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(54) VALVE TIMING CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE

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(57) **ABSTRACT**

A valve timing control apparatus includes a driving side rotational member synchronously rotated with a crankshaft, a driven side rotational member provided coaxially with the driving side rotational member and synchronously rotated with a camshaft, a fluid pressure chamber being separated into an advanced angle chamber and a retarded angle chamber, a phase control apparatus controlling an operation fluid to be supplied to and discharged from one of, or both of the advanced angle chamber and the retarded angle chamber, for displacing a relative rotational phase between the driving side rotational member and the driven side rotational member within a range from a most advanced angle phase to a most retarded angle phase, a locking mechanism restraining the relative rotational phase at a lock phase between the most advanced angle phase and the most retarded angle phase.

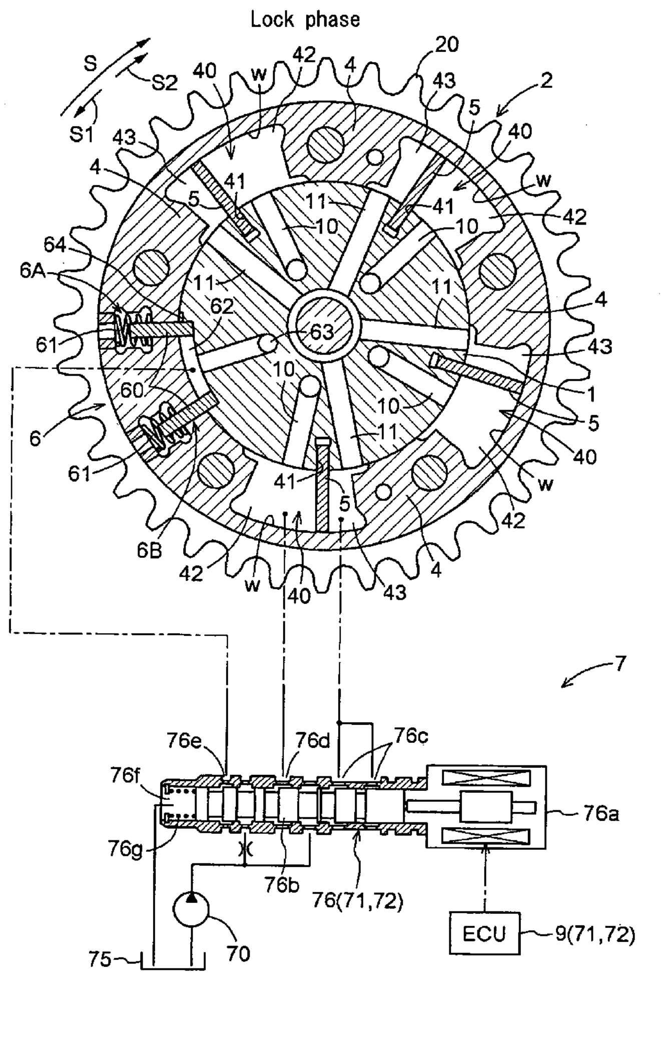


FIG. 1

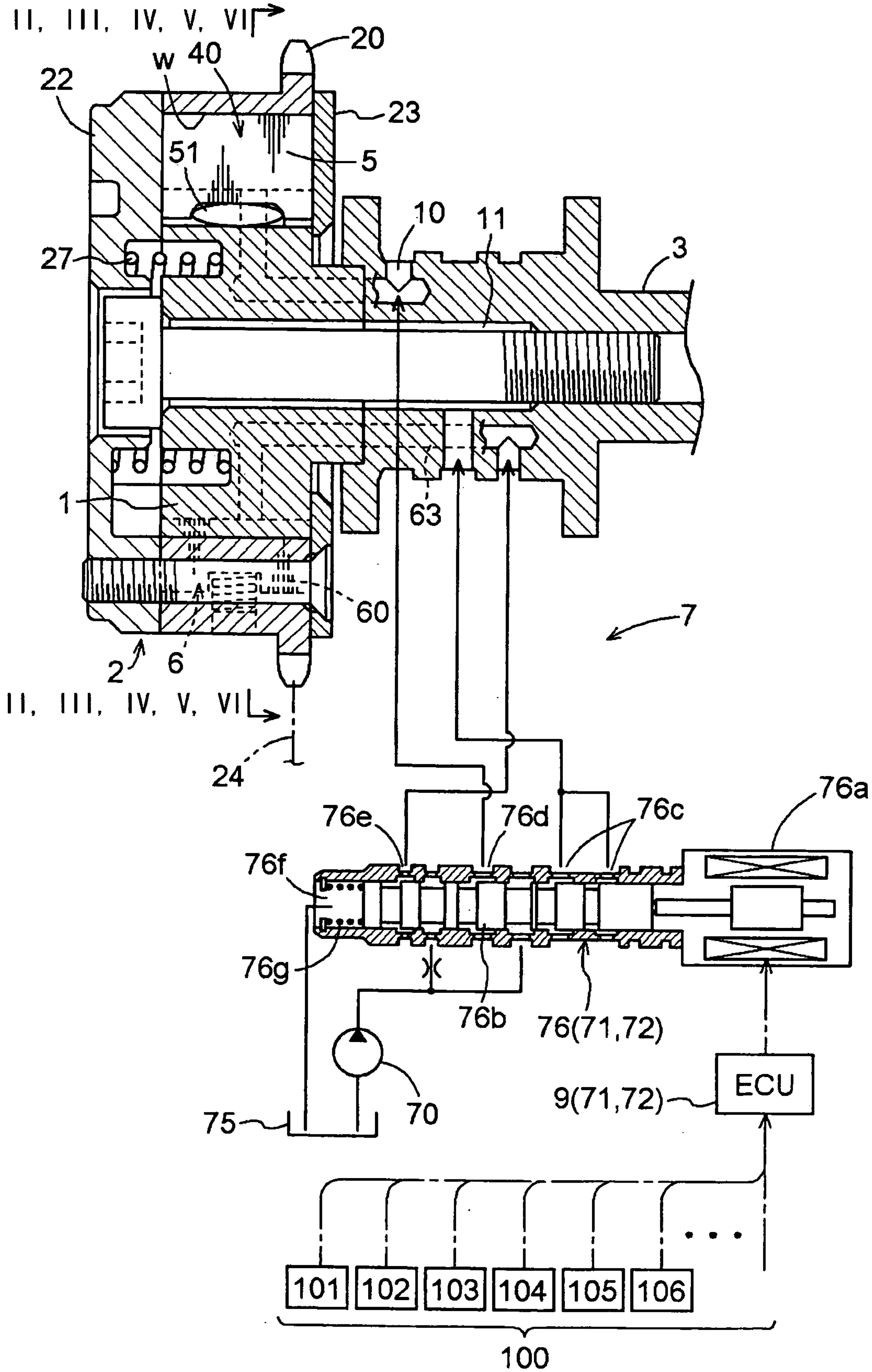

II, III, IV, V, VI
20
W
40
22
23
51
5
10
11
3
27
1
63
60
7
2
6
II, III, IV, V, VI
24
76a
76e
76d
76c
76f
76g
76b
76(71,72)
70
75
ECU
9(71,72)
101
102
103
104
105
106
100

FIG. 2

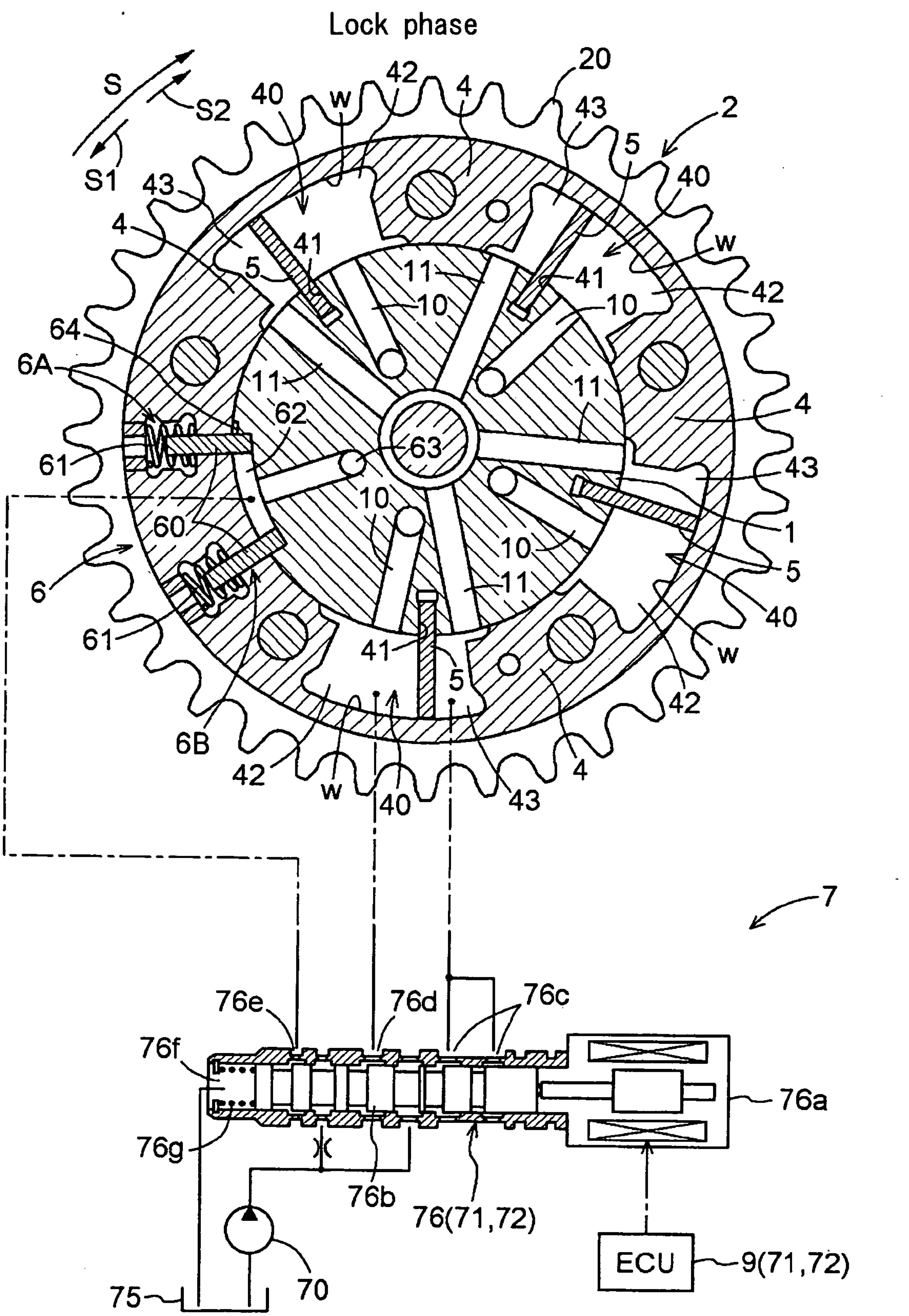

Lock phase
S
S1
S2
40
w
42
4
20
43
2
5
40
w
41
11
10
42
43
4
64
6A
61
62
63
11
4
43
1
60
6
10
5
61
41
5
40
w
6B
42
w
40
43
4
42
7
76e
76d
76c
76f
76a
76g
76b
76(71,72)
70
ECU
9(71,72)
75

FIG. 3

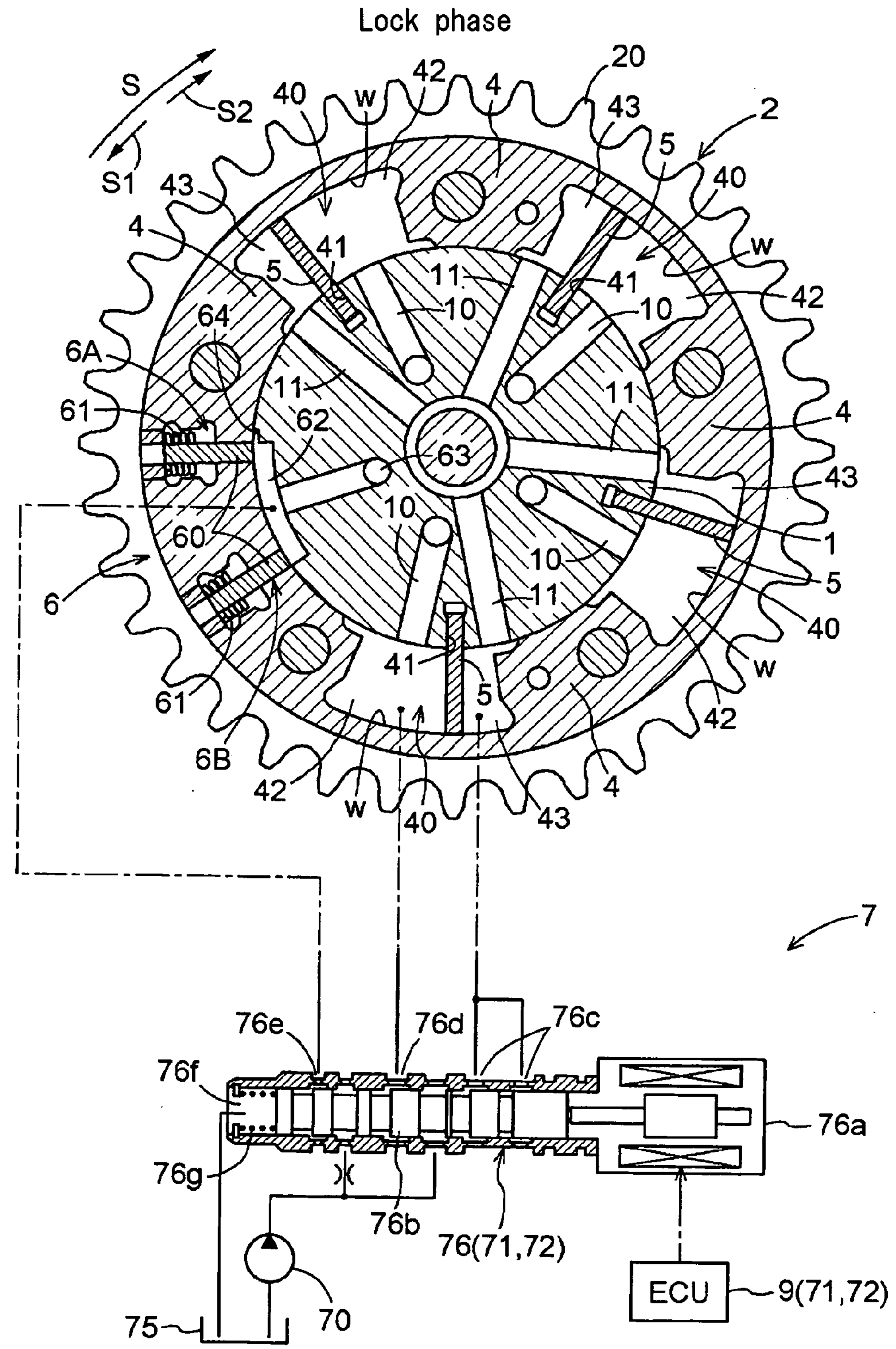

Lock phase
S
S1
S2
20
2
40
42
w
4
43
5
41
11
10
64
6A
61
62
63
60
6
6B
1
7
76e
76d
76c
76f
76a
76g
76b
76(71,72)
ECU
9(71,72)
75
70

FIG. 4

Restriction phase

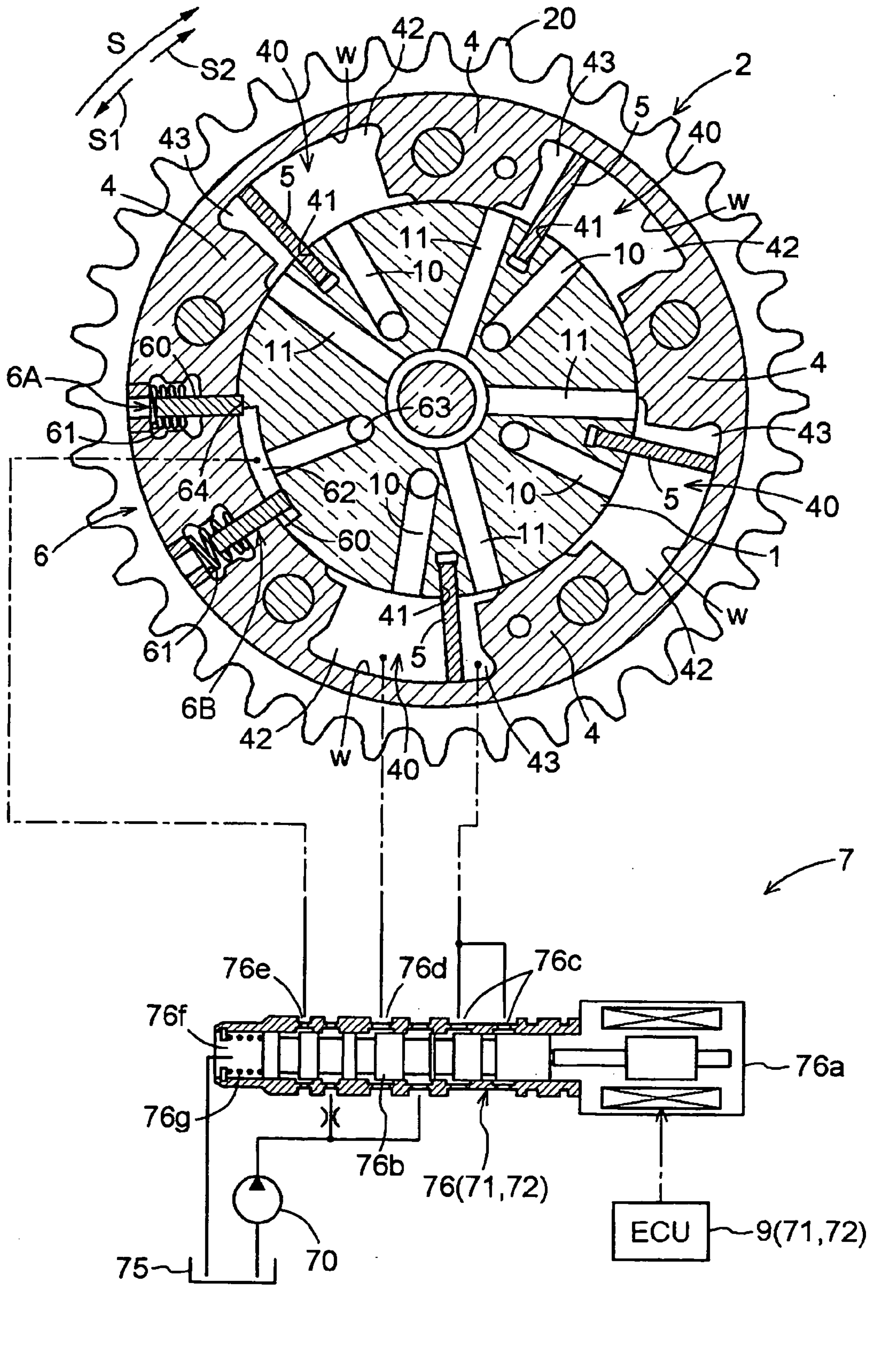


FIG. 5

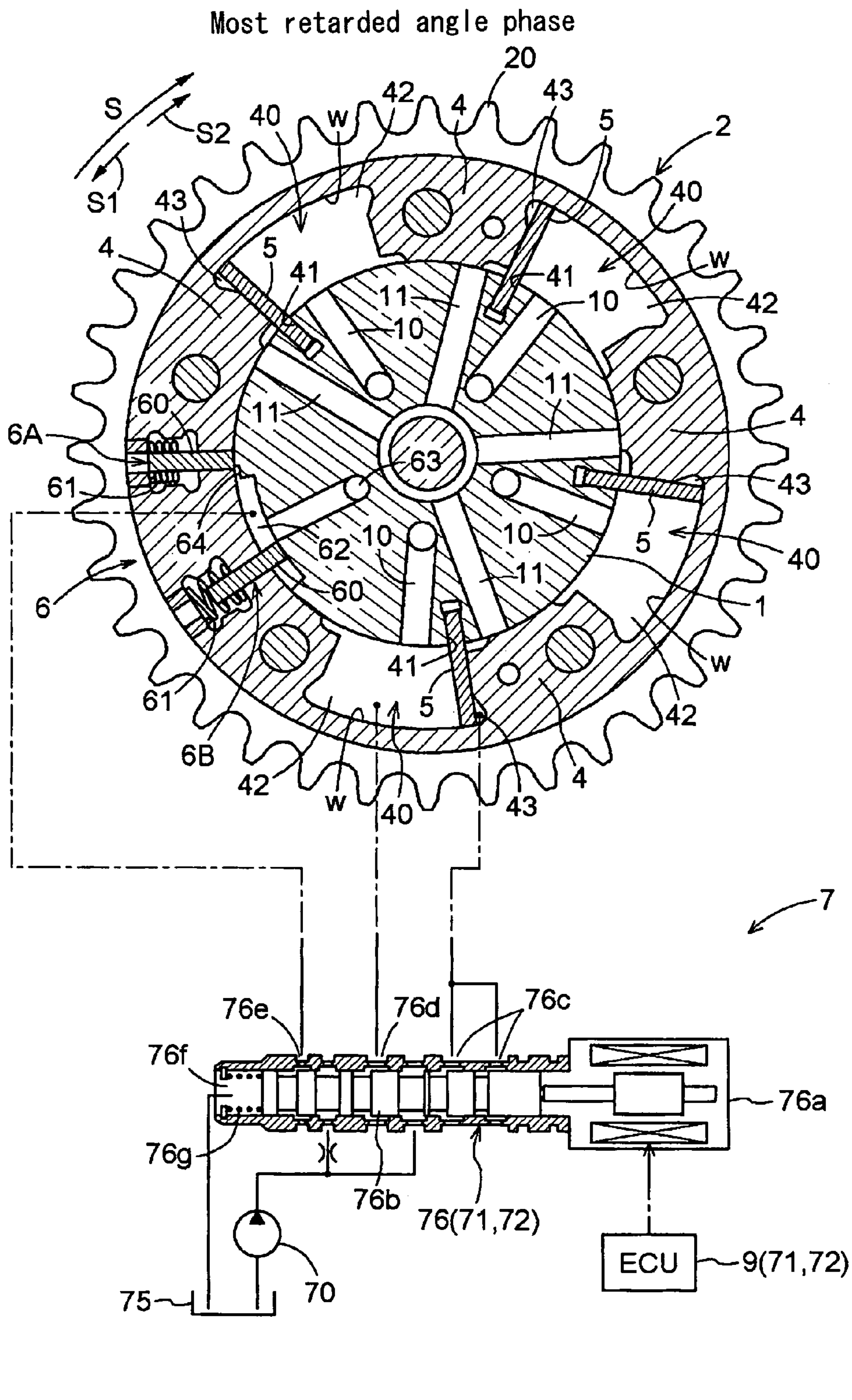
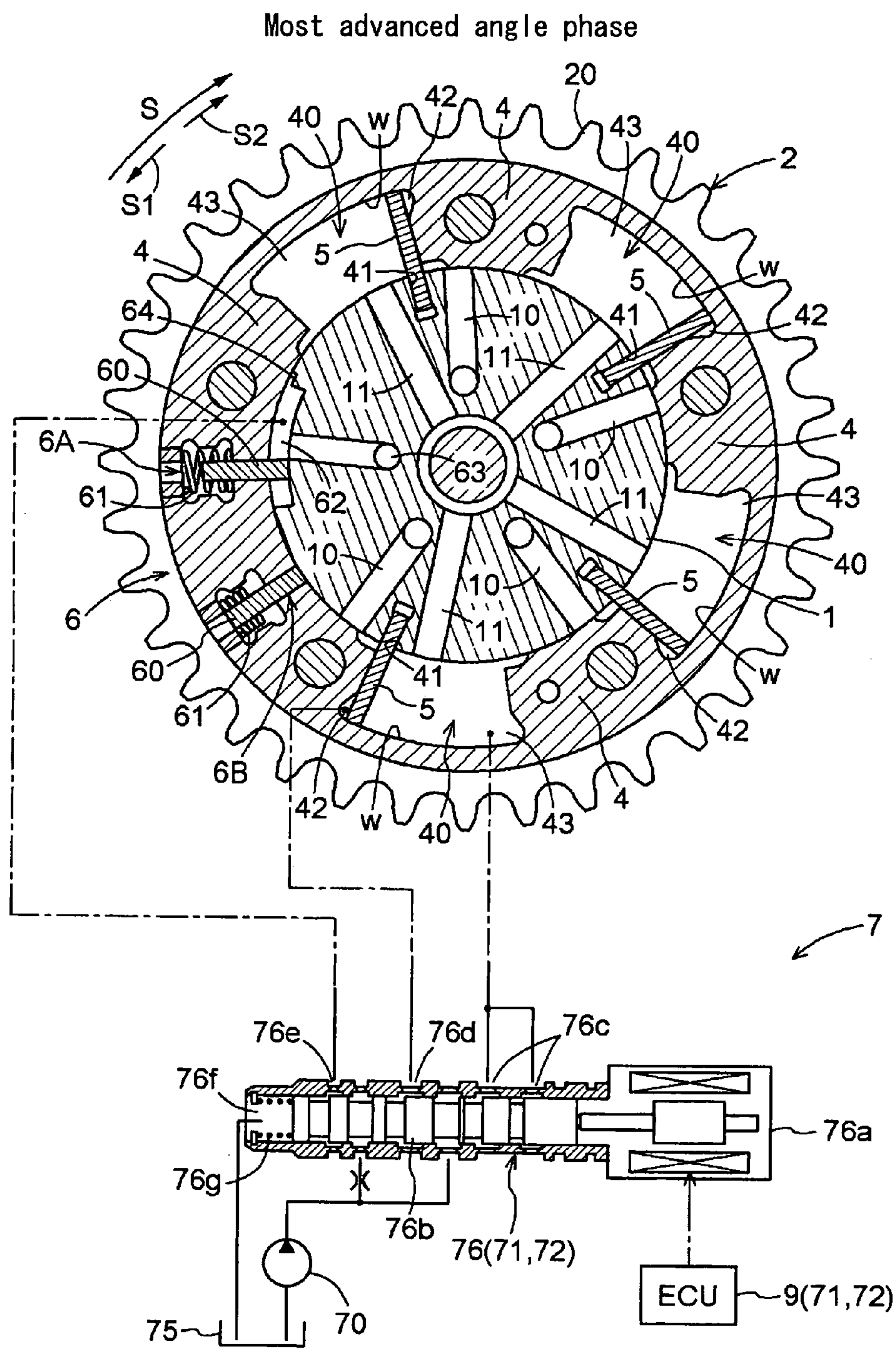

Most retarded angle phase
20
42
43
4
5
2
S
S2
S1
40
W
41
11
10
42
60
6A
61
63
64
62
6
6B
1
76e
76d
76c
76f
76a
76g
76b
76(71,72)
70
75
ECU
9(71,72)
7

FIG. 6



Most advanced angle phase
S
S2
S1
40
w
42
4
20
43
40
2
43
5
41
4
64
60
6A
61
6
60
61
6B
10
11
63
62
1
w
42
7
76e
76d
76c
76f
76a
76g
76b
76(71,72)
ECU
9(71,72)
75
70

FIG. 7

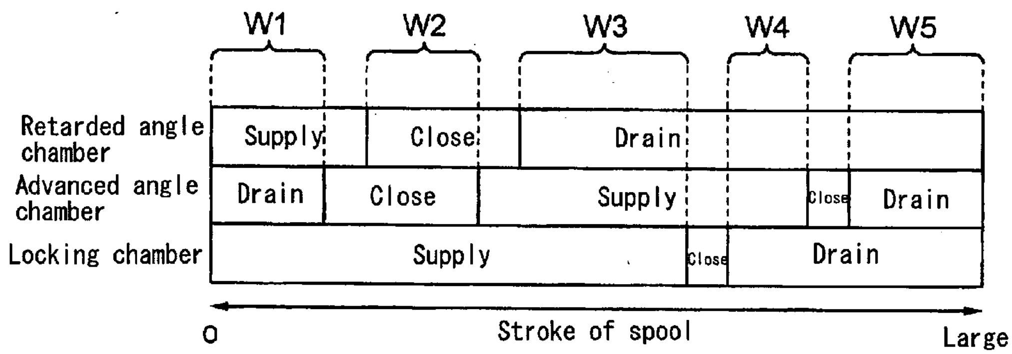

W1
W2
W3
W4
W5
Retarded angle chamber
Advanced angle chamber
Locking chamber
Supply
Close
Drain
Drain
Close
Supply
Close
Drain
Supply
Close
Drain
0
Stroke of spool
Large

FIG. 8

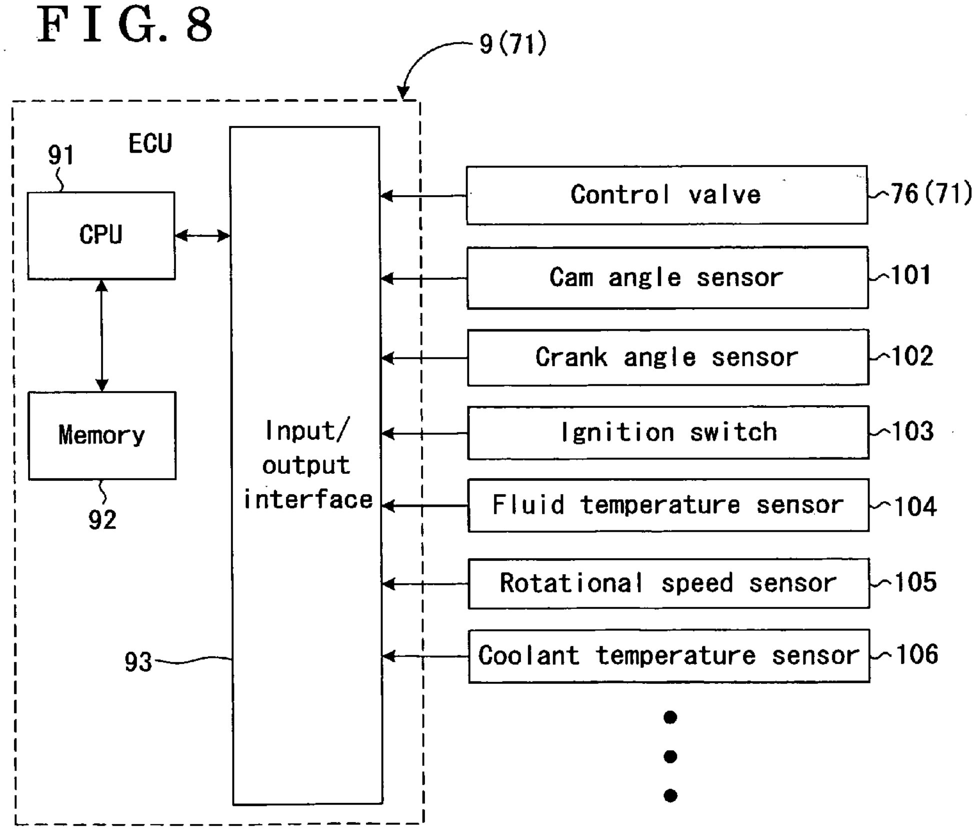

9(71)
ECU
91
CPU
Memory
92
Input/
output
interface
93
Control valve
76(71)
Cam angle sensor
101
Crank angle sensor
102
Ignition switch
103
Fluid temperature sensor
104
Rotational speed sensor
105
Coolant temperature sensor
106

FIG. 9

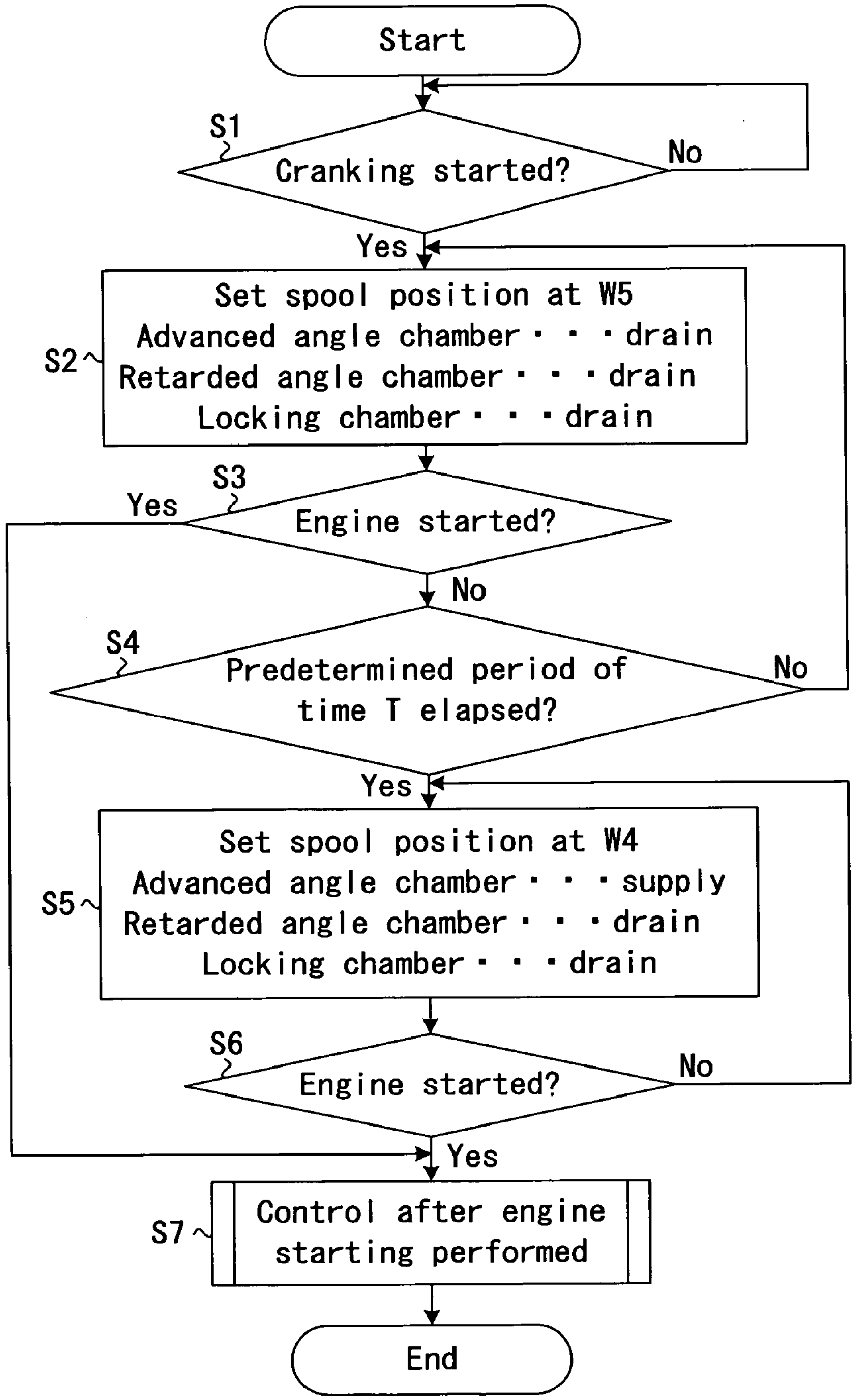

Start
S1
Cranking started?
No
Yes
Set spool position at W5
Advanced angle chamber · · · drain
Retarded angle chamber · · · drain
Locking chamber · · · drain
S2
S3
Engine started?
Yes
No
S4
Predetermined period of time T elapsed?
No
Yes
Set spool position at W4
Advanced angle chamber · · · supply
Retarded angle chamber · · · drain
Locking chamber · · · drain
S5
S6
Engine started?
No
Yes
Control after engine starting performed
S7
End

FIG. 10

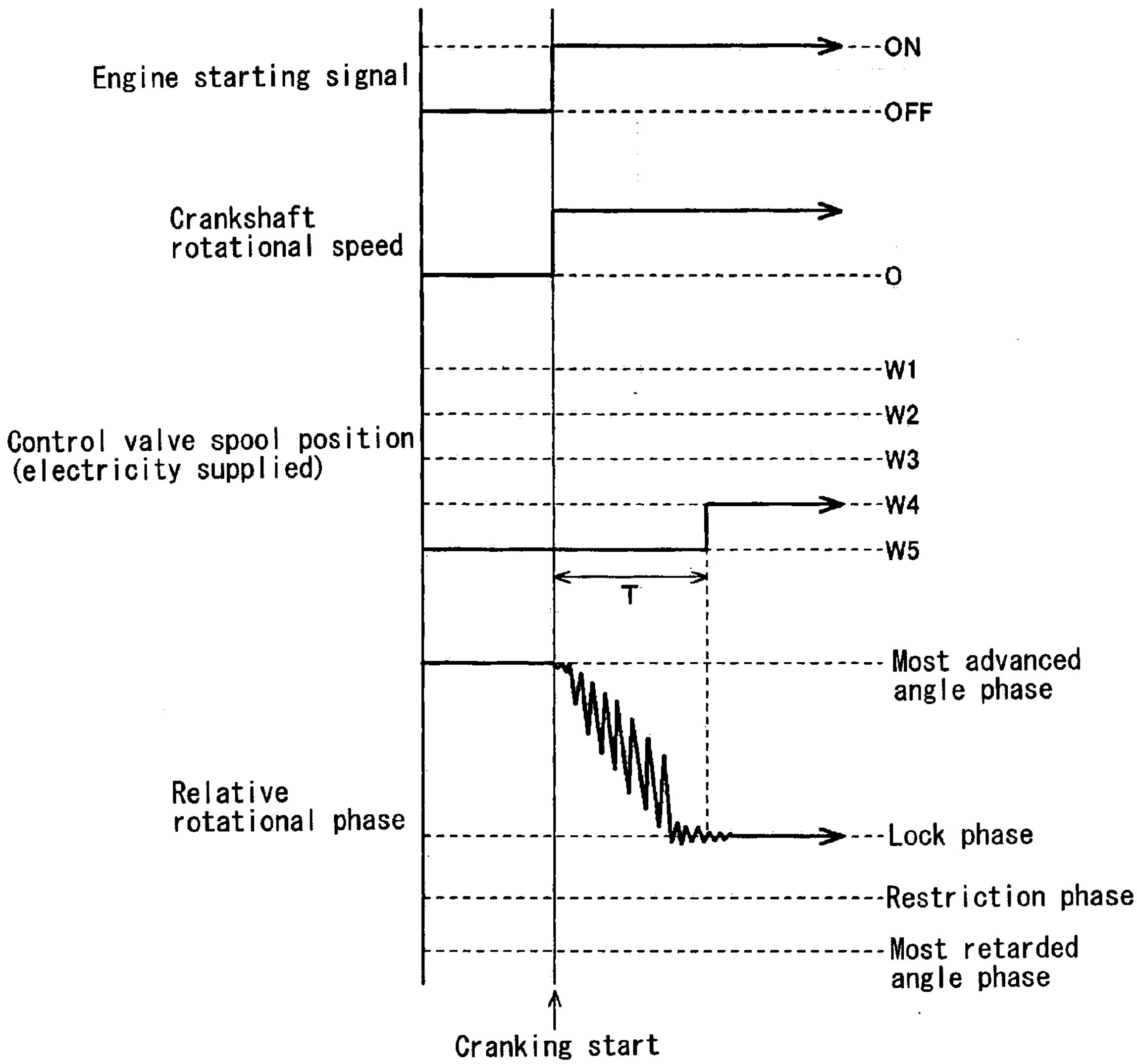
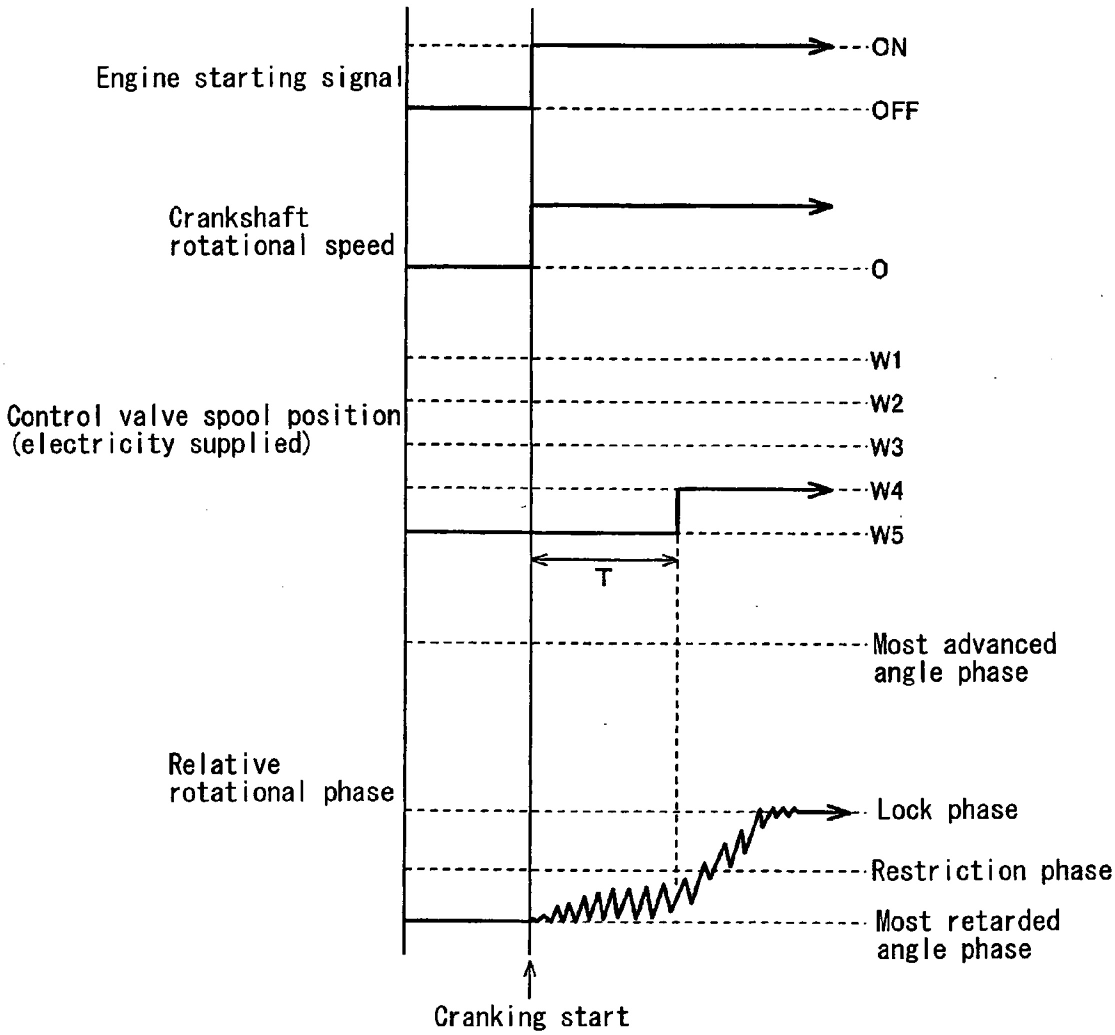

Engine starting signal
ON
OFF
Crankshaft rotational speed
0
Control valve spool position (electricity supplied)
W1
W2
W3
W4
W5
T
Most advanced angle phase
Relative rotational phase
Lock phase
Restriction phase
Most retarded angle phase
Cranking start

FIG. 11


Engine starting signal
ON
OFF
Crankshaft rotational speed
0
Control valve spool position (electricity supplied)
W1
W2
W3
W4
W5
T
Most advanced angle phase
Relative rotational phase
Lock phase
Restriction phase
Most retarded angle phase
Cranking start

VALVE TIMING CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE

[0001] This application is based on and claims priority under 35 U.S.C. §119 to Japanese Patent Application 2004-361972, filed on Dec. 14, 2004, the entire content of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to a valve timing control apparatus for controlling an opening and closing timing of valves of an internal combustion engine for a vehicle engine, or the like.

BACKGROUND

[0003] A valve timing control apparatus is known which appropriately adjusts an opening and closing timing of a valve, and achieves optimal driving conditions by means of a displacement of a relative rotational phase between a driving side rotational member, which rotates in synchronization with a crankshaft, and a driven side rotational member, which rotates in synchronization with a camshaft. A known valve timing control apparatus is disclosed in JP2002-097912A (see pp. 2-3 **FIGS. 2-5**).

[0004] The disclosed valve timing control apparatus includes a housing member synchronously rotatable with the crankshaft, a rotor member synchronously rotatable with the camshaft, a relative rotation controlling mechanism actuated in response to supply and discharge of operation fluid, a fluid pressure circuit for controlling the operation fluid to be supplied to and discharged from an advanced angle fluid chamber, a retarded angle fluid chamber, and the relative rotation controlling mechanism, and an auxiliary controlling mechanism actuated in response to the operation fluid supplied to and discharged from the fluid pressure circuit. The rotor is relatively rotatably assembled on a shoe portion provided at the housing member and forms the advanced angle fluid chamber and the retarded angle fluid chamber at a vane portion in the housing member. The relative rotation controlling mechanism allows a relative rotation of the housing member and the rotor member under an unlock state, and restricts the relative rotation of the housing member and the rotor member at a lock phase between a most advanced angle phase and a most retarded angle phase under a lock state. The auxiliary controlling mechanism allows the relative rotation of the housing member and the rotor member under the unlock state, and restricts the relative rotation of the rotor member only to the retarded angle side (or to the advanced angle side) relative to the housing member at a set phase between the most retarded angle phase (or the most advanced angle phase) and the lock phase under the lock state.

[0005] According to this known valve timing control apparatus, when the relative rotational phase between the housing member and the rotor member is displaced from the most retarded angle phase (or the most advanced angle phase) to the set phase by means of a torque fluctuation applied to the camshaft, the auxiliary controlling mechanism comes into the lock state. Then, the auxiliary controlling mechanism restricts the relative rotation of the rotor member only to the retarded angle side (or to the advanced angle side) relative to the housing member, and an initial value of the relative rotational phase is held at the set phase. Accordingly, thereafter, the relative rotational phase between the housing member and the rotor member is displaced to the lock phase by means of the torque fluctuation applied to the camshaft, and the relative rotation of the housing member and the rotor member is restricted at the lock phase by means of the relative rotation controlling mechanism. Thereby, the time required for the relative rotation of the housing member and the rotor member to be restricted at the lock phase from the point of the internal combustion engine starting by means of the relative rotation controlling mechanism can be reduced. Further, an occurrence of a hitting sound and difficulties associated with a startability of the internal combustion engine can be reduced.

[0006] The valve timing control apparatus disclosed in JP2002-097912A, oscillates the relative rotational phase to displace its posture to the set phase by means of the torque fluctuation applied to the camshaft, and then makes the auxiliary controlling mechanism into the lock state. Therefore, depending on, for example, conditions of the operation fluid in the valve timing control apparatus, or types of the operation fluid at the time of the displacement of the relative rotational phase, a sufficient oscillation of the relative rotational phase cannot be ensured because of a resistance of the operation fluid, and the valve timing control apparatus may occasionally fail to displace the relative rotational phase to the set phase. For example, shortly after a stop of the internal combustion engine, when the advanced angle fluid chamber, the retarded angle fluid chamber, and the fluid pressure circuit communicating therewith are filled with the operation fluid, or when a temperature of the operation fluid is at a lower degree, the resistance of the operation fluid at the time of the oscillation of the relative rotational phase is increased. On this occasion, the valve timing control apparatus may occasionally fail to displace the relative rotational phase to the set phase. In such a case, the relative rotation controlling mechanism might fail to restrain the relative rotational phase at the lock phase, and a startability of the internal combustion engine may occasionally be adversely affected.

[0007] A need thus exists for a valve timing control apparatus, which, notwithstanding the conditions of the operation fluid in the valve timing control apparatus, or types of the operation fluid, certainly restrains the relative rotational phase between the driving side rotational member and the driven side rotational member at the lock phase, and improves the startability of the internal combustion engine.

SUMMARY OF THE INVENTION

[0008] According to an aspect of the present invention, a valve timing control apparatus includes a driving side rotational member synchronously rotated with a crankshaft, a driven side rotational member provided coaxially with the driving side rotational member and synchronously rotated with a camshaft, a fluid pressure chamber formed on at least one of the driving side rotational member and the driven side rotational member, the fluid pressure chamber being separated into an advanced angle chamber and a retarded angle chamber, a phase control apparatus controlling an operation fluid to be supplied to and discharged from one of, or both of the advanced angle chamber and the retarded angle chamber, for displacing a relative rotational phase between the driving side rotational member and the driven side rotational member within a range from a most advanced angle phase to a most retarded angle phase, a locking mechanism restraining the relative rotational phase between the driving side rotational member and the driven side rotational member at a lock phase between the most advanced angle phase and the most retarded angle phase. During cranking, the relative rotational phase is displaced relatively in one of an advanced angle direction and a retarded angle direction while oscillating. The phase control apparatus performs a starting point control for draining the operation fluid from the advanced angle chamber and the retarded angle chamber during a predetermined period of time after a starting of cranking, and supplying the operation fluid into one of the advanced angle chamber and the retarded angle chamber for displacing the relative rotational phase to the other of the advanced angle direction and the retarded angle direction after the predetermined period of time is elapsed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The foregoing and additional features and characteristics of the present invention will become more apparent from the following detailed description considered with reference to the accompanying drawings, wherein:

[0010] **FIG. 1** is a sectional view of a valve timing control apparatus according to an embodiment of the present invention.

[0011] **FIG. 2** is a sectional view of the valve timing control apparatus illustrating a condition where a relative rotational phase is at a lock phase and a locking mechanism is at a lock state, the sectional view which is taken along line II-II of **FIG. 1**.

[0012] **FIG. 3** is a sectional view of the valve timing control apparatus illustrating a condition where the relative rotational phase is at the lock phase and the locking mechanism is at an unlock state of the sectional view which is taken along line III-III of **FIG. 1**.

[0013] **FIG. 4** is a sectional view of the valve timing control apparatus illustrating a condition where the relative rotational phase is at a restriction phase, the sectional view which is taken along line IV-IV of **FIG. 1**.

[0014] **FIG. 5** is a sectional view of the valve timing control apparatus illustrating a condition where the relative rotational phase is at a most retarded angle phase, the sectional view which is taken along line V-V of **FIG. 1**.

[0015] **FIG. 6** is a sectional view of the valve timing control apparatus illustrating a condition where the relative rotational phase is at a most advanced angle phase, the sectional view which is taken along line VI-VI of **FIG. 1**.

[0016] **FIG. 7** is a view for explaining a relation between a stroke degree of a spool and operating conditions of a control valve according to the embodiment of the present invention.

[0017] **FIG. 8** is a block diagram illustrating an electrical connection structure of a control unit according to the embodiment of the present invention.

[0018] **FIG. 9** is a flowchart illustrating an operation control of the valve timing control apparatus at a starting of an engine.

[0019] **FIG. 10** is a timing chart illustrating an operation of the valve timing control apparatus in a condition where the relative rotational phase at a starting of cranking is at the most advanced angle phase.

[0020] **FIG. 11** is a timing chart illustrating an operation of the valve timing control apparatus in a condition where the relative rotational phase at the starting of cranking is at the most retarded angle phase.

DETAILED DESCRIPTION

[0021] An embodiment of the present invention will be explained hereinbelow with reference to the attached drawings.

[0022] As illustrated in **FIGS. 1-3**, a valve timing control apparatus according to the embodiment of the present invention includes an outer rotor **2** (i.e., a driving side rotational member), and an inner rotor **1** (i.e., a driven side rotational member). The outer rotor **2** rotates in synchronization with a crankshaft of an engine (not shown), and the inner rotor **1** is coaxially provided with the outer rotor **2** and rotates in synchronization with a camshaft **3**.

[0023] The inner rotor **1** is integrally assembled at an end portion of the camshaft **3**, which configures a rotational shaft of a cam for controlling an opening and closing timing of an intake valve and an exhaust valve of the engine. The camshaft **3** is rotatably assembled to a cylinder head of the engine.

[0024] Relative to the inner rotor **1**, the outer rotor **2** is externally attached, and relatively rotatable within a predetermined relative rotational phase range. The outer rotor **2** is integrally provided with, at a side in which the camshaft **3** is connected, a rear plate **23**, and is integrally provided with, at the other side, a front plate **22**. Further, the outer rotor **2** is integrally provided with, at an outer circumference, a timing sprocket **20**. A transmission member **24** such as a timing chain, a timing belt, or the like, is hung across the timing sprocket **20** and a sprocket assembled to the crankshaft of the engine.

[0025] When the crankshaft of the engine is rotated, a rotational force is transmitted to the timing sprocket **20** through the transmission member **24**, then the outer rotor **2** rotates in a rotational direction S as illustrated in **FIG. 2**. Consequently, the inner rotor **1** rotates in the rotational direction S, then the camshaft **3** rotates, and then the cam provided at the camshaft **3** pushes down the intake valve or the exhaust valve of the engine to open the valve.

[0026] As illustrated in **FIG. 2**, the outer rotor **2** is arranged with plural protruding portions **4** along a rotational direction in such a manner to separate from each other. Each protruding portion **4** (i.e., a shoe) is protruded in a radial direction. Between each adjacent protruding portion **4** of the outer rotor **2**, a fluid pressure chamber **40**, defined by the outer rotor **2** and the inner rotor **1**, is provided. According to the embodiment of the present invention, four fluid pressure chambers **40** are provided.

[0027] The inner rotor **1** is formed with, at a part of an outer circumferential portion facing the fluid pressure chamber **40**, a vane groove **41**. A vane **5**, which separates the fluid pressure chamber **40** into an advanced angle chamber **43** and a retarded angle chamber **42** in a relative rotational direction (a direction of arrows S1 and S2 in **FIG. 2**), is slidably inserted into the vane groove **41** in a radial direction. As illustrated in **FIG. 1**, the vane **5** is biased toward an inner wall surface w of the fluid pressure chamber **40** by means of a spring **51** provided at a side of an inner diameter of the vane **5**.

[0028] The advanced angle chamber **43** of the fluid pressure chamber **40** is communicated with an advanced angle passage **11** formed in the inner rotor **1**, the retarded angle chamber **42** is communicated with a retarded angle passage **10** formed in the inner rotor **1**, and the both of the advanced and retarded angle passages **11** and **10** are connected to a fluid pressure circuit **7**. By supplying or discharging the operation fluid through the fluid pressure circuit **7** relative to one of, or both of the advanced angle chamber **43** and the retarded angle chamber **42**, a biasing force is generated. The biasing force displaces a relative rotational phase between the inner rotor **1** and the outer rotor **2** within a range from a most advanced angle phase to a most retarded angle phase, or holds the relative rotational phase between the inner rotor **1** and the outer rotor **2** at a given phase.

[0029] As illustrated in **FIG. 1**, between the inner rotor **1** and the front plate **22** of the outer rotor **2**, a torsion spring **27** serving as a biasing mechanism is provided that biases the relative rotational phase between the inner rotor **1** and the outer rotor **2** in the advanced angle direction. More particularly, the torsion spring **27** applies a torque, which normally biases the inner rotor **1** and the outer rotor **2**, in a direction in which the vane **5** is displaced in the advanced angle direction (a direction of S2 in **FIG. 2**). A torque setting of the torsion spring **27** is set so as to displace the relative rotational phase between the outer rotor **2** and the inner rotor **1** (hereinafter, the relative rotational phase) relatively in the retarded angle direction while oscillating during cranking for starting the engine. More particularly, according to the embodiment of the present invention, a torque fluctuation applied to the camshaft **3** during cranking is large in the retarded angle direction, and is small in the advanced angle direction. Therefore, by means of the torque fluctuation, the relative rotational phase is displaced relatively in the retarded angle direction while oscillating. The torque setting of the torsion spring **27** is set for biasing the relative rotational phase in the advanced angle direction within a range in which the displacement of the relative rotation in the retarded angle direction is not interrupted. The torque fluctuation, which is applied to the camshaft **3** during cranking, is generated by means of, for example, a resistance of a valve spring in a condition where the cam provided at the camshaft **3** performs an opening and closing operation of the engine valve against the biasing force of the valve spring.

[0030] Further, between the inner rotor **1** and the outer rotor **2**, the locking mechanism **6** is provided that is capable of restraining the relative rotation of the inner rotor **1** and the outer rotor **2** in a condition where the relative rotational phase is at a predetermined lock phase (a phase illustrated in **FIG. 2**) between the most advanced angle phase and the most retarded angle phase. The locking mechanism **6** includes a retarded angle locking portion **6**A and an advanced angle locking portion **6**B both of which are provided at the outer rotor **2**. The locking mechanism **6** further includes a recess formed locking chamber **62** provided at a part of the outer circumference portion of the inner rotor **1**. The locking chamber **62** communicates with a locking passage **63** formed in the inner rotor **1**, and the locking passage **63** is connected to the fluid pressure circuit **7**.

[0031] Each retarded angle locking portion **6**A and the advanced angle locking portion **6**B includes a locking member **60**, which is provided at the outer rotor **2** and slidable in the radial direction, and a spring **61**, which biases the locking member **60** inwardly in the radial direction. According to various usages, the locking member **60** may adopt various shapes such as a plate shape, and a pin shape.

[0032] The retarded angle locking portion **6**A prevents the inner rotor **1** from relatively rotating in the retarded angle direction relative to the outer rotor **2** by protruding the locking member **60** into the locking chamber **62**. In contrast, the advanced angle locking portion **6**B prevents the inner rotor **1** from relatively rotating in the advanced angle direction relative to the outer rotor **2** by protruding the locking member **60** into the locking chamber **62**. More particularly, by protruding one of the retarded angle locking portion **6**A and the advanced angle locking portion **6**B into the locking chamber **62**, a displacement of the relative rotational phase into one of the retarded angle direction and the advanced angle direction is restricted, and the displacement of the relative rotational phase into the other of the retarded angle direction and the advanced angle direction is allowed. On this occasion, a protruding operation of the locking member **60** into the locking chamber **62** is performed, by means of a biasing force of the spring **61**, in a drain condition where the operation fluid is not supplied into the locking chamber **62**.

[0033] According to the embodiment of the present invention, the locking chamber **62** is provided with, at a retarded angle side, a restricting step portion **64**. The restricting step portion **64** is formed stepwise on an outer circumferential surface of the inner rotor **1**. The restricting step portion **64** is provided at a wall portion extending in the radial direction at the retarded angle side of the locking chamber **62** into which the retarded angle locking portion **6**A is insertable. According to the embodiment of the present invention, a restriction phase is defined between the most retarded angle phase (a phase illustrated in **FIG. 5**) and the lock phase (phases illustrated in **FIGS. 2-3**). When the retarded angle locking portion **6**A of the locking mechanism **6** is protruded and engaged with the restricting step portion **64** as illustrated in **FIG. 4**, the restricting step portion **64** restricts the displacement of the relative rotational phase to the retarded angle side from the restriction phase, and allows the displacement of the relative rotational phase to the advanced angle side.

[0034] As illustrated in **FIG. 2**, in a condition where the locking member **60** of the retarded angle locking portion **6**A and the locking member **60** of the advanced angle locking portion **6**B are protruded into the locking chamber **62**, a lock state is achieved for restraining the displacement of the relative rotational phase between the inner rotor **1** and the outer rotor **2** at the predetermined lock phase, which is set between the most advanced angle phase (a phase illustrated in **FIG. 6**) and the most retarded angle phase. Regarding a valve opening and closing timing of the engine, the lock phase is set for obtaining a smooth startability of the engine.

[0035] The locking member **60** is retracted from the locking chamber **62** by supplying the operation fluid into the locking chamber **62** through the locking passage **63**. More particularly, when the locking chamber **62** is filled with the operation fluid, because of a pressure of the operation fluid in the locking chamber **62**, a biasing force, which is applied in a direction in which the locking member **60** is housed in the outer rotor **2** (a direction in which the locking member **60** is retracted from the locking chamber **62**) is generated. In a condition where the biasing force generated by the pressure of the operation fluid becomes greater degree than the biasing force of the spring **61**, which is applied in a direction in which the locking member **60** is protruded into the locking chamber **62**, the locking member **60** is retracted from the locking chamber **62** as illustrated in **FIG. 3**. Accordingly, the locking mechanism **6** achieves an unlock state, which allows the displacement of the relative rotational phase between the inner rotor **1** and the outer rotor **2**.

[**0036**] The fluid pressure circuit **7** includes an oil pump **70**, a control valve **76**, and an oil pan **75**. The oil pump **70** supplies the operation fluid relative to the control valve **76** by means of a driving force of the engine, the control valve **76** controls supply and discharge of the operation fluid at plural ports by means of a control of a control unit **9** (ECU: Electric Control Unit), and the oil pan **75** stores the operation fluid therein. According to the embodiment of the present invention, an electromagnetic spool valve is used as the control valve **76** that operates and displaces a spool **76***b* against a spring **76***g* by means of an energization from the control unit **9** to a solenoid **76***a*.

[**0037**] A first port **76***c* of the control valve **76** is connected to the advanced angle passage **11** communicating with the advanced angle chamber **43**, a second port **76***d* of the control valve **76** is connected to the retarded angle passage **10** communicating with the retarded angle chamber **42**, and a third port **76***e* of the control valve **76** is connected to the locking passage **63** communicating with the locking chamber **62**. Further, a drain port **76***f* of the control valve **76** is communicated with the oil pan **75**.

[**0038**] By means of the control of the control unit **9**, the control valve **76** controls, through the advanced angle passage **11** and the retarded angle passage **10**, supply and discharge of the operation fluid relative to one of, or both of the advanced angle chamber **43** and the retarded angle chamber **42**, and varies the relative position of the vane **5** in the fluid pressure chamber **40**, and thereby controls the displacement of the relative rotational phase between the outer rotor **2** and the inner rotor **1** within the range from the most advanced angle phase (a phase in which a volume of the advanced angle chamber **43** is maximized) as illustrated in **FIG. 6** to the most retarded angle phase (a phase in which a volume of the retarded angle chamber **42** is maximized) as illustrated in **FIG. 5**. Accordingly, the control valve **76** and the control unit **9** for controlling the control valve **76** both represent a phase control apparatus **71** according to the embodiment of the present invention.

[**0039**] According to the embodiment of the present invention, the control valve **76** also serves as a lock control apparatus **72**, which controls an operation for varying a position of the locking mechanism **6** between the lock state and the unlock state. More particularly, by means of the control of the control unit **9**, the control valve **76** controls supply and discharge of the operation fluid relative to the locking chamber **62** through the locking passage **63**, and controls the protruding operation and a retracting operation of the locking member **60** relative to the locking chamber **62**.

[**0040**] As illustrated in **FIG. 7**, by controlling an amount of electricity supplied from the control unit **9** to the solenoid **76***a*, the control valve **76** of the fluid pressure circuit **7** controls a degree of a stroke of the spool **76***b*, and changes a spool position from position W**1** to position W**5**, and thereby switches operations of supply, discharge (drain), and stop (close) of the operation fluid relative to the advanced angle chamber **43**, the retarded angle chamber **42**, and the locking chamber **62**. According to the embodiment of the present invention, a control for the amount of electricity supplied to the solenoid **76***a* is performed by varying a duty value (%) of current for supplying to the solenoid **76***e*. The degree of the stroke of the spool **76***b* is proportional to the amount of electricity supplied to the solenoid **76***a* (the duty value of current). However the invention is not limited thereto. Alternatively, or in addition, the control for the amount of electricity supplied to the solenoid **76***a* may be performed by various methods such as, by varying a current value, by varying a duty value (%) of an electrical pressure, and by varying an electrical pressure value. Control operations of the control valve **76** at each predetermined spool position is explained with reference to **FIG. 7**. However, the control operation is not limited as described below, and variations and changes may be made by others.

[**0041**] In a condition where the spool position is at the position W**1**, the control valve **76** supplies the operation fluid into the locking chamber **62**, retracts the locking member **60** from the locking chamber **62**, and makes the locking mechanism **6** into a unlock state. Further, by supplying the operation fluid into the retarded angle chamber **42** while draining the operation fluid from the advanced angle chamber **43**, the control valve **76** performs a retarded angle direction displacement operation for displacing the relative rotational phase between the outer rotor **2** and the inner rotor **1** in a retarded angle direction S**1**.

[**0042**] In a condition where the spool position is at position W**2**, the control valve **76** stops supply and discharge of the operation fluid relative to both of the advanced angle chamber **43** and the retarded angle chamber **42** (closes the first port **76***c* and the second port **76***d*), and performs a phase holding operation for holding the relative rotational phase between the outer rotor **2** and the inner rotor **1** at a given time at a given position.

[**0043**] In a condition where the spool position is at position W**3**, the control valve **76** supplies the operation fluid into the locking chamber **62**, and makes the locking mechanism **6** into the unlock state. Further, by supplying the operation fluid into the advanced angle chamber **43** while draining the operation fluid from the retarded angle chamber **42**, the control valve **76** performs an advanced angle direction displacement operation for displacing the relative rotational phase between the outer rotor **2** and the inner rotor **1** in an advanced angle direction S**2**.

[**0044**] In a condition where the spool position is at position W**4**, the control valve **76** drains the operation fluid from the locking chamber **62**, and when the relative rotational phase becomes the lock phase, the control valve **76** makes the locking mechanism **6** into a lockable position. Further, the control valve **76** supplies the operation fluid into the advanced angle chamber **43** while draining the operation fluid from the retarded angle chamber **42**. Thereby, the control valve **76** performs an advanced angle biasing operation for biasing the relative rotational phase in the advanced angle direction S**2** in a condition where the locking mechanism **6** is at the lockable position. This operation is performed, as described below, for making the relative rotational phase into the lock phase and making the locking mechanism **6** into the lock state in a starting point control.

[**0045**] In a condition where the spool position is at the position W**5**, a drain operation is performed for making a condition in which the operation fluid of the advanced angle chamber **43**, the retarded angle chamber **42**, and the locking chamber **62** can be discharged to the oil pan **75**. Because of this operation, all of the first port **76***c*, the second port **76***d*, and the third port **76***e* of the control valve **76** communicate with the drain port **76***f*.

[**0046**] As illustrated in **FIG. 8**, the control unit **9** includes a central processing unit **91** (i.e., a CPU) for calculation, a memory **92** for storing predetermined programs, data tables, or the like, an input/output interface **93**. The control unit **9** receives signals detected by various sensors such as a cam angle sensor **101** for detecting a camshaft phase, a crank angle sensor **102** for detecting a crankshaft phase, an ignition switch **103**, a fluid temperature sensor **104** for detecting a temperature of the operation fluid, a rotational speed sensor **105** for detecting a rotational speed of the crankshaft (a rotational speed of the engine), a coolant temperature sensor **106** for detecting a temperature of a cooling water of the engine. The control unit **9** further receives the signals detected by various sensors such as a vehicle speed sensor (not shown) and a throttle angle sensor (not shown). On the basis of the signals detected by the various sensors, the control unit **9** detects operating conditions of the engine.

[**0047**] On the basis of a phase of the camshaft **3** detected by the cam angle sensor **101** and a phase of the crankshaft detected by the crank angle sensor **102**, the control unit **9** can calculate a present value of a relative rotational phase between the camshaft **3** and the crankshaft (i.e., the relative rotational phase between the inner rotor **1** and the outer rotor **2** of the valve timing control apparatus).

[**0048**] On the basis of operating conditions of the engine such as a temperature of an engine fluid, a rotational speed of the crankshaft, a vehicle speed, a throttle angle, or the like, detected by the various sensors, the control unit **9** controls the amount of electricity supplied to the control valve **76**. Thereby, the control unit **9** controls supply and discharge of the operation fluid relative to the advanced angle chamber **43**, the retarded angle chamber **42**, and the locking chamber **62**, by means of the control valve **76**. Accordingly the control unit **9** appropriately varies the relative rotational phase between the inner rotor **1** and the outer rotor **2**, and conditions of the locking mechanism **6** so as to be suitable for the operating conditions of the engine of that time.

[**0049**] With reference to a flowchart illustrated in **FIG. 9**, an operation control of the valve timing control apparatus according to the embodiment of the present invention is explained by focusing a control at a starting of the engine (the starting point control).

[**0050**] When the control unit **9** receives an engine starting signal from the ignition switch **103**, cranking is started (step S**1**: YES). Then, the control unit **9** changes the spool position of the control valve **76** to the position W**5** for performing a drain operation so that the operation fluid in both of the advanced angle chamber **43** and the retarded angle chamber **42** is drainable (step S**2**). At the position W**5**, the operation fluid in the locking chamber **62** is also drainable. In this condition, by means of the torque fluctuation supplied to the camshaft **3** during cranking, the vane **5** is oscillated in the advanced angle direction and in the retarded angle direction one after the other. In case the advanced angle chamber **43** and the retarded angle chamber **42** are filled with the operation fluid at a starting of cranking, by means of an oscillation of the vane **5**, the operation fluid in the advanced angle chamber **43** and the retarded angle chamber **42** is discharged. Thereby, a facility of an operation of the vane **5** by means of the torque fluctuation, i.e., a flexibility of the oscillation and the displacement of the relative rotational phase between the outer rotor **2** and the inner rotor **1** can be well ensured.

[**0051**] The torque fluctuation applied to the camshaft **3** during cranking in the retarded angle direction is larger degree than that of in the advanced angle direction. Further, the torque setting of the torsion spring **27** is set in such a manner not to interrupt the displacement of the relative rotational phase in the retarded direction. Therefore, when the flexibility of the oscillation and the displacement of the relative rotational phase is ensured, the relative rotational phase is displaced relatively in the retarded angle direction while oscillating during cranking. Accordingly, when the relative rotational phase at the starting of cranking is positioned at the advanced angle side position relative to the lock phase, the relative rotational phase is displaced in the retarded angle direction by means of the torque fluctuation and achieves the lock phase during cranking. On this occasion, because the operation fluid in the locking chamber **62** is also drainable, the locking mechanism **6** comes into the lock state when the relative rotational phase reaches the lock phase. Thereby a condition is achieved where the engine can be well started. Then, when the engine is started (step S**3**: YES), a control after an engine starting is started (step S**7**).

[**0052**] **FIG. 10** illustrates an example in case the relative rotational phase at the starting of cranking is positioned at the advanced angle side position relative to the lock phase. A timing chart illustrated in **FIG. 10** indicates an operation of the valve timing control apparatus according to the embodiment of the present invention in a condition where the relative rotational phase at the starting of cranking is positioned at the most advanced angle phase as shown in **FIG. 6**. In this case, when the engine starting signal is inputted, the crankshaft is rotated by means of an electrical motor, or the like, and then cranking is started, and thereby the relative rotational phase is displaced relatively in the retarded angle direction while oscillating by means of the torque fluctuation applied to the camshaft **3**. Then, the locking mechanism **6** comes into the lock state when the relative rotational phase reaches the lock phase, and the relative rotational phase is thereby restrained at the lock phase. **FIG. 10** illustrates an example in case the advanced angle chamber **43** and the retarded angle chamber **42** are filled with operation fluid at the starting of cranking, and an oscillation level of the relative rotational phase is increased in response to a degree of the operation fluid to be discharged from the advanced angle chamber **43** and the retarded angle chamber **42** by means of the oscillation of the vane **5**.

[**0053**] According to **FIG. 10**, the spool position of the control valve **76** is changed to the position W**4** after a predetermined period of time T is elapsed. However, normally, the relative rotational phase is restrained at the lock phase and the engine is started (step S**3**: YES) before the predetermined period of time T is elapsed, and the operation control of the valve timing control apparatus progresses the control after the engine starting (step S**7**). Therefore, a control after a termination of the predetermined period of time T (step S**5**), is not usually performed.

[**0054**] In contrast, when the relative rotational phase at the starting of cranking is positioned at the retarded angle side position relative to the lock phase, even if the relative rotational phase is displaced in the retarded angle direction by means of the torque fluctuation applied to the camshaft **3** during cranking, because the lock phase is positioned in the advanced angle side relative to the present relative rotational phase, the locking mechanism **6** does not come into the lock state. On this occasion, the relative rotational phase is oscillated in the vicinity of the most retarded angle phase. In such a condition, a startability of the engine may be adversely affected, and the engine m ay occasionally fail to start.

[**0055**] In a condition where the engine is not started (step S**3**: NO) and the predetermined period of time T is elapsed (step S**4**: YES), the control unit **9** changes the spool position of the control valve **76** to the position W**4** and performs the advanced angle biasing operation, and supplies the operation fluid into the advanced angle chamber **43** while draining the operation fluid from the retarded angle chamber **42** (step S**5**). On this occasion, the operation fluid of the locking chamber **62** is also drained. Therefore, the relative rotational phase is displaced relatively in the retarded angle direction by means of the pressure of the operation fluid supplied into the advanced angle chamber **43** while oscillating by means of the torque fluctuation applied to the camshaft **3** during cranking. Accordingly, when the relative rotational phase at the starting of cranking is positioned at the retarded angle side position relative to the lock phase, the relative rotational phase is displaced in the advanced angle direction by means of the pressure of the operation fluid supplied in the advanced angle chamber **43** and achieves the lock phase. On this occasion, because the operation fluid in the locking chamber **62** is also dischargeable, the locking mechanism **6** comes into the lock state when the relative rotational phase reaches the lock phase. Thereby the condition in which the engine can be well started is achieved. Then, when the engine is started (step S**6**: YES), the control after the engine starting is started (step S**7**).

[**0056**] The predetermined period of time T is set, in a condition where cranking is started with the advanced angle chamber **43** and the retarded angle chamber **42** filled with the operation fluid longer than, or equal to, a time required for a center of the oscillation of the relative rotational phase during cranking to be displaced to the lock phase from the most advanced angle phase. In other words, the predetermined period of time T is set, in a condition where the lock phase is positioned in a direction (retarded angle direction) in which the relative rotational phase is displaced by means of the torque fluctuation applied to the camshaft **3** during cranking relative to the relative rotational phase at the starting of cranking (in a condition where the relative rotational phase at the starting of cranking is positioned at the advanced angle side position relative to the lock phase) longer than, or equal to, an estimated longest time required for the relative rotational phase to be displaced to the lock phase by means of the torque fluctuation. According to the embodiment of the present invention, the valve timing control apparatus at the estimated longest time is in a condition where the advanced angle chamber **43** and the retarded angle chamber **42** are filled with the operation fluid, and the relative rotational phase is positioned at the most advanced angle phase. The predetermined period of time T can be statistically calculated by means of a regression analysis on the basis of a test.

[**0057**] **FIG. 11** illustrates an example in case of the relative rotational phase at the starting of cranking is positioned at the retarded angle side position relative to the lock phase. A timing chart illustrated in **FIG. 11** indicates an operation of the valve timing control apparatus according to the embodiment of the present invention in a condition where the relative rotational phase at the starting of cranking is positioned at the most retarded angle phase as shown in **FIG. 5**. In this case, when the engine starting signal is inputted, the crankshaft is rotated by means of an electrical motor, or the like, and then cranking is started. According to this operation, the relative rotational phase is oscillated by means of the torque fluctuation applied to the camshaft **3**. However, because the relative rotational phase cannot be displaced in the retarded direction more than the present position, the relative rotational phase is oscillated in the vicinity of the most retarded angle phase. Therefore, on this occasion, the relative rotational phase does not reach the lock phase. Thus, after the predetermined period of time T is elapsed, the control unit **9** changes the spool position of the control valve **76** to the position W**4** (step S**5**). Thereby, the relative rotational phase is displaced relatively in the advanced angle direction by means of the pressure of the operation fluid supplied into the advanced angle chamber **43** while oscillating by means of the torque fluctuation. Then, when the relative rotational phase reaches the restriction phase, the locking member **60** of the locking mechanism **6** protrudes and engages with the restricting step portion **64**, and thereby the displacement of the relative rotational phase in the retarded direction is restricted. Further, the locking mechanism **6** comes into the lock state when the relative rotational phase is displaced in the advanced angle direction and reached the lock phase. Thereby the relative rotational phase is restrained at the lock phase and the condition in which the engine can be well started is achieved. Then, when the engine is started (step S**6**: YES), the control after the engine starting is started (step S**7**). **FIG. 11** illustrates an example in case cranking is started with the advanced angle chamber **43** and the retarded angle chamber **42** are filled with the operation fluid, and the oscillation level of the relative rotational phase is increased in response to a degree of the operation fluid to be discharged from the advanced angle chamber **43** and the retarded angle chamber **42** by means of the oscillation of the vane **5**.

[**0058**] According to the embodiment of the present invention, by means of the torque fluctuation applied to the camshaft **3** during cranking, the relative rotational phase between the outer rotor **2** and the inner rotor **1** is displaced relatively in the retarded angle direction while oscillating. However the invention is not limited thereto. Alternatively, or in addition, the relative rotational phase may be displaced relatively in the advanced angle direction while oscillating during cranking by means of the torque fluctuation applied to the camshaft **3** during cranking. In such a case the torsion spring **27** is provided for biasing the relative rotational phase in the retarded angle direction. The aforementioned explanation for the operation control at the starting of the engine (the starting point control) can be applied to this variation on a condition that the words advanced and retarded are switched.

[0059] According to the embodiment of the present invention, the locking chamber **62** is provided with, at the retarded angle side, the restricting step portion **64**. The restricting step portion **64**, at the restriction phase defined between the most retarded angle phase and the lock phase, restricts the displacement of the relative rotational phase to the retarded angle side from the restriction phase, and allows the displacement of the relative rotational phase to the advanced angle side. Thereby, a reliability of a restraint of the relative rotational phase by means of the locking mechanism **6** can be improved. However the invention is not limited thereto. Alternatively, or in addition, the valve timing control apparatus may be configured without the restricting step portion **64**. It is because, according to the embodiment of the present invention, the displacement of the rotational phase from the most retarded angle phase to the lock phase can be certainly performed by forcibly displacing the relative rotation in the advanced angle direction by supplying the operation fluid into the advanced angle chamber **43** after the predetermined period of time T is elapsed.

[0060] According to the embodiment of the present invention, during the predetermined period of time after the staring of cranking, the cranking is performed in a condition where the operation fluid in both of the advanced angle chamber and the retarded angle chamber is drainable. Therefore, by means of the oscillation of the relative rotational phase, the relative rotational phase can be displaced in one of the advanced angle direction and the retarded angle direction while draining the operation fluid from the advanced angle chamber and the retarded angle chamber. Accordingly, in a condition where the lock phase is positioned at one of the advanced angle side and the retarded angle side relative to the relative rotational phase at the starting of cranking, the relative rotational phase can be restrained by means of the locking mechanism. In contrast, in a condition where the lock phase is not positioned at the one of the advanced angle side and the retarded angle side, the operational fluid is supplied into one of the advanced angle chamber and the retarded angle chamber for displacing the relative rotational phase to the other of the advanced angle side and the retarded angle side after the predetermined period of time is elapsed, thus the relative rotational phase can be restrained by means of the locking mechanism. Accordingly, the reliability of the restraint of the relative rotational phase by means of the locking mechanism at the starting of the internal combustion engine can be improved.

[0061] The present invention is applicable as long as the predetermined period of time is set, in a condition where cranking is started with the fluid pressure chamber filled with the operation fluid, longer than, or equal to, the time required for the center of the oscillation of the relative rotational phase during cranking to be displaced to the lock phase from one of the most advanced angle phase and the most retarded angle phase positioned in the other of the advanced angle direction and the retarded angle direction. In such a condition, the relative rotational phase can certainly be reached to the lock phase in a condition where the lock phase is positioned at the one of the advanced angle side and the retarded angle side. Accordingly, the reliability of the restraint by means of the locking mechanism can be improved.

[0062] The present invention is applicable as long as the phase control apparatus discontinues the starting point control when the internal combustion engine is started, and starts the control after the engine starting.

[0063] The principles, preferred embodiment and mode of operation of the present invention have been described in the foregoing specification. However, the invention which is intended to be protected is not to be construed as limited to the particular embodiment disclosed. Further, the embodiment described herein are to be regarded as illustrative rather than restrictive. Variations and changes may be made by others, and equivalents employed, without departing from the spirit of the present invention. Accordingly, it is expressly intended that all such variations, changes and equivalents which fall within the spirit and scope of the present invention as defined in the claims, be embraced thereby.

1. A valve timing control apparatus comprising:

a driving side rotational member synchronously rotated with a crankshaft;

a driven side rotational member provided coaxially with the driving side rotational member and synchronously rotated with a camshaft;

a fluid pressure chamber formed on at least one of the driving side rotational member and the driven side rotational member, the fluid pressure chamber being separated into an advanced angle chamber and a retarded angle chamber;

a phase control apparatus controlling an operation fluid to be supplied to and discharged from one of, or both of the advanced angle chamber and the retarded angle chamber, for displacing a relative rotational phase between the driving side rotational member and the driven side rotational member within a range from a most advanced angle phase to a most retarded angle phase; and

a locking mechanism restraining the relative rotational phase between the driving side rotational member and the driven side rotational member at a lock phase between the most advanced angle phase and the most retarded angle phase, wherein

during cranking, the relative rotational phase is displaced relatively in one of an advanced angle direction and a retarded angle direction while oscillating, and wherein

the phase control apparatus performs a starting point control for discharging the operation fluid from the advanced angle chamber and the retarded angle chamber during a predetermined period of time after a starting of cranking, and supplying the operation fluid into one of the advanced angle chamber and the retarded angle chamber for displacing the relative rotational phase to the other of the advanced angle direction and the retarded angle direction after the predetermined period of time is elapsed.

2. The valve timing control apparatus according to claim 1, wherein

the predetermined period of time is set, in a condition where cranking is started with the fluid pressure chamber filled with the operation fluid, longer than, or equal to, a time required for a center of an oscillation of the relative rotational phase during cranking to be displaced to the lock phase from one of the most advanced angle phase and the most retarded angle phase positioned in the other of the advanced angle direction and the retarded angle direction.

3. The valve timing control apparatus according to claim 1, wherein

the phase control apparatus discontinues the starting point control when the internal combustion engine is started, and starts a control after an engine starting.

4. The valve timing control apparatus according to claim 1, wherein

The phase control apparatus includes:

a biasing mechanism set for displacing the relative rotational phase between the driving side rotational member and the driven side rotational member to the advanced angle direction, wherein

by means of the biasing mechanism and a pressure of the operation fluid supplied into one of the advanced angle chamber and the retarded angle chamber, the phase control apparatus displaces the relative rotational phase relatively in one of the advanced angle direction and the retarded angle direction while oscillating during cranking.

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