankshaft) is shifted toward the most-retarded phase position suitable for low-rpm conditions. This can improve not only the stability of rotation of the engine but also fuel economy at the idling condition.

[0067] After this condition, during the engine operating at high-rpm under a normal driving condition, in order to shift the rotational phase toward the most-advanced phase position, further larger control current is supplied to the electromagnetic coil 20 by the controller 24. When the hysteresis ring 18 of the spiral guide disk 13 receives the braking force by the above control current, the spiral guide disk 13 relatively rotates further in the reverse direction to the rotation of the timing sprocket 2. And therefore, as can be seen in Fig. 9, the engaging pin 11 is guided by the spiral guide groove 15 and moves toward an innermost portion of the normal section 15b, and also the top end portion 8b moves in the radially inward direction in and along the radial direction guide window 7. Thus, the rotational phase of the driven rotary member 4 relative to the timing sprocket 2 is shifted toward the most-advanced phase position by the motion-conversion mechanism or working of the link member 8. As a result, the rotational phase of the camshaft 1 relative to the engine crankshaft is shifted toward the most-advanced phase position. This can bring about a high power generation of the engine.

[0068] Here, regarding characteristics of the above spiral guide groove and rotational phase with respect to the rotational angle θ of spiral guide disk 13, they are shown in Fig. 10. As can be seen in Fig. 10, a shape of the spiral guide groove 15, namely a distance or position of the spiral guide groove from a center of the spiral guide disk 13, corresponds to a solid line X. That is, at a middle position or point (or portion) of the spiral guide groove 15 (not at both ends of the

spiral guide groove 15), the most-retarded phase position is set or positioned. On the other hand, a solid line Y shows the cam phase with respect to the phase of the timing sprocket 2 (the crankshaft).

[0069] Firstly, regarding the solid line X, it rises in the A section from the initial position "a" of the early stage of the engine start-up (corresponding to the top end 15d) to the most-retarded phase position "b" of the idling condition (corresponding to the inflexion point 15c). On the other hand, in the B section or area from the most-retarded phase position "b" to the most-advanced phase position "c" of the high-rpm engine operating condition under the normal driving condition (corresponding to the innermost portion of the normal section 15b), the solid line X gently falls. As for the solid line Y, it falls in the A section from the initial position "a" of the early stage of the engine start-up to the most-retarded phase position "b" of the idling condition. On the other hand, in the B section from the most-retarded phase position "b" to the most-advanced phase position "c" of the high-rpm engine operating condition, the solid line Y gently rises.

[0070] Accordingly, in the embodiment, by the provision of the specific-shaped outermost groove section 15a of the spiral guide groove 15, that is, by the setting of the outermost groove section 15a having the small phase-change rate (great speed-reduction ratio), an advanced phase area or region where the engine can easily start up widens, and therefore the working resistance of the engaging pin 11 in this advanced phase region becomes great. That is, when the spiral guide disk 13 receives the unintentional torque resulting from the disturbing force, the spiral guide disk 13 attempts to rotate in the rotational direction that makes the engaging pin 11 move toward the inflexion point 15c. And at this time, the engaging pin 11 attempts to move in a radially outward direction (indicated by an arrow in Fig. 6) at the top end 15d of the outermost groove section 15a. However, since the movement of the engaging pin 11 is blocked by an outer edge of the top end 15d, the movement can be restrained. Accordingly, even if the disturbance such as an alternate torque in the rotational direction arises and is transferred to the link member 8 or the spiral guide disk 13, the spiral guide disk 13 does not rotate unintentionally. Consequently, a retaining force between engaging pin 11 and outermost groove section 15a is improved at the engine start-up, and thereby ensuring the stable and good engine startability.

[0071] Further, after the engine start-up, the spiral guide disk 13 can be rapidly rotated in the reverse direction to the rotation of the timing sprocket 2 by way of the enhanced braking force by increasing the control current supplied to the electromagnetic coil 20. Because of this, a deterioration in the response of the valve timing control in the most-retarded and advanced directions can be prevented.

[0072] In Fig. 10, with respect to broken lines P and Q, they are characteristics of spiral guide groove and rotational phase with respect to the rotational angle θ of spiral guide disk 13 of a case where the whole spiral guide groove is formed at a constant curvature, not bent inwardly at the inflexion point 15c like this embodiment.

[0073] As previously described, the rotational angle detection sensor 27 and the controller 24 precisely detect the phase angle in the middle point between the A and B sections. That is, the pulse signals (voltages) are picked up and output by the rotational angle detection sensor 27 as shown in Figs. 11A to 11C. In the initial position of the early stage of the engine start-up illustrated in Fig. 11A, the pulse signal S of the first target protrusion 25 and the pulse signal D of the second target protrusion 26 are sent or output at regular intervals of 20° angle (deg).

[0074] When the condition shifts to the idling condition after the engine start-up, the braking force acts on the spiral guide disk 13 by the energization of the electromagnetic coil 20, and therefore the position of the spiral guide groove 15 (the position of the engaging pin 11 on the spiral guide groove 15) and the cam phase are respectively shifted to the middle points "b", "b'" in Fig. 10. In the most-retarded phase position illustrated in Fig. 11B, the first and second target protrusions 25, 26 are spaced a predetermined angle. In more detail, the pulse signal D of the second target protrusion 26 shifts further by 50.5° angle from the initial position of Fig. 11A. That is, the each pulse signal D (1', 2', 3' and 4') of the second target protrusion 26 are spaced apart from the each pulse signal S (1, 2, 3 and 4) of the first target protrusion 25 at 70.5° angle.

[0075] Further, when the condition shifts to the high-rpm engine operating condition from the normal driving condition, the braking force is kept acting on the spiral guide disk 13, and therefore the above positions are shifted to the most-advanced phase positions "c", "c' ". The first and second target protrusions 25, 26 are further spaced apart from each other at 251° angle as illustrated in Fig. 11C.

[0076] In this way, the rotational angle detection sensor 27 outputs this relative angle change or shift to the controller 24. The relative rotational angle (advanced - the most-retarded - the most-advanced) between the camshaft 1 and timing sprocket 2 can be then detected by the following detection manner.

[0077] Figs. 12 and 13 are flow charts for the detection and control of the relative rotational angle. The controller 24 detects and controls the relative rotational angle by the flow charts based on the output pulse signals of the first and second target protrusions 25, 26 from the rotational angle detection sensor 27.

[0078] Firstly, at step S1 in Fig. 12, the controller 24 reads the engine speed N (rpm) from a revolution speed of the timing sprocket 2 (the crankshaft), which is obtained from the rotational position of the first target protrusion 25 picked up by the rotational angle detection sensor 27.

[0079] At step S2, the controller 24 recognizes the pulse signal S (the reference pulse signal) and the pulse signal D by comparing the pulse widths of the first and second target protrusions 25, 26 output from the rotational angle detection

sensor 27. At this time, the controller 24 judges that a wider pulse is the pulse signal S, and a narrower pulse is the pulse signal D.

[0080] At step S3, the controller 24 detects a rising time difference Δt between the pulse signals S and D. At step S4, the controller 24 calculates the phase difference θ_1 from the rising time difference Δt by the following expression.

$$\theta_1 = \Delta t / (N/60) \times 360 \times 2 (^{\circ} \text{ CA})$$

At step S5, the controller 24 calculates the conversion angle θ between the timing sprocket 2 and camshaft 1 from an expression $\theta = \theta_1 - 20^{\circ}$ (the rotational angle 20° of the initial set value (crank angle 40°)).

[0081] In this way, in this embodiment, the rotational angle θ of the spiral guide disk 13, i.e. the relative rotational conversion angle θ between the timing sprocket 2 and camshaft 1, can be detected from the relative rotational positions between the first and second target protrusions 25, 26.

[0082] Next, a way of judgment of the A and B sections and a way of change of the control will be explained based on Fig. 13.

[0083] At step S11, the controller 24 detects the current rotational angle θ of the spiral guide disk 13. At step S12, a judgment is made as to whether or not the current rotational angle θ is greater than or equal to a phase angle θ_t . Here, θ_t is a phase angle corresponding to the most-retarded phase position "b, b'" (the inflexion point 15c of the spiral guide groove 15). In this embodiment, the phase angle θ_t is set to 50.5° (cam angle).

[0084] At this step S12, if the rotational angle (conversion angle) θ is judged to be equal to the phase angle θ_t of the points "b, b'", the controller 24 can judge that the spiral guide disk 13 is the middle position or point (the most-retarded phase position). On the other hand, if the rotational angle θ is judged to be greater than the phase angle θ_t , the controller 24 can judge that the spiral guide disk 13 is positioned at the side of the points "c, c'" (at the advanced side) from the points "b, b'".

[0085] When the controller 24 judges that the rotational angle θ is greater than or equal to the phase angle θ_t at step S12, the routine proceeds to the step S13. At this step S13, the controller 24 judges whether the controller 24 controls the rotational angle θ to the retarded or advanced side in accordance with the engine operating condition.

[0086] Here, for instance, in a case where the rotational angle θ is controlled to be shifted to the retarded side (in the retarded phase direction), the routine proceeds to step S14. At step S14, the controller 24 executes the control that decreases the control current supplied to the electromagnetic coil 20. By this current control, the spiral guide disk 13 is rotated in the retarded phase direction (in the direction of the point "b") by way of the spring force of the torsion spring 16.

[0087] On the other hand, at step S13, in a case where the rotational angle θ is controlled to be shifted to the advanced side (in the advanced phase direction), the routine proceeds to step S15. At step S15, the controller 24 executes the control that increases the control current supplied to the electromagnetic coil 20. By this current control, the braking force acts on the spiral guide disk 13, and the spiral guide disk 13 is thus relatively rotated in the advanced phase direction with respect to the timing sprocket 2.

[0088] Returning to step S12, when the controller 24 judges that the rotational angle θ is smaller than the phase angle θ_t , namely, that when the rotational angle θ is judged to be smaller than the middle position (the most-retarded phase position), the routine proceeds to step S16.

[0089] At step S16, the spiral guide disk 13 is positioned at the side of the points "a, a'" from the middle points (the most-retarded phase position) "b, b'". The controller 24 judges whether the controller 24 controls the rotational angle θ to the retarded or advanced side in accordance with the engine operating condition. Here, in a case where the rotational angle θ is controlled to be shifted from the side of the points "a, a'" to the side of the middle points, the routine proceed to step S17.

[0090] At step S17, the controller 24 executes the control that increases the control current supplied to the electromagnetic coil 20. By this current control, the braking force acts on the spiral guide disk 13, and the spiral guide disk 13 is rotated to the most-retarded phase side (to the middle point) and further rotated to the advanced side through the most-retarded phase position.

[0091] On the other hand, at step S16, in a case where the rotational angle θ is controlled to be shifted further to the side of the points "a, a'", the routine proceeds to step S18. At step S18, the controller 24 executes the control that decreases the control current supplied to the electromagnetic coil 20. By this current control, the spiral guide disk 13 is rotated in the advanced phase direction (in the direction of the point "a") by way of the spring force of the torsion spring 16.

[0092] As explained above, according to this embodiment, the controller detects not the rotational phase angle of the camshaft 1 but the rotational phase angle of the spiral guide disk 13 directly, and then detects the phase angle difference between the timing sprocket 2 and camshaft 1 by this detection pulse signal D of the spiral guide disk 13 and the reference pulse signal S. Thus, the relative rotational phase between the timing sprocket 2 and camshaft 1 can be detected, and the detection of the middle rotational angle (the most-retarded phase angle) becomes possible. And an accuracy of the

detection of the phase angle can be improved as compared with the case where the rotational angles are independently or separately detected by the cam angle and crank angle sensors.

[0093] With this detection method or way, the controller 24 can judge whether the controller 24 executes the phase-advance control or the phase-retard control by increasing the control current supplied to the electromagnetic coil 20. And also, the controller 24 can judge whether the controller 24 executes the phase-advance control or the phase-retard control by decreasing the control current supplied to the electromagnetic coil 20.

[0094] Regarding the pulse detection, when the spiral guide disk 13 rotates from the middle position (the most-retarded phase position) to the advanced side (in the advanced phase direction) by the application of the braking force, as illustrated in Fig. 11C, the second target protrusion 26 (the pulse signal D) passes the first target protrusion 25 (the pulse signal S). Because of this, the phase difference can not be detected from the relative position between the first and second target protrusions 25, 26. In this case, the controller 24 detects the relative rotational phase difference between the timing sprocket 2 and camshaft 1 by comparing a cam angle signal detected by the cam angle sensor with the pulse signal S, with this first target protrusion 25 (the pulse signal S) being the reference position (the reference pulse signal).

[0095] In this embodiment, the hysteresis brake 17 is used for the relative angular phase control mechanism 3. Thus, the considerably high braking force can be obtained by increasing the control current supplied to the electromagnetic coil 20. It is therefore possible to easily and effectively prevent the deterioration in the response of the phase shift from the engine start-up to the normal operating condition by increasing the control current between the engine start-up and the initiation of the normal operating control.

[0096] Further, the spiral guide groove 15 can be formed to a desired shape except the outermost groove section 15a whose rate of change is small. Thus, a desired control can be executed without affecting the control after the engine start-up.

[0097] As explained above, the variable valve timing control apparatus with the phase control can control the relative rotational phase between the crankshaft and the camshaft 1 not only to the most-retarded/advanced rotational phases but also to an arbitrary rotational phase by the control of the braking force of the hysteresis brake 17 by changing the control current amount according to the engine operating condition. Thus, for instance, the relative rotational phase can also be held or maintained at the substantially middle position of the cam angle 50.5° by a balance between the spring force of the torsion spring 16 and the braking force of the hysteresis brake 17.

[0098] The present invention is not limited to the configuration of the above embodiment. As the relative angular phase control mechanism, the spiral guide disk 13 could be formed by a gear speed reduction mechanism or a mechanical reduction gear mechanism, which has a plurality of gears and outputs a unidirectional rotational force (torque) at a predetermined gear ratio. In this case, to pick up and generate (output) the pulse signal by the sensor, at least one target protrusion might be provided at an output side of the gear speed reduction mechanism.

[0099] Further, as the drive rotary member rotated by the engine crankshaft in synchronization with the engine crankshaft, a timing pulley driven by an elastic timing belt or a member driven by gear engagement other than the sprocket, could be possible.

[0100] Furthermore, instead of the electromagnetic brake, the relative angular phase control mechanism might have a helical gear type brake.

[0101] Moreover, as an unit or mechanism for forcing the spiral guide disk to turn in one direction, the following means can be possible instead of using the torsion spring. That is, the convergence rate of the spiral guide groove is set such that the spiral guide disk turns toward a rotational position suitable for the engine start-up by using torque difference between the positive and negative torque fluctuations generated at camshaft as a power source.

[0102] With respect to the radial direction guide window, instead of this, a guiding projection or a guiding groove to slidably hold and guide the engaged portion could be used.

[0103] In the above embodiment, the spiral guide groove having a bottom is used. However, a spiral guide groove without a bottom, that is, spiral guide groove that penetrates the intermediate rotary member (the spiral guide disk 13) can be used. Moreover, the spiral guide groove may be formed by forming a protrusion. In addition, the movable member can be formed into any proper shape, and a roller or a ball can be provided at a top end portion of the movable member as a sliding member.

[0104] Further, in the above embodiment, the four target protrusions are provided. The number of the target protrusions is not limited to four. At least one target protrusion could be provided at the timing sprocket 2 and the spiral guide disk 13 respectively.

[0105] In addition, in the above embodiment, to detect the rotational angles of the timing sprocket 2 and the spiral guide disk 13, the target protrusion is provided. However, instead of the target protrusion, a mark or mark portion such as a notch might be formed for the detection of the respective rotational angles. In this case also, to recognize the respective rotational angles (to generate the two different pulse signals), a shape or length of the mark differs between the timing sprocket 2 and the spiral guide disk 13.

[0106] This application is based on a prior Japanese Patent Application No. 2006-171420 filed on June 21, 2006. The entire contents of this Japanese Patent Application No. 2006-171420 are hereby incorporated by reference.

[0107] Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

Claims

1. A phase angle detection apparatus comprising:

an intermediate rotary member (13) changing an operating angle of a driven member (4) that is driven by a driving member (2);
a detection unit (27, 25, 26) detecting a rotational angle of the intermediate rotary member (13), which corresponds to the operating angle of the driven member (4), and outputting the rotational angle as a detection pulse signal (D);
a controller (24) receiving the detection pulse signal (D) and calculating a pulse rising time difference (Δt) between the detection pulse signal (D) and a pre-set reference pulse signal (S), and
the controller (24) detecting, based on the pulse rising time difference (Δt), a predetermined middle angle position of the driven member (4) from all the operating angles of the driven member (4).

2. A phase angle detection apparatus comprising:

a drive rotary member (2) rotated by an engine crankshaft in synchronization with the engine crankshaft;
a driven rotary member (4) connected with a camshaft (1) having a cam (1a) that opens/closes an engine valve, and driven by the drive rotary member (2);
a phase-change mechanism (3) having an intermediate rotary member (13) and relatively changing a rotational phase angle of the driven rotary member (4) with respect to the drive rotary member (2) by changing a rotational angle of the intermediate rotary member (13);
a detection unit (27, 25, 26) detecting the rotational angle of the intermediate rotary member (13) and outputting the rotational angle as a detection pulse signal (D);
a controller (24) calculating a pulse rising time difference (Δt) between the detection pulse signal (D) and a reference pulse signal (S) corresponding to the rotational angle of the drive rotary member (2), and
the controller (24) detecting, based on the pulse rising time difference (Δt), a predetermined middle angle position of the driven rotary member (4) from all the rotational phase angles of the driven rotary member (4).

3. A variable valve timing control apparatus of an internal combustion engine, which controls an open/close timing of an engine valve in accordance with an engine operating condition, comprising:

a drive rotary member (2) that is rotated by an engine crankshaft in synchronization with the engine crankshaft;
a driven rotary member (4) that is connected with a camshaft (1) provided with a cam (1a) for opening/closing the engine valve, and is driven by the drive rotary member (2);
a phase-change mechanism (3) that has an intermediate rotary member (13) relatively shifting a rotational phase angle of the driven rotary member (4) with respect to the drive rotary member (2), and changes a rotational phase angle of the cam (1a) by controlling a rotational angle of the intermediate rotary member (13);
a detection system (27, 25, 26) that detects the rotational angles of the intermediate rotary member (13) and the drive rotary member (2);
a controller (24) that calculates a rotational phase difference between the intermediate rotary member (13) and the drive rotary member (2); and
the controller (24) detecting, based on the rotational phase difference, a middle angle position of the driven rotary member (4) from all the rotational phase angles of the driven rotary member (4), which corresponds to a middle point between retarded and advanced direction control areas of the engine valve open/close timing.

4. The phase angle detection apparatus as claimed in claim 2, wherein:

the intermediate rotary member is formed by a spiral disk (13) having a spiral groove (15) for controlling a rotational position of the cam (1a) within a range from a most-advanced phase position to a most-retarded phase position through the middle position,
the drive rotary member is formed by a sprocket (2) transferring a rotational force of the engine crankshaft to

the camshaft (1),
the driven rotary member (4) has a follower portion (8; 8b) moving in a radial direction of the sprocket (2) while
being moved along the spiral groove (15), and
the radial movement of the follower portion (8; 8b) is controlled by controlling a rotational direction of the spiral
disk (13).

5 **5.** The phase angle detection apparatus as claimed in claim 4, wherein:

10 the spiral disk (13) has at least one mark portion (26) at an outer surface thereof for detecting the rotational
angle of the spiral disk (13) by the detection unit (27).

6. The phase angle detection apparatus as claimed in claim 5, wherein:

15 the mark portion is formed by a target protrusion (26).

7. The phase angle detection apparatus as claimed in claim 2, wherein:

20 the intermediate rotary member (13) is formed by a gear speed reduction mechanism that has a plurality of
gears and outputs a unidirectional rotational force at a predetermined gear ratio.

8. The phase angle detection apparatus as claimed in claim 7, wherein:

25 the gear speed reduction mechanism has at least one mark portion (26) at an output side thereof for detecting
the rotational angle of the gear speed reduction mechanism by the detection unit (27).

9. The phase angle detection apparatus as claimed in claim 8, wherein:

 the mark portion is formed by a target protrusion (26).

30 **10.** The phase angle detection apparatus as claimed in claim 2, wherein:

 the detection pulse signal (D) corresponding to the detected rotational angle of the intermediate rotary member
(13) and the reference pulse signal (S) corresponding to the rotational angle of the drive rotary member (2) are
different in at least pulse width, and
35 the detection pulse signal (D) and the reference pulse signal (S) are detected by one sensor provided in the
detection unit (27).

11. The phase angle detection apparatus as claimed in claim 10, wherein:

40 the controller (24) recognizes the detection pulse signal (D) and the reference pulse signal (S) by the difference
of the pulse width of the pulse signal, and calculates a delay of the detection pulse signal (D) with respect to
the reference pulse signal (S).

45 **12.** The phase angle detection apparatus as claimed in claim 2, wherein:

 the detection pulse signal (D) corresponding to the detected rotational angle of the intermediate rotary member
(13) and the reference pulse signal (S) corresponding to the rotational angle of the drive rotary member (2) are
shifted from each other at an engine start-up.

50 **13.** The phase angle detection apparatus as claimed in claim 12, wherein:

 the detection pulse signal (D) is shifted with respect to the reference pulse signal (S) by 20° angle at the engine
start-up.

FIG.1

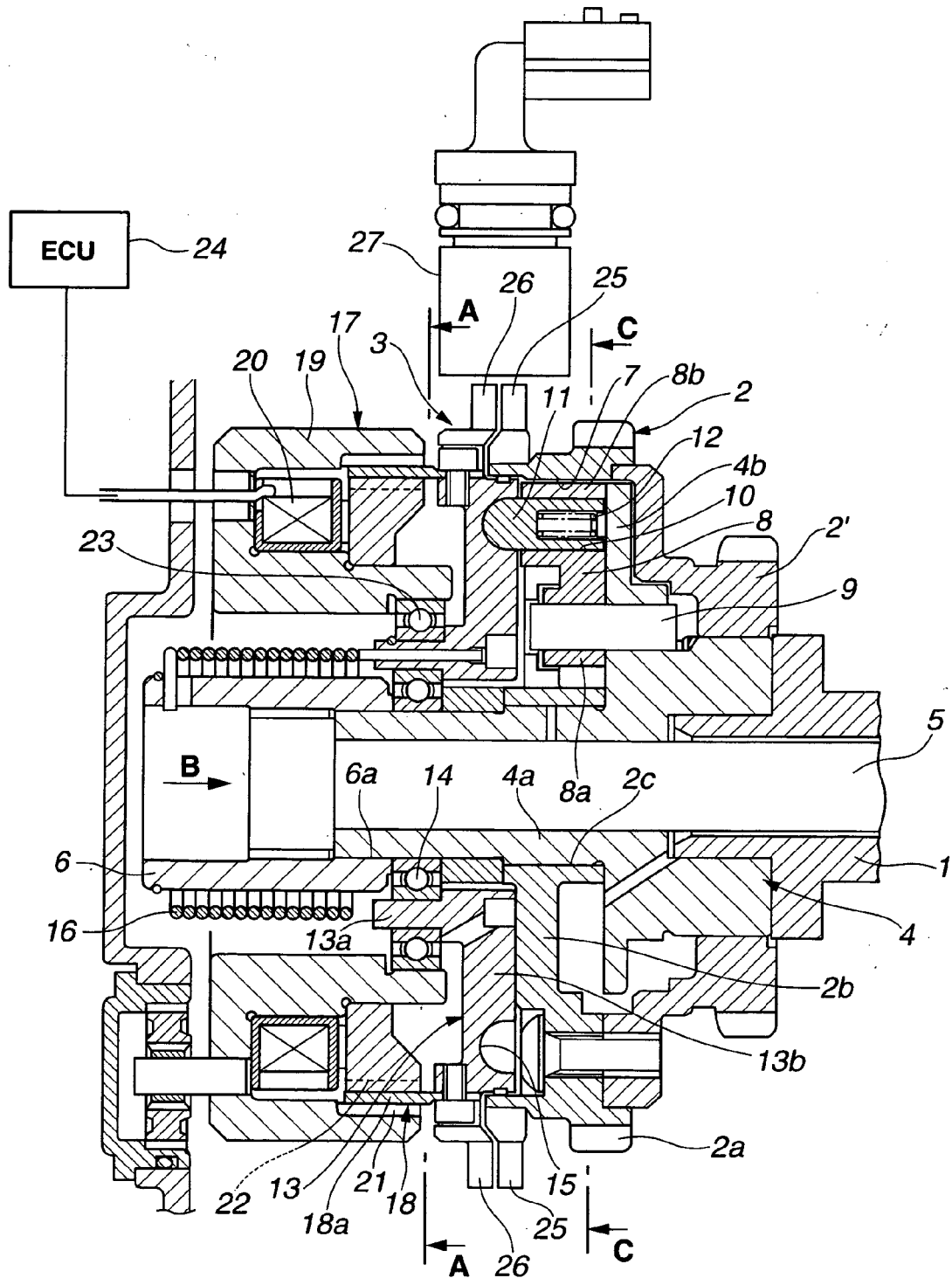
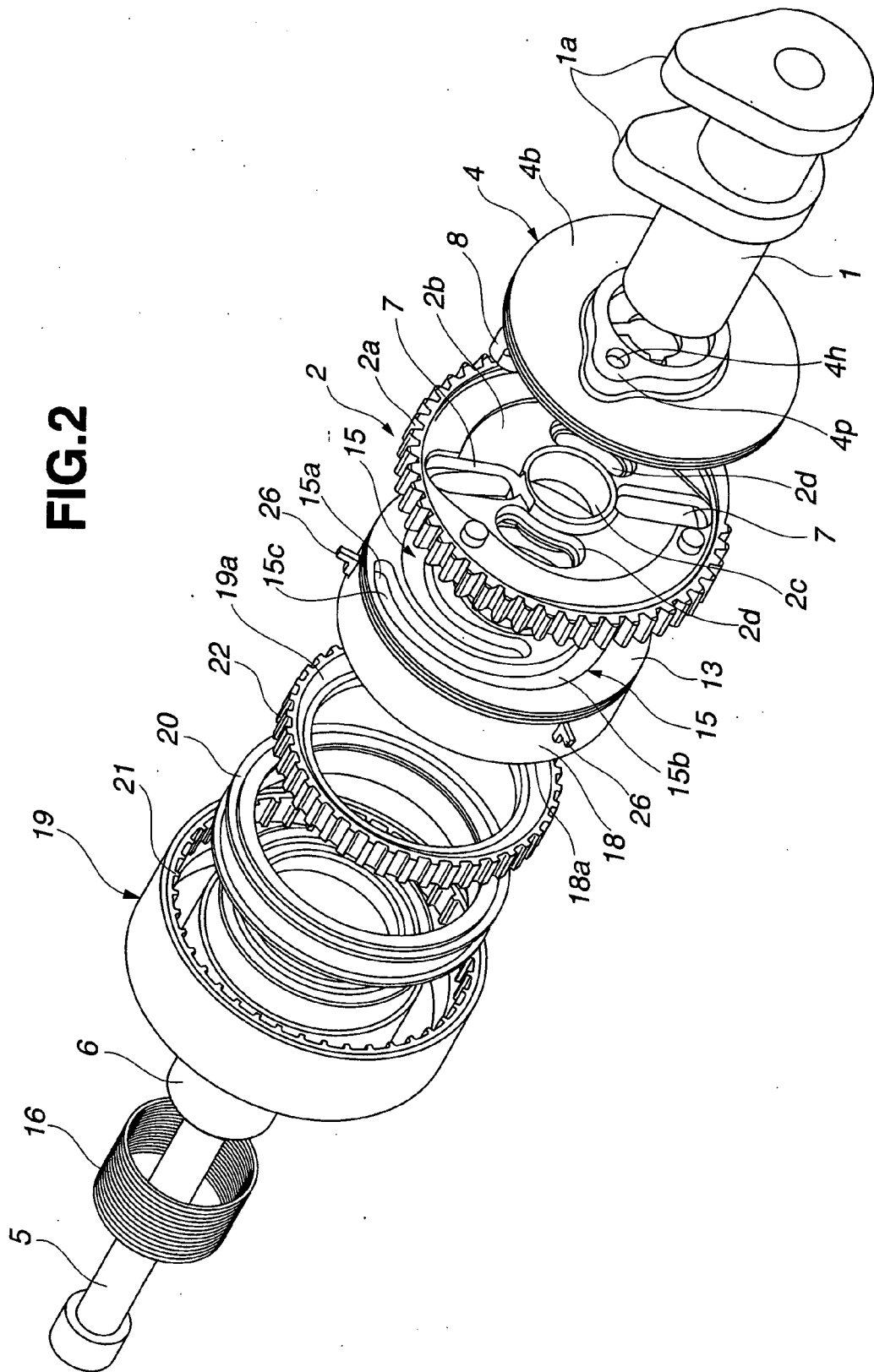


FIG.2



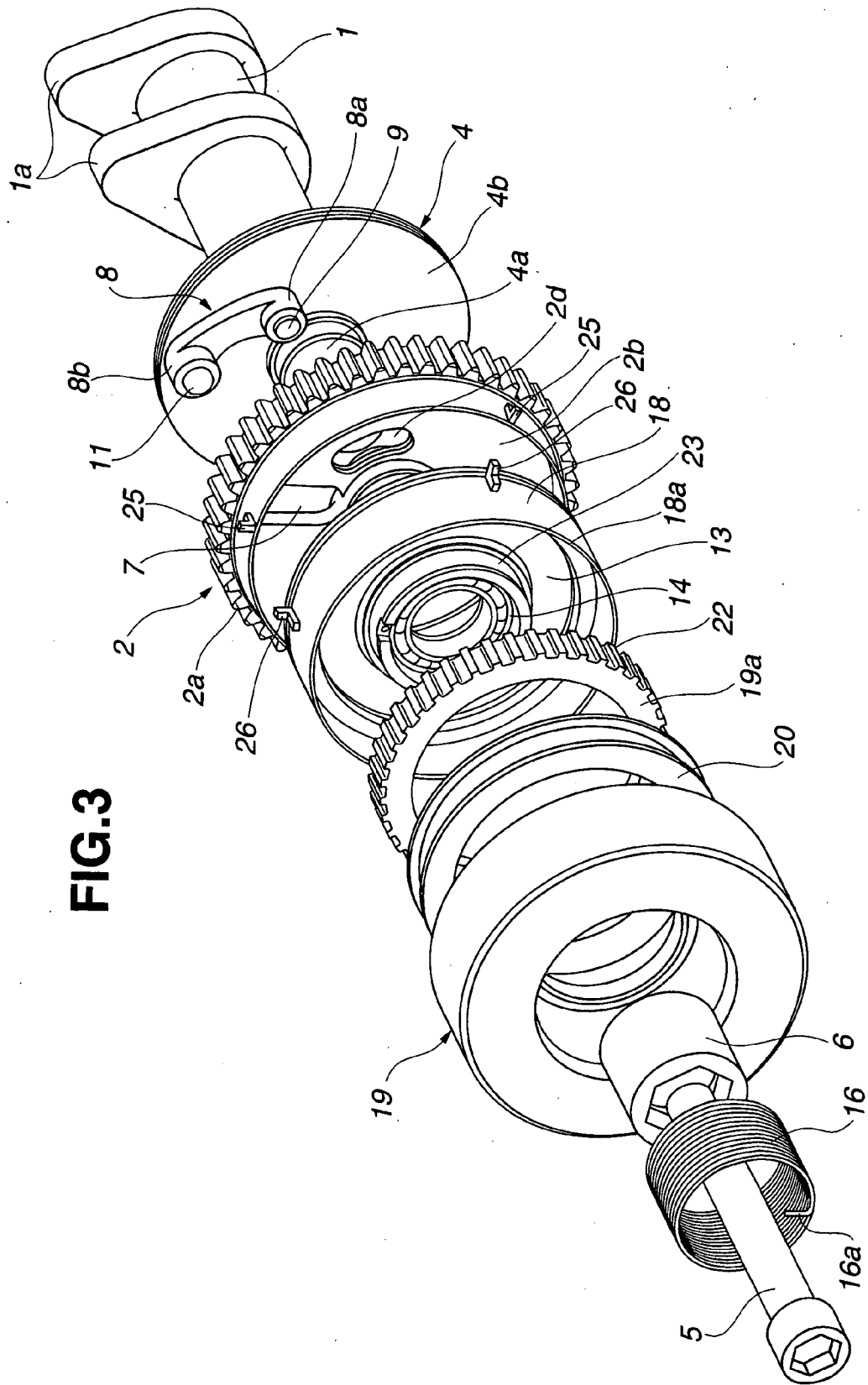


FIG.4

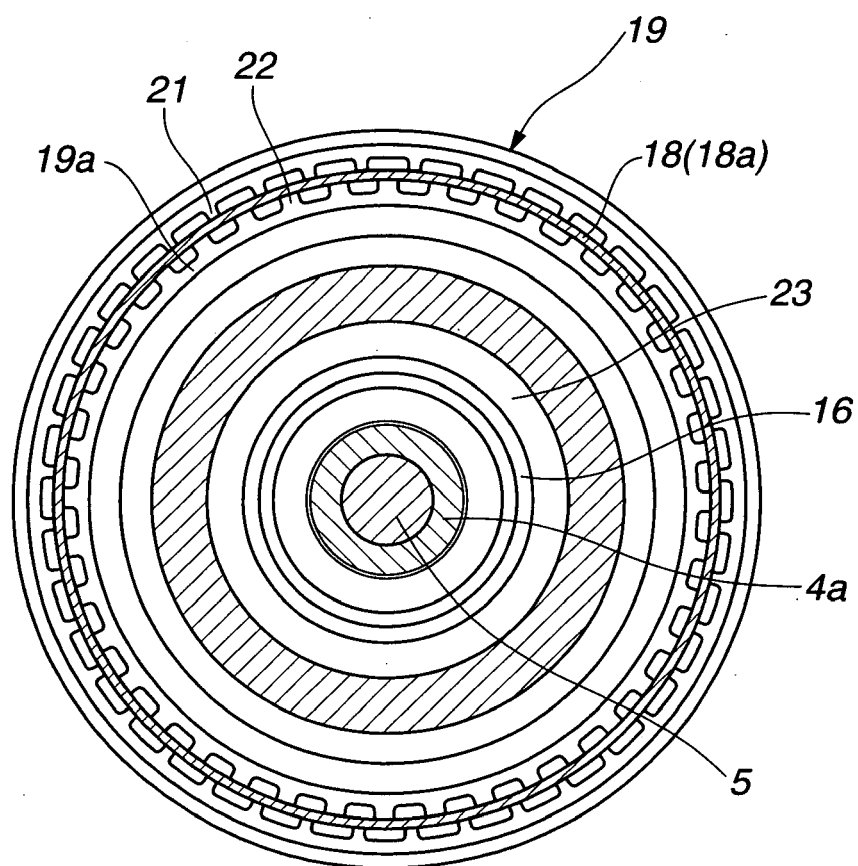


FIG.5

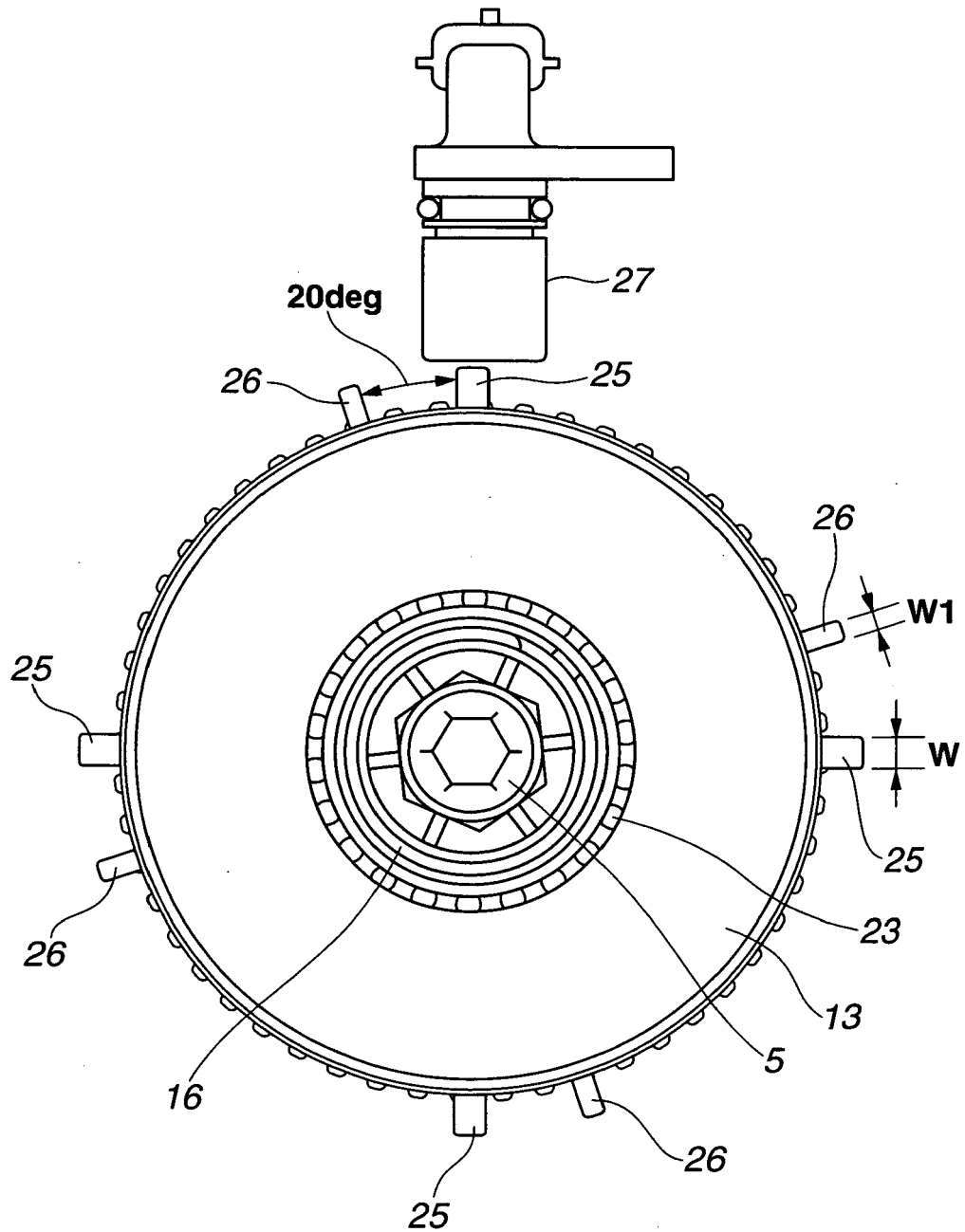


FIG.6

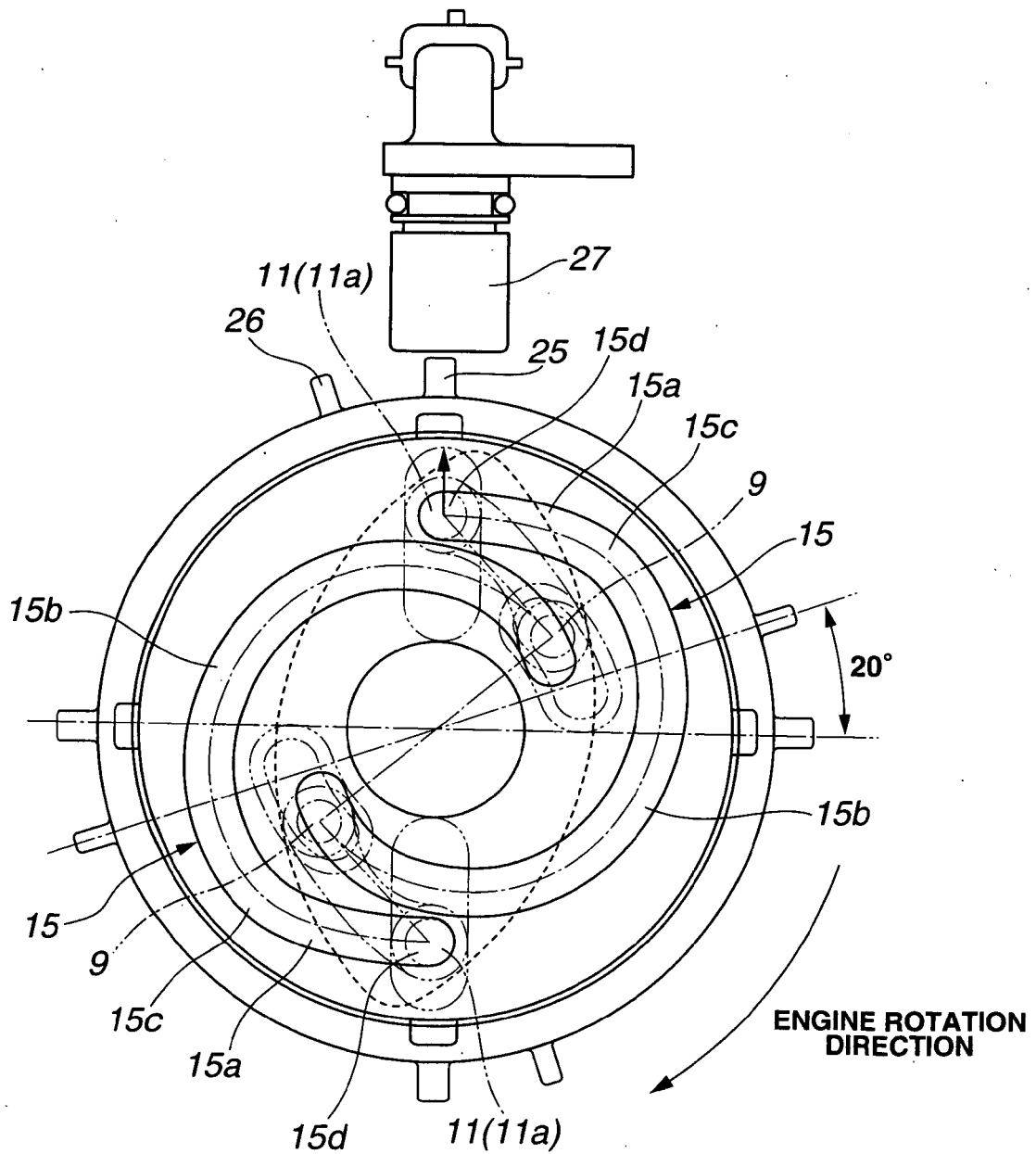


FIG.7

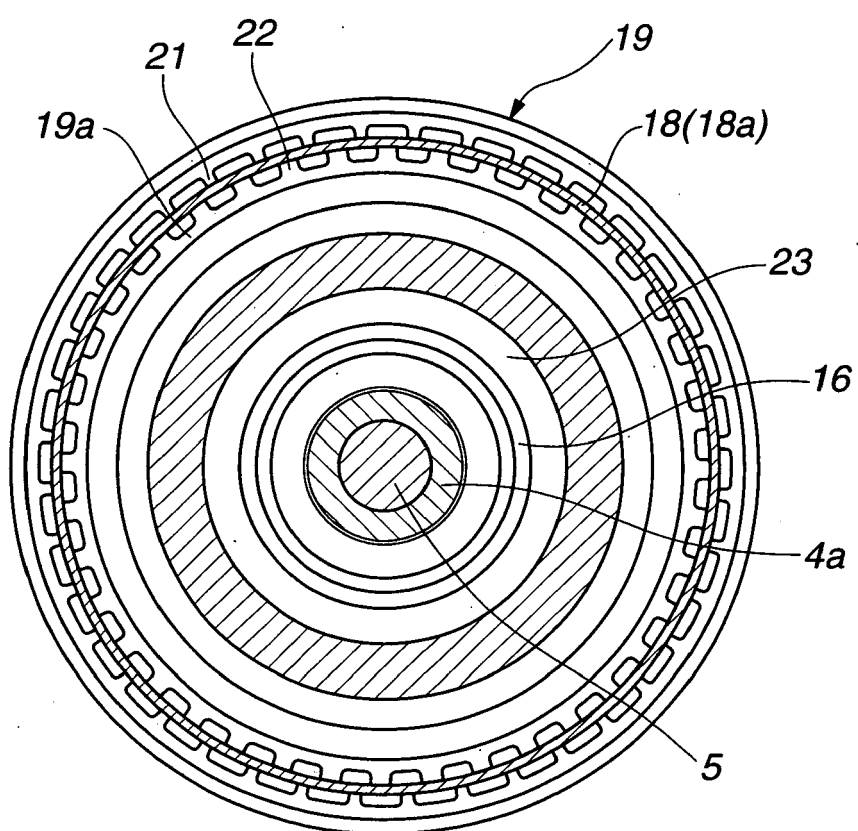


FIG.8

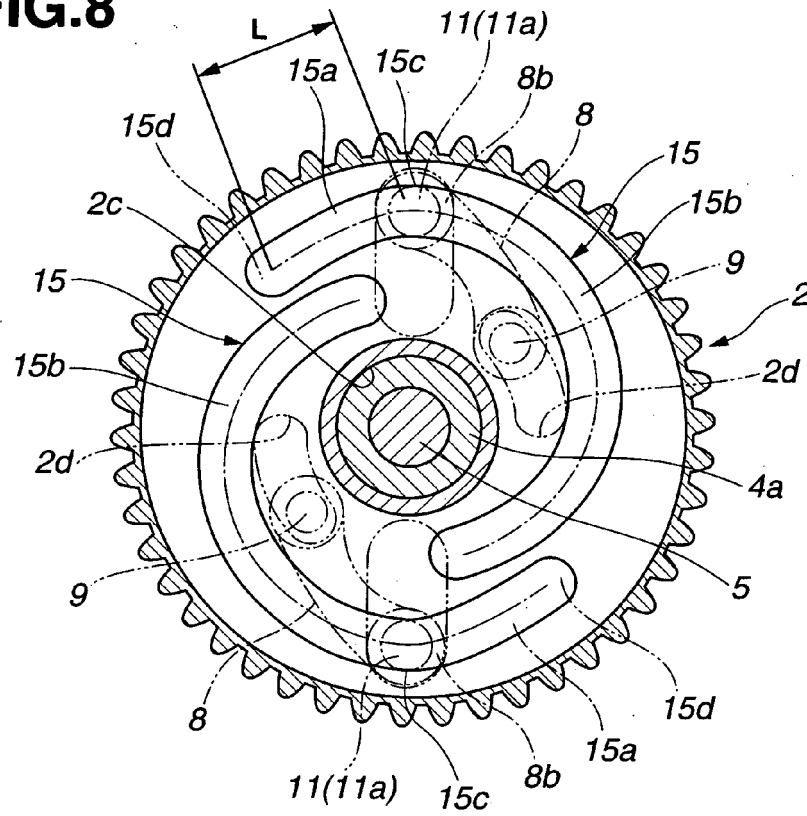


FIG.9

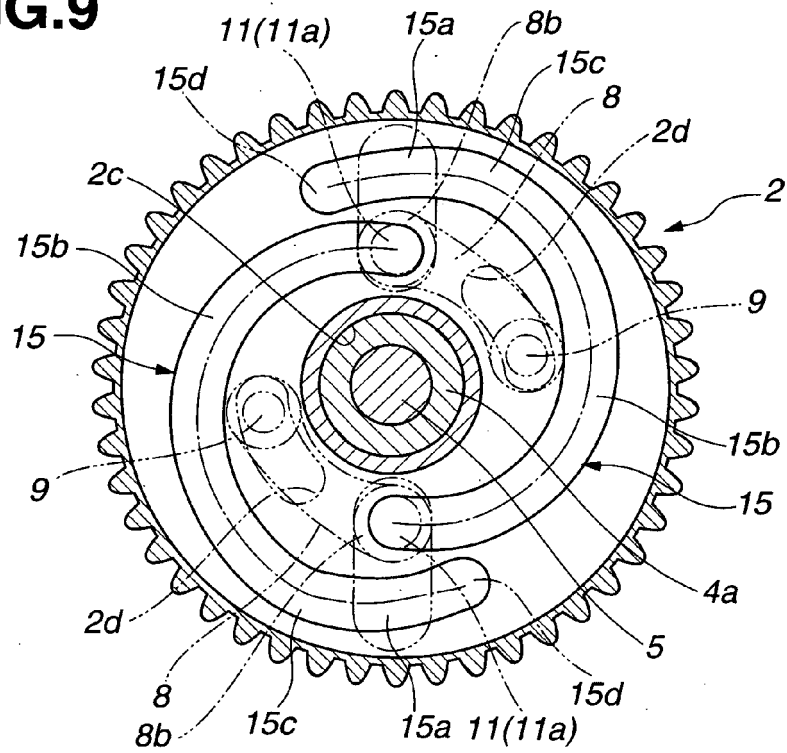


FIG.10

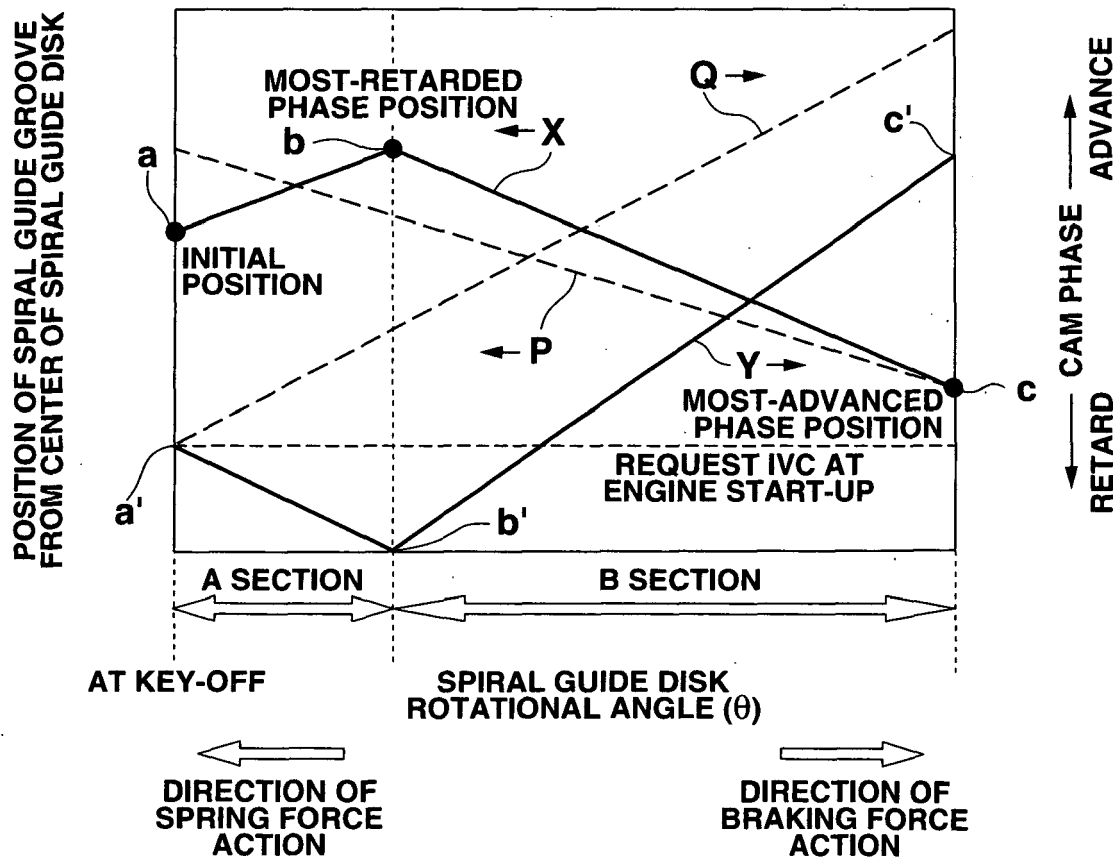


FIG.11A

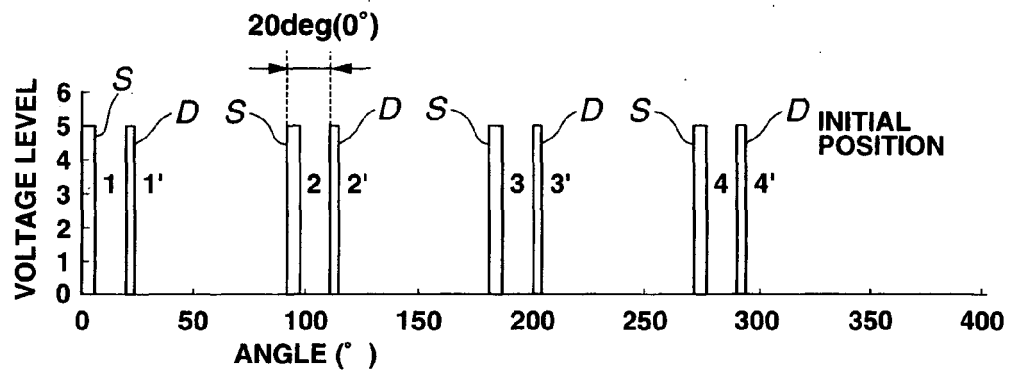


FIG.11B

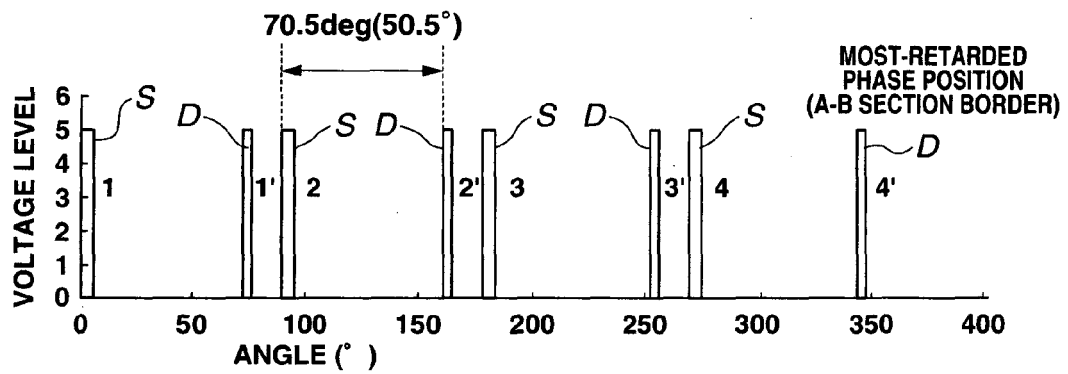


FIG.11C

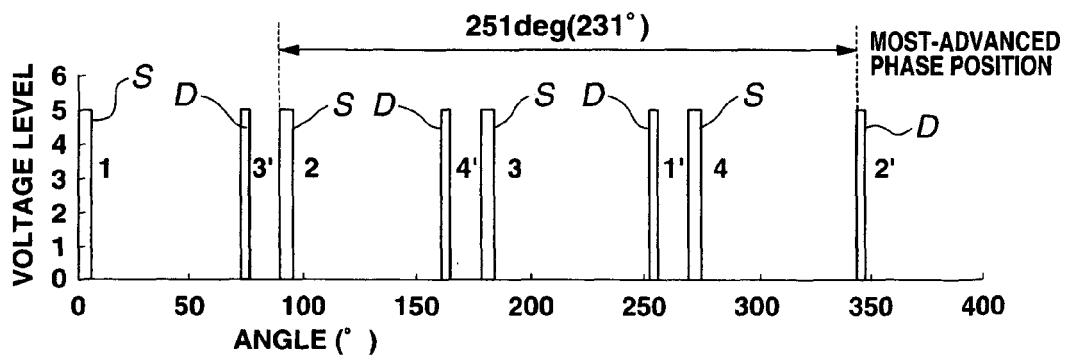


FIG.12

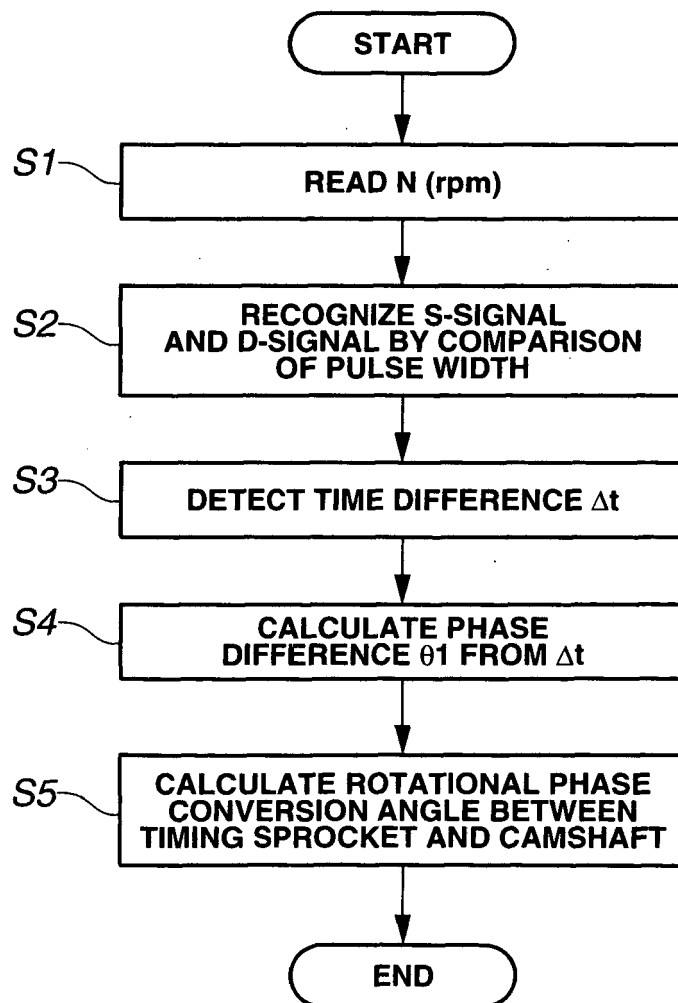
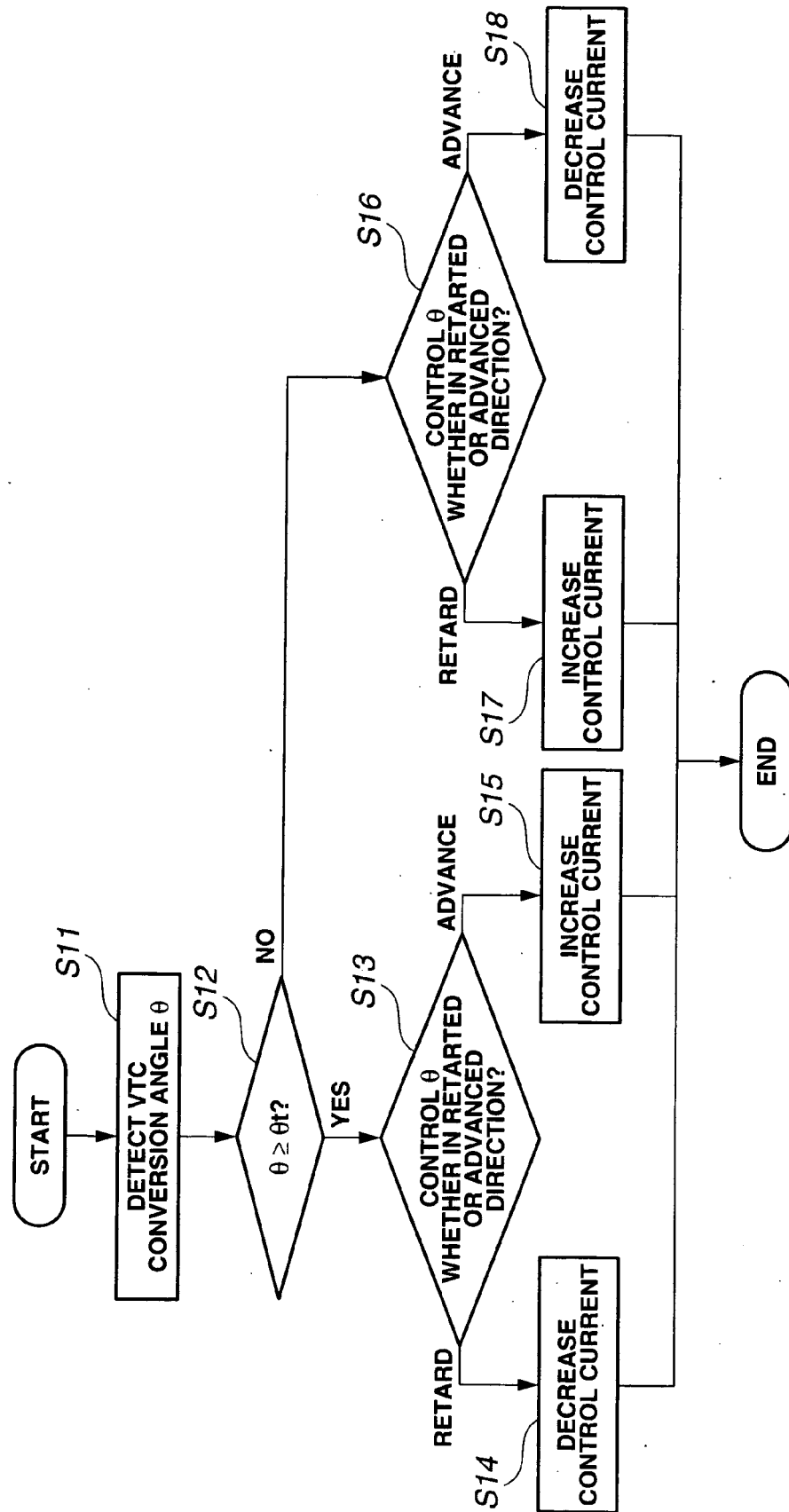


FIG.13



REFERENCES CITED IN THE DESCRIPTION

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