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(54) **FLUID CONTROL VALVE**

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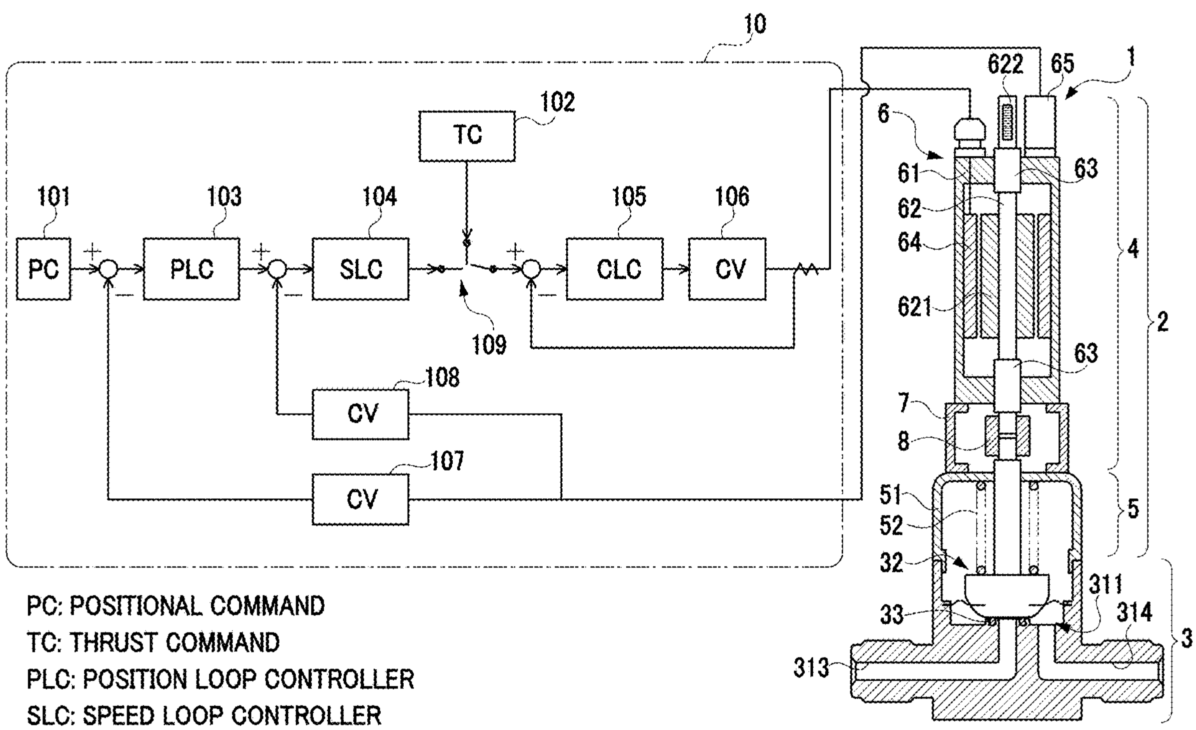
(57) **ABSTRACT**

The present invention has: a valve body; a servo motor having a drive shaft for operating the valve body; a position control mode for controlling the drive shaft to move the drive shaft to a target position, and a thrust control mode for controlling the drive shaft to cause the drive shaft to obtain a target thrust; and a control program that, when operating the valve body from a valve open position to a valve close position, controls the servo motor in the position control mode from the valve open position until the valve body reaches a predetermined position before reaching the valve close position, and, from the predetermined position, switches the control of the servo motor from the position control mode to the thrust control mode with a target thrust of zero, and causes the valve body to reach the valve close position only by the biasing force.



PC: POSITIONAL COMMAND
TC: THRUST COMMAND
PLC: POSITION LOOP CONTROLLER
SLC: SPEED LOOP CONTROLLER
CLC: CURRENT LOOP CONTROLLER
CV: CONVERTER

FIG. 1

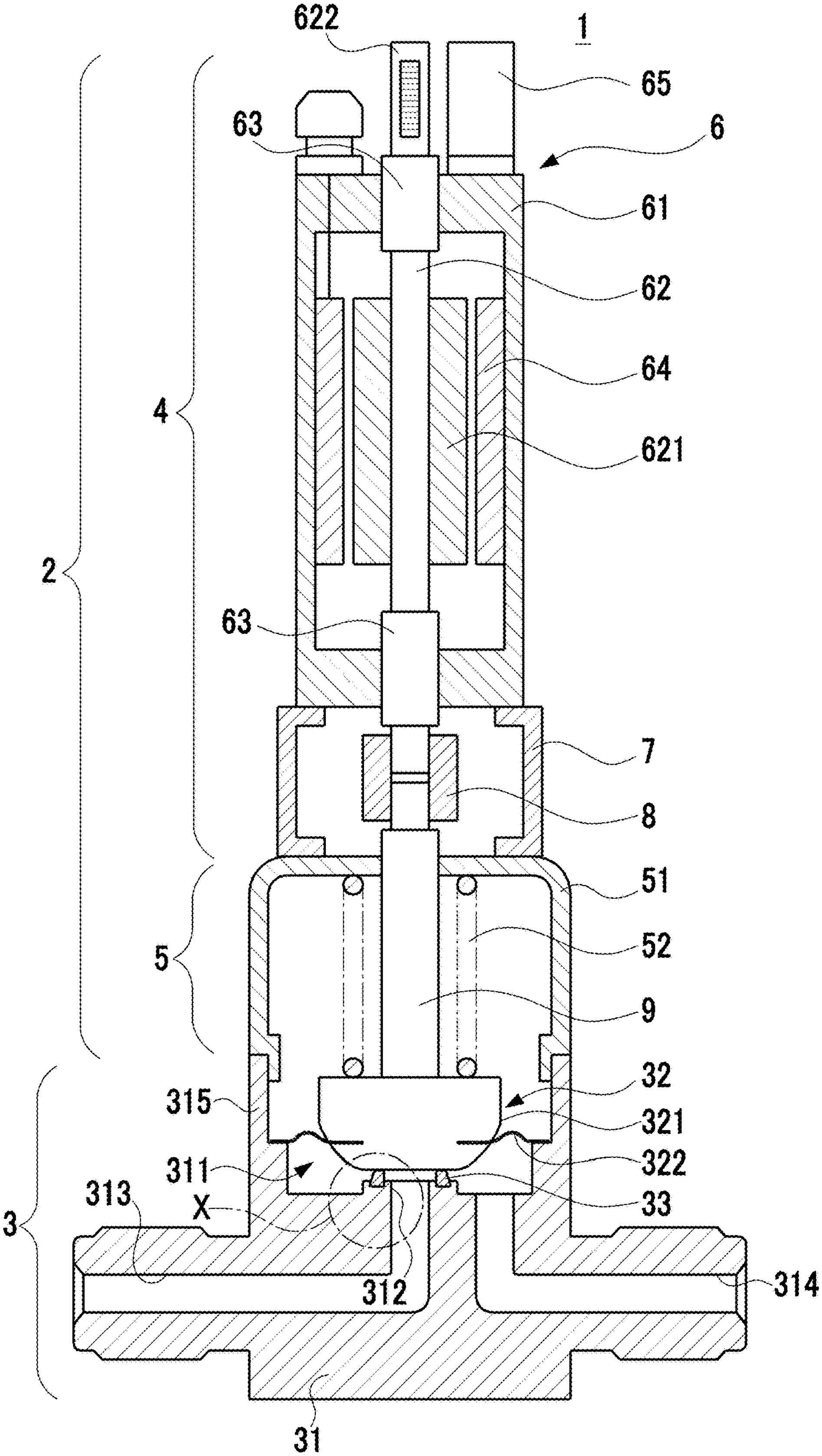

622
1
65
63
6
61
62
64
4
621
2
63
7
8
51
52
5
9
32
315
321
311
322
313
33
X
3
314
312
31

FIG. 2

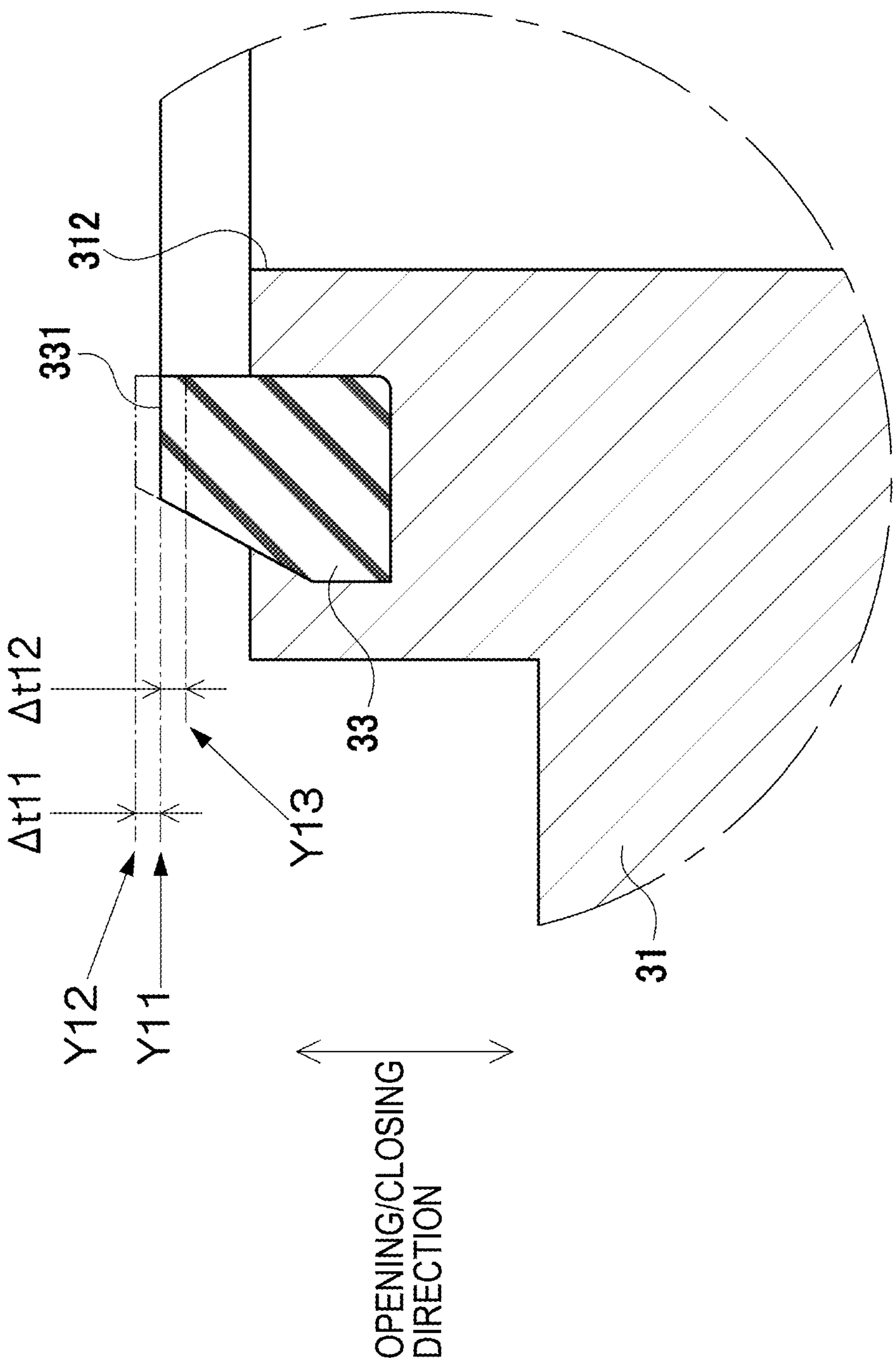
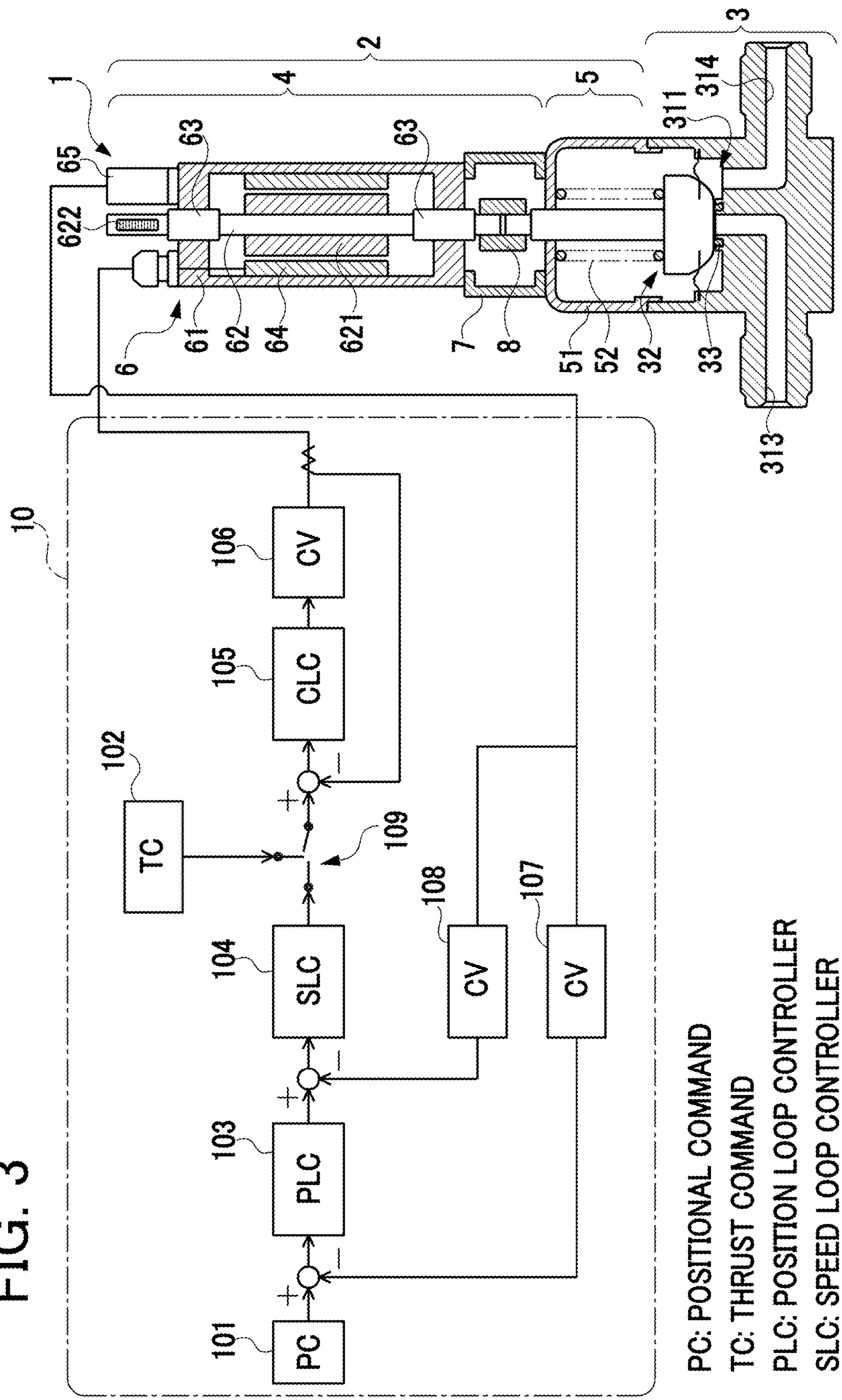

312
331
33
Δt12
Δt11
Y13
Y12
Y11
31
OPENING/CLOSING DIRECTION

FIG. 3



PC: POSITIONAL COMMAND
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PLC: POSITION LOOP CONTROLLER
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CLC: CURRENT LOOP CONTROLLER
CV: CONVERTER

FIG. 4

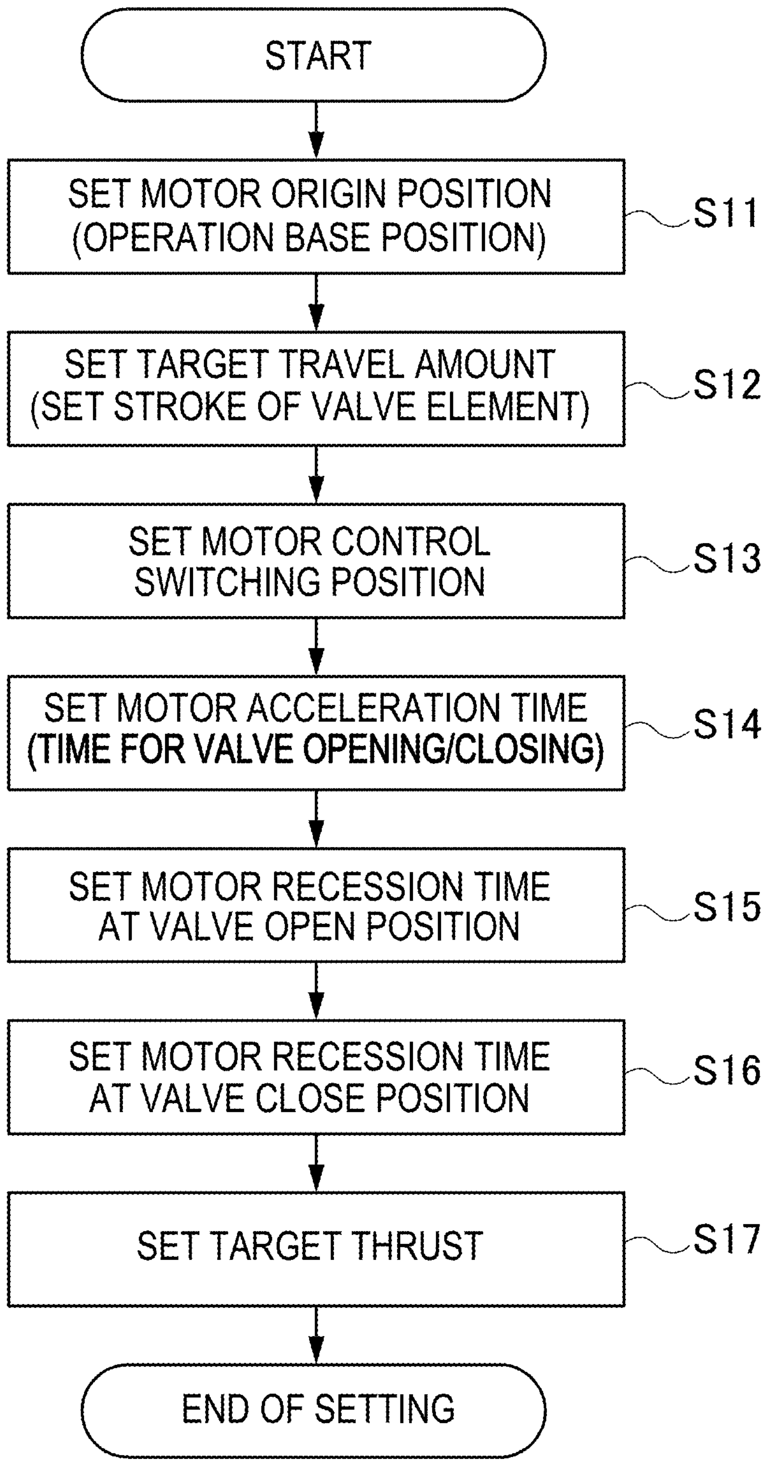

START
SET MOTOR ORIGIN POSITION (OPERATION BASE POSITION)
S11
SET TARGET TRAVEL AMOUNT (SET STROKE OF VALVE ELEMENT)
S12
SET MOTOR CONTROL SWITCHING POSITION
S13
SET MOTOR ACCELERATION TIME (TIME FOR VALVE OPENING/CLOSING)
S14
SET MOTOR RECESSION TIME AT VALVE OPEN POSITION
S15
SET MOTOR RECESSION TIME AT VALVE CLOSE POSITION
S16
SET TARGET THRUST
S17
END OF SETTING

FIG. 5

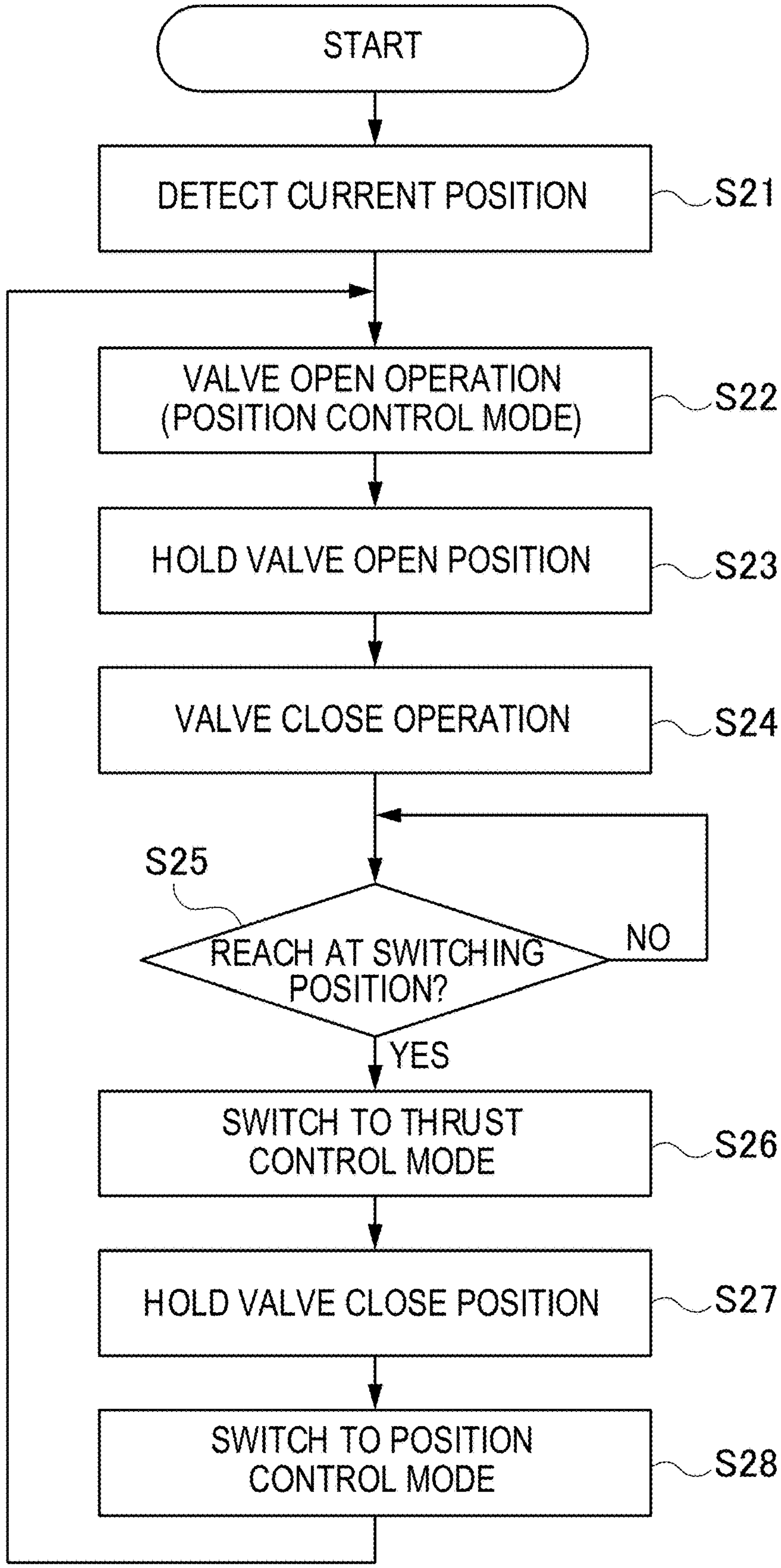
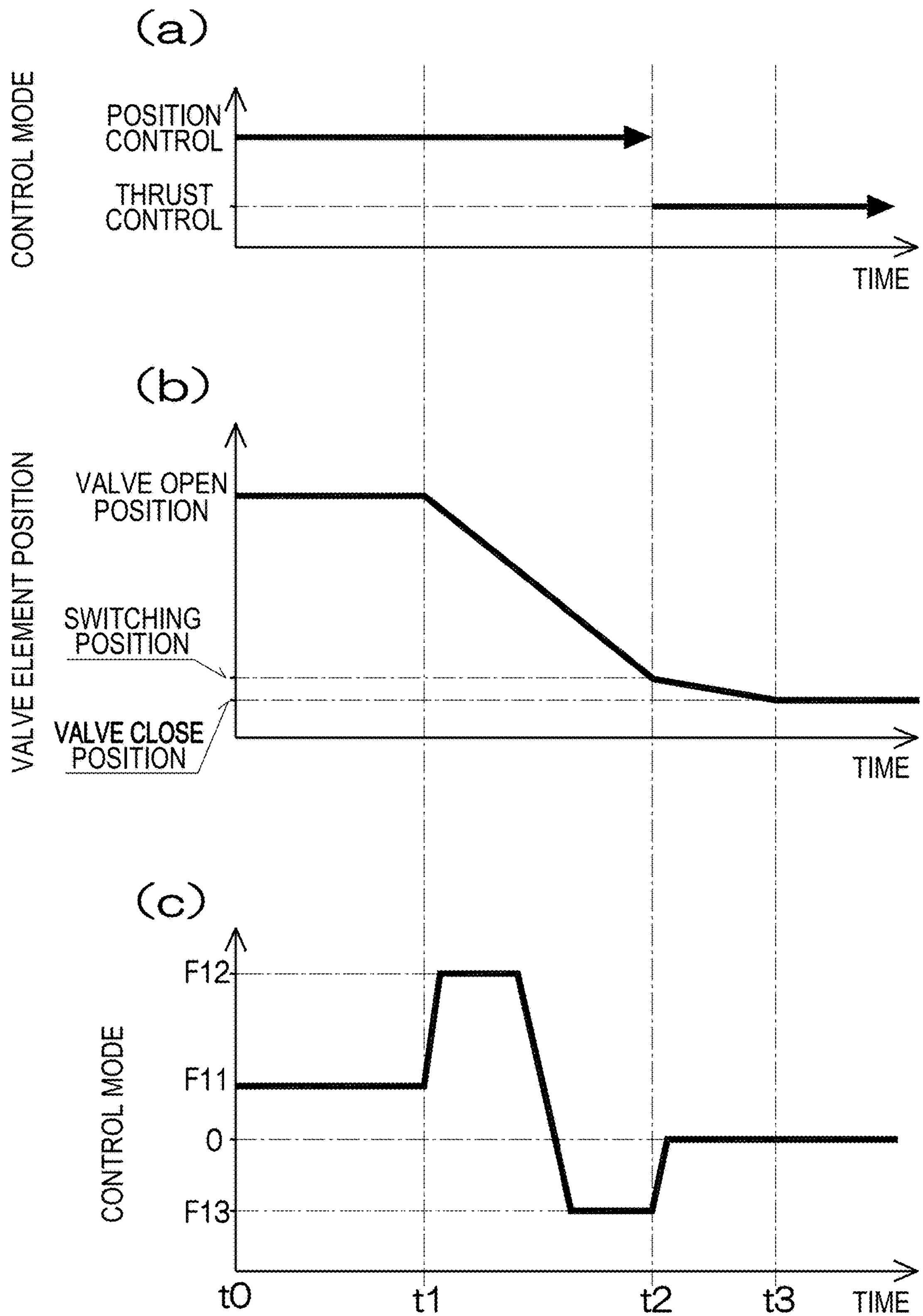

START
DETECT CURRENT POSITION
S21
VALVE OPEN OPERATION (POSITION CONTROL MODE)
S22
HOLD VALVE OPEN POSITION
S23
VALVE CLOSE OPERATION
S24
S25
REACH AT SWITCHING POSITION?
NO
YES
SWITCH TO THRUST CONTROL MODE
S26
HOLD VALVE CLOSE POSITION
S27
SWITCH TO POSITION CONTROL MODE
S28

FIG. 6


(a)
CONTROL MODE
POSITION CONTROL
THRUST CONTROL
TIME
(b)
VALVE ELEMENT POSITION
VALVE OPEN POSITION
SWITCHING POSITION
VALVE CLOSE POSITION
TIME
(c)
CONTROL MODE
F12
F11
0
F13
t0
t1
t2
t3
TIME

FLUID CONTROL VALVE

TECHNICAL FIELD

[0001] The present invention relates to a fluid control valve comprising a motor, a valve element, a valve seat, and a passage to control a control fluid flowing through the passage by operating the valve element by the motor from a valve open position, at which the valve element is separated from the valve seat, to a valve close position, at which the valve element comes to contact with the valve seat.

BACKGROUND ART

[0002] Several types of process gases are used for film forming processing in a semiconductor manufacturing process. A fluid control valve is used for controlling each flow rate of these process gases. As fluid control valves, for example, a fluid control valve disclosed in the Patent Literature 1 has been known. The fluid control valve disclosed in the Patent Document 1 is an air-operated-type open/close valve that is to perform flow rate control of a process gas by controlling contact and separation motion of a valve element (a diaphragm) and a valve seat by an air cylinder.

[0003] Further, the fluid control valve disclosed in the Patent Document 1 is an air-operated-type open/close valve provided with an air cylinder as a driving device, but another example is to adopt an electric driving type that utilizes a linear servomotor as a driving source. When the linear servomotor is used as the driving source, for example, a position at which a valve element and a valve seat come to contact with each other is set as an origin position of the servomotor, and a valve open degree is adjusted based on a relative position from the origin position. Then, the servomotor is made to return to the origin position for valve closing, and thereby the valve element and the valve seat are brought into contact with each other.

RELATED ART DOCUMENTS

Patent Documents

[0004] Patent Document 1: JP-A-2017-223318

SUMMARY OF INVENTION

Problems to be Solved by the Invention

[0005] However, the above-mentioned fluid control valve utilizing the linear servomotor has the following problem.

[0006] Normally, arrangement of an origin position is usually made by a user of a fluid control valve under a normal temperature atmosphere. However, a process gas to be controlled is extremely hot like 200° C., for example. A valve seat is usually made of resin such as PFA, and accordingly, the valve seat is heated by the control fluid and expanded. By this expansion, a dimension of the valve seat in an opening/closing direction (a thickness dimension) of a valve element could be larger than a dimension under the normal temperature. This increase in the thickness dimension of the valve seat causes contact of the valve element and the valve seat before the servomotor reaches the origin position while the valve is to be closed from the valve open state. However, the servomotor tries to return to the origin position even after the valve element and the valve seat are contacted, which could cause strong interference of the valve element and the valve seat, resulting in high load to the servomotor. A fluid control valve performing fluid control of a process gas in a semiconductor manufacturing process needs to accurately control a valve open degree, and therefore a servomotor with high resolution is used. By this reason, only a several micrometers of expansion of the valve seat could cause significantly high load to the servomotor. Applying continuous high load to the servomotor could cause breakage in the servomotor such as burn damage of a motor coil.

[0007] Further, when the valve seat gets abraded due to repetitive contact and separation of the valve element and the valve seat, a thickness dimension of the valve seat could be smaller than that of an initial state. When the thickness dimension of the valve seat becomes smaller, there is a possibility that the valve element and the valve seat could not be contacted even if the servomotor has reached the origin position while the valve is to be closed from the valve open state. Failure in contact of the valve element and the valve seat could cause leakage of fluid by sealing failure.

[0008] The present invention has been made in view of the above problems and has a purpose of providing a fluid control valve that can be responsive to changes in a dimension of a valve seat in an opening/closing direction of a valve element.

Means of Solving the Problems

[0009] To solve the above problem, a fluid control valve according to one aspect of the present invention has the following configuration.

[0010] (1) The fluid control valve is characterized as a fluid control valve provided with a motor, a valve element, a valve seat, and a passage, and configured to perform controlling of a control fluid to flow through the passage by moving the valve element with the motor between a valve open position at which the valve element is separated from the valve seat and a valve close position at which the valve element is contacted with the valve seat, wherein the fluid control valve is provided with an elastic member to apply an urging force to the valve element in a closing direction, the motor is provided with a drive shaft to operate the valve element, a position control mode to control the drive shaft to move to a target position and a thrust control mode to control the drive shaft to obtain a target thrust are provided, and while the valve element moves from the valve open position to the valve close position, the fluid control valve is provided with a control program configured to control the motor with the position control mode until the valve element reaches a predetermined position before reaching the valve close position from the valve open position and to switch control of the motor from the position control mode to the thrust control mode with the target thrust of zero to bring the valve element to reach the valve close position from the predetermined position only by the urging force.

[0011] According to the fluid control valve described in (1), while the valve element moves from the valve open position to the valve close position, the motor is controlled by the position control mode until the valve element reaches the predetermined position before reaching the valve close position from the valve open position, control of the motor is switched from the position control mode to the thrust control mode with the target thrust of zero from the predetermined position, and the valve element is controlled to reach the valve close position only by the urging force of the elastic member. In other words, the valve element is driven only by the urging force of the elastic member from the predetermined position to the valve close position. Accordingly, even if the valve element and the valve seat come to contact before the motor reaches the origin position due to expansion of the valve seat, the motor would not try to return to the origin position thereafter. Therefore, the motor is not subjected to the high load, and breakage of the motor such as burn damage of a motor coil can be prevented.

[0012] Further, even when the valve seat gets abraded to become smaller in size and the valve element and the valve seat fail to contact each other even after the motor has reached the origin position, the valve element is driven only by the urging force of the elastic member from the predetermined position, and thus the valve element would not stop at the origin position but is assuredly driven to the valve close position to be in contact with the valve seat. Accordingly, occurrence of fluid leakage due to sealing failure can be prevented.

[0013] (2) In the fluid control valve described in (1), preferably, the control program is configured to maintain a state in which the valve element is at the valve close position after the valve element reaches the valve close position by the thrust control mode with the target thrust of zero.

[0014] According to the fluid control valve described in (2), a case of maintaining the valve closed state, namely, a state in which the valve element is at the valve close position is maintained by the thrust control mode with the target thrust of zero. To be specific, the motor is not subjected to the load but the valve closed state is maintained only by the urging force of the elastic member. Thereby, the load applied to the motor can be reduced, and thus lifespan of the motor can be extended. Further, for example, even when the fluid control valve gets broken or power supply to the fluid control valve is shut down due to power outage and others, the valve closed state can be maintained only by the urging force of the elastic member, thereby achieving high safety in view of fail safe.

[0015] (3) In the fluid control valve described in (1) or (2), preferably, the predetermined position is determined based on a thermal expansion amount of the valve seat in an opening/closing direction of the valve element.

[0016] In order to enhance responsivity in driving the valve element from the valve open position to the valve close position, it is preferable to arrange the predetermined position as close as possible to the valve seat to reduce a range of relying only on the urging force of the elastic member between the valve open position and the valve close position as narrow as possible. Accordingly, the predetermined position is determined based on the thermal expansion amount of the valve seat in the opening/closing direction of the valve element. Specifically, for example, when the thermal expansion amount of the valve seat is Δt, the predetermined position is set at a position behind the origin position of the motor by the amount Δt and an additional several micrometers. This position is a point at which the valve element advances by 90 to 95% from the valve open position toward the closing direction during stroke of the valve element from the valve open position to the valve close position. The predetermined position is thus set so that the valve element is driven to a position directly before contacting the expanded valve seat under the position control mode of the motor, and thus the valve can be closed with high responsivity.

Effects of the Invention

[0017] According to the fluid control valve of the present invention, the valve can respond to changes in a dimension of a valve seat in an opening/closing direction of a valve element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** is a schematic sectional view of a fluid control valve;

[0019] FIG. **2** is a partial enlarged view of a part X in FIG. **1**;

[0020] FIG. **3** is a block diagram of a control system of the fluid control valve;

[0021] FIG. **4** is a flow of an initial setting program of the fluid control valve;

[0022] FIG. **5** is a flow of a control program of the fluid control valve; and

[0023] FIG. **6** (*a*) is a diagram indicating a state of a control mode of a servomotor while a valve element moves from a valve open position to a valve close position, (*b*) is a graph indicating a position of the valve element while the valve element moves from the valve open position to the valve close position, and (*c*) is a graph indicating a thrust value of a drive shaft while the valve element moves from the valve open position to the valve close position.

MODE FOR CARRYING OUT THE INVENTION

[0024] An embodiment of a fluid control valve according to the present invention is explained in detail with reference to the accompanying drawings.

(Configuration of Fluid Control Valve)

[0025] A configuration of a fluid control valve **1** according to the present embodiment is explained with reference to FIG. **1**. FIG. **1** is a schematic sectional view of the fluid control valve **1**. The fluid control valve **1** is an electric-motor-operated gas valve disposed in a gas supply system of a semiconductor manufacturing device and is formed of a drive unit **2** and a valve unit **3**. Further, the drive unit **2** is formed of an actuator part **4** and a spring part **5**.

[0026] Firstly, the actuator part **4** is explained. The actuator part **4** is provided with a direct-acting servomotor **6** (one example of a motor) and a connecting bracket **7** for connecting the servomotor **6** and the spring part **5**.

[0027] The servomotor **6** is provided with a parallelepiped case **61** and a columnar drive shaft **62** that is inserted in a center portion of the case **61**. The case **61** is provided with linear bearings **63** each of which is placed on an end portion (a lower end portion in the figure) on the connecting bracket **7** side and on an end portion (an upper end portion in the figure) on an opposite side from the connecting bracket **7** side. These linear bearings **63** support the drive shaft **62** to be reciprocally movable in an axial direction. The axial direction of the drive shaft **62** is an upper and lower direction in FIG. **1** and coincides with an opening/closing direction of a valve element **32** which will be explained below. Herein, an upper side in the figure represents the opening direction and a lower side represents the closing direction.

[0028] The drive shaft **62** is provided with a magnet **621** on an outer circumference in a portion that is inserted in the case **61**. Further, the case **61** is provided with a coil **64** placed to surround the magnet **621** of the drive shaft **62**. The magnet **621** is to be moved in the opening/closing direction corresponding to each magnitude of a voltage and a current in energization of the coil **64**. Thereby, the drive shaft **62** joined to the magnet **621** is driven in the opening/closing direction.

[0029] The drive shaft **62** is provided with a linear scale **622** on the end portion (the upper end portion in the figure) on the opposite side from the connecting bracket **7** side. Further, the servomotor **6** is provided on the upper end portion of the case **61** with a linear encoder **65** to detect changes in a vertical position of the linear scale **622**. The linear encoder **65** detects changes in the vertical position of the linear scale **622**, and thereby the position in the opening/closing direction of the drive shaft **62** can be detected.

[0030] The end portion (the lower end portion in the figure) of the drive shaft **62** on the connecting bracket **7** side protrudes from the case **61** and is coupled with the columnar rod **9** by a coupling **8** inside the connecting bracket **7**. The rod **9** is inserted in the spring part **5** and extends from an inside of the connecting bracket **7** to the valve unit **3**.

[0031] Next, the spring part **5** is explained. The spring part **5** is provided with a housing **51** and a spring **52** (one example of an elastic member). The housing **51** is of a hollow shape and the rod **9** is inserted therethrough in a center portion. Then, the spring **52** is placed coaxially with the rod **9**. The spring **52** is a compression coil and continuously urges the valve element **32** in the closing direction (a lower direction in the figure) by bringing its end portion (a lower end portion in the figure) on the valve unit **3** side into contact with an end face (an upper end face in the figure) of the valve element **32** on the spring **52** side, which will be explained below.

[0032] Next, the valve unit **3** is explained. The valve unit **3** is provided with a body **31** and the valve element **32**. The body **31** is provided with a cylindrical portion **315** connected to the spring part **5**. Further, the body **31** is perforated with a valve chamber **311** on an inside of the cylindrical portion **315**.

[0033] The valve chamber **311** is communicated with an input passage **313** in its center portion through a valve port **312**. This input passage **313** is used for intaking process gas to the valve chamber **311**. Further, the annular valve seat **33** is provided coaxially with the valve port **312** on an outer circumferential portion of the valve port **312** on a bottom surface of the valve chamber **311**. Furthermore, the valve chamber **311** is communicated with an output passage **314** on an outside in a radial direction of the valve seat **33**. This output passage **314** is used for discharging the process gas from the valve chamber **311**. Specifically, the input passage **313**, the valve chamber **311**, and the output passage **314** constitute a series of passages through which the process gas flows.

[0034] The valve seat **33** is, for example, made of PI (polyimide) or PFA (tetrafluoroethylene perfluoroalkylvinyl ether copolymer) with high thermal resistance. An end face of the valve seat **33** opposing to the valve element **32** is a contact surface **331** (see FIG. **2**) that is to be contacted with the valve element **32**.

[0035] A position Y**11** of the contact surface **331** in the opening/closing direction shown in FIG. **2** is a position under a normal temperature. The process gas flowing through the fluid control valve **1** is at an exceptionally high temperature such as 200° C., for example, and thus the valve seat **33** is heated by the process gas and expanded. A position of the contact surface **331** in the opening/closing direction after this expansion is a position indicated with a position Y**12**. For example, when a material of the valve seat **33** is PFA and a dimension (a thickness dimension) of the valve seat **33** in the opening/closing direction is about 1.5 mm, an expansion amount Δt**11** is about 20 to 30 μm.

[0036] On the other hand, there are a possibility that the valve seat **33** gets abraded by repetitive contact and separation of the valve element **32** and the valve seat **33** and a possibility that the valve seat **33** is deformed due to creep and others. By the abrasion or the creep, a position of the contact surface **331** in the opening/closing direction becomes a position indicated with a position Y**13**. A gap of the position Y**11** and the position Y**13** at this time is defined as a contraction amount Δt**12**.

[0037] The valve element **32** is provided with a main body **321** and a diaphragm **322**. The main body **321** is made of stainless steel, for example. The main body **321** is coupled with the rod **9** on an upper end portion and is moved in the opening/closing direction (in an upper and lower direction in the figure) in accordance with reciprocal motion of the drive shaft **62**. Then, a lower end face of the main body **321** constitutes a contact surface to be in contact with the valve seat **33**.

[0038] The diaphragm **322** is a circular disc-like thin film member made of, for example, Ni alloy. The main body **321** and the diaphragm **322** are connected by laser welding, for example. Further, an outer peripheral edge of the diaphragm **322** is fixed to a housing **51**. Thus, the diaphragm **322** divides an inside of a cylindrical portion **315** of the body **31** into the valve chamber **311** and its upper portion and repeats elastic deformation in accordance with motion of the main body **321** in the opening/closing direction (in the upper and lower direction in the figure).

(Control System of Fluid Control Valve)

[0039] A control system of the fluid control valve **1** is explained with reference to FIG. **3**. FIG. **3** is a block diagram of the control system of the fluid control valve **1**. A driver **10** for controlling the servomotor **6** is provided with a controller for position control **101**, a controller for thrust control **102**, a position loop controller **103**, a speed loop controller **104**, a current loop controller **105**, converters **106**, **107**, **108**, and a control switcher **109**. The servomotor **6** has a position control mode to control the drive shaft **62** to move to a target position and a thrust control mode to control the drive shaft **62** to obtain a target thrust. The position control mode and the thrust control mode are switchable by the control switcher **109**.

[0040] Control by the position control mode is performed as follows. First, the controller for position control **101** outputs a positional command to the position loop controller **103** based on the target position of the drive shaft **62**.

[0041] Then, the position loop controller **103** performs, for example, PD control based on the positional command and a current position of the drive shaft **62** that is fed back from the linear encoder **65**, and calculates a speed command. Herein, the current position of the drive shaft **62** that is fed back from the linear encoder **65** is a signal output from the converter **107** based on a pulse number that is output from the linear encoder **65**.

[0042] Then, the speed loop controller **104** performs, for example, PID control based on the speed command calculated by the positional loop controller **103** and the current speed of the drive shaft **62** that is fed back from the linear encoder **65**, and calculates the torque command. Herein, the current speed of the drive shaft **62** that is fed back from the linear encoder **65** represents a signal output from the converter **108** based on a pulse number that is output from the linear encoder **65**.

[0043] Then, the current loop controller **105** outputs a current command based on the torque command that is calculated by the speed loop controller **104**. The current required for the converter **106** is supplied to the servomotor **6** based on this current command, and thereby the position of the drive shaft **62** of the servomotor **6** is controlled.

[0044] The control by the thrust control mode is performed as follows. First, the controller for thrust control **102** outputs the thrust command to the current loop controller **105** based on the target thrust of the drive shaft **62**. Then, the current loop controller **105** outputs the current command based on the thrust command output from the controller for thrust control **102**. The converter **106** supplies the required current to the servomotor **6** based on this current command, and thereby the thrust of the drive shaft **62** of the motor **2** is controlled.

(Operation of Fluid Control Valve)

[0045] In the above-mentioned control system, the fluid control valve **1** is operated as follows. FIG. **4** is a flow of an initial setting program of the fluid control valve **1**. FIG. **5** is a flow of a control program of the fluid control valve **1**. FIG. **6** (*a*) shows a state of a control mode of the servomotor **6** when the valve element **32** is operated from the valve open position to the valve close position. FIG. **6** (*b*) is a graph showing a position of the valve element **32** when the valve element **32** is operated from the valve open position to the valve close position. FIG. **6** (*c*) is a graph showing a thrust value of the drive shaft **62** when the valve element **32** is operated from the valve open position to the valve close position.

[0046] Before starting use of the fluid control valve **1**, parameters (items indicated in S**11** to S**17** in FIG. **4**) necessary for controlling the fluid control valve **1** is performed with initial setting according to the initial setting program. Specific explanation is given below.

[0047] Firstly, an origin position of the servomotor **6** is set (S**11** in FIG. **4**). Specifically, the valve element **32** is brought into contact with the valve seat **33** under a normal temperature. To be specific, the valve element **32** is placed in the valve close position. Then, a position of the drive shaft **62** in this state is set as the origin position. Further, at this time, a position of a contact surface **331** of the valve element **32** to be in contact with the valve element **32** in the opening/closing direction is a position Y**11**.

[0048] Next, a target position is set (S**12** in FIG. **4**). This target position represents a travel amount of the drive shaft **62** from the origin position to the opening direction. In the position control mode, the controller for position control **101** (see FIG. **3**) outputs a positional command based on this target position. The valve element **32** is moved from the valve close position to the opening direction by a travel amount of the drive shaft **62** from the origin position to the opening direction, and thus setting of the target position is synonymous with setting a stroke of the valve element **32** from the valve close position to the valve open position. This target position is appropriately determined based on a flow rate of process gas that is obtained by film forming process in the semiconductor manufacturing process, and others. For example, the stroke is about 1 mm in the present embodiment.

[0049] Subsequently, a switching position (one example of a predetermined position) for switching control of the servomotor **6** is set (S**13** in FIG. **4**). Specifically, when the valve element **32** is to be operated from the valve open position to the valve close position, where to switch control of the servomotor **6** from the position control mode to the thrust control mode in a rage from the valve open position to the valve close position is set.

[0050] A switching position is determined based on a thermal expansion amount Δt**11** of the valve seat **33** in the opening/closing direction of the valve element **32**. Specifically, when the valve seat **33** has the thermal expansion amount Δt**11** for example, the switching position is set at a position behind the origin position of the servomotor **6** by the thermal expansion amount Δt**11** and an additional several micrometers. This position is a point where the valve element **32** has advanced by 90 to 95% from the valve open position to the closing direction in the stroke (for example, 1 mm) from the valve open position to the valve close position of the valve element **32**.

[0051] Subsequently, acceleration time of the servomotor **6** is set (S**14** in FIG. **4**). This setting is to set a period of time required for the drive shaft **62** to move from the origin position to the target position. This setting is synonymous with setting a period of time for the valve element **32** to travel between the valve open position and the valve close position.

[0052] Subsequently, a recession time of the servomotor **6** at the valve open position is set (S**15** in FIG. **4**). This setting is to set a period of time for maintaining the valve open state of the valve element **32** after the valve element **32** reaches the valve open position.

[0053] Subsequently, the recession time of the servomotor **6** at the valve close position is set (S**16** in FIG. **14**). This setting is to set a period of time for maintaining the valve closed state after the valve element **32** reaches the valve close position. Each period of time set in each of S**14** to S**16** in FIG. **4** as mentioned above is appropriately set in accordance with a cycle time of opening and closing operation that is required in the film forming step in the semiconductor manufacturing process.

[0054] Subsequently, a target thrust is set (S**17** in FIG. **4**). This setting is to set the thrust for driving the drive shaft **62** when the servomotor **6** is controlled by the thrust control mode. Herein, the target thrust is set as zero. When the setting of the target thrust is completed, initial setting of the parameters is completed. Herein, an order of setting the respective parameters (S**11** to S**17** in FIG. **4**) is not limited to the above order. Further, the step S**17** in FIG. **4** may be omitted and the target thrust may have been set as zero in advance.

[0055] Opening and closing operation of the fluid control valve **1** is performed by a control program explained below.

[0056] Firstly, when operation of the fluid control valve **1** is started, the linear encoder **65** detects a current position of the drive shaft **62** (S**21** in FIG. **5**). The current position of the drive shaft **62** specifically represents a current position of the valve element **32**. The valve element **32** is continuously urged to the closing direction by the spring **52**, and therefore, the valve element **32** is in the valve close position at the timing of starting operation of the fluid control valve **1**. Accordingly, herein, the current position is detected to be at the origin position.

[0057] Subsequently, the valve opening operation is performed (S**22** in FIG. **5**). Namely, the valve element **32** is driven to move to the valve open position. This is performed under the position control mode, and thus performed based on the target position set by the initial setting (see S**12** in FIG. **4**). In the present embodiment, the stroke is set as 1 mm, and thus the valve element **32** is moved by 1 mm from the origin position to the opening direction. A travel speed at this time is based on the acceleration time of the servomotor **6** that has been set by the initial setting (see S**14** in FIG. **4**).

[0058] Herein, a time point to in FIG. **6** is a point of time when the valve element **32** has reached the valve open position. As shown in FIG. **6** (*a*), at the time point to, the control mode of the servomotor **6** is the position control mode. Further, as shown in FIG. **6** (*b*), the valve element **32** is placed at the valve open position. Further, the thrust of the drive shaft **62** indicates a value (F**11**) larger than zero. The thrust is generated in the drive shaft **62** because the position of the drive shaft **62** is maintained at the valve open position against the urging force of the spring **52**. Herein, whether the valve element **32** has reached the valve open position is monitored by checking whether a change amount of the current position of the drive shaft **62** is within a certain range of a deviation pulse. When the change amount is within the subject range, the valve element **32** is determined to have reached the valve open position.

[0059] Subsequently, after the valve element **32** has moved to the valve open position, the valve element **32** is retained in the valve open position (S**23** in FIG. **5**). This retention period of time continues based on the recession time (see S**15** in FIG. **4**) of the servomotor **6** at the valve open position that has been set by the initial setting.

[0060] Herein, a term from the time point t**0** to a time point t**1** in FIG. **6** corresponds to this recession time. During the term from the time point t**0** to the time point t**1**, the valve element **32** is maintained to be at the valve open position by the position control mode (see FIGS. **6** (*a*) and (*b*)). The thrust generated in the drive shaft **62** also remains constant during the time point t**0** to the time point t**1** (see FIG. **6** (*c*)).

[0061] After elapse of the above recession time, the valve closing operation is subsequently performed (S**24** in FIG. **5**). This operation is performed under the position control mode, and the drive shaft **62** of the servomotor **6** is controlled to move toward the origin position, so that the valve element **32** is driven toward the valve close position. A travel speed at this time is based on the acceleration time (see S**14** in FIG. **4**) of the servomotor **6** that has been set by the initial setting.

[0062] Herein, the time point t**1** in FIG. **6** represents a time point when the valve closing operation is started. While the position control mode is maintained from the time point t**1**, the valve element **32** starts its operation toward the valve close position (see FIGS. **6** (*a*) and (*b*)). Then, the thrust of the drive shaft **62** indicates the maximum value (F**12**) directly after starting the valve closing operation. This is for the purpose of abruptly accelerating the drive shaft **62** in the closing direction. Then, as the valve element **32** approaches the valve close position, the thrust works in the opening direction to brake the drive shaft **62**. Accordingly, in FIG. **6** (*c*), the thrust decreases to a minus value (F**13**).

[0063] Subsequently, when the valve closing operation is started, whether the drive shaft **62** has reached a switching position for controlling the servomotor **6** is monitored (S**25** in FIG. **5**). The switching position for controlling the servomotor **6** represents a position at which the control of the servomotor **6** is switched from the position control mode to the thrust control mode that has been set by the initial setting (see S**13** in FIG. **4**). Until reaching the switching position, the drive shaft **62** of the servomotor **6** continues to be controlled to move to the origin position by the position control mode (S**25**: NO). Then, when the drive shaft **62** has reached the switching position (S**25**: YES), switching to the thrust control mode is performed (S**26** in FIG. **5**). This switching is performed by switching the control switcher **109** (see FIG. **3**).

[0064] After the mode is switched to the thrust control mode, the servomotor **6** is controlled based on the target thrust. The target thrust is a parameter that is set by the initial setting (see S**17** in FIG. **4**), and herein, the target thrust is set as zero. Accordingly, when the mode is switched to the thrust control mode, supply of electric current to the servomotor **6** from the converter **106** (see FIG. **3**) is recessed. Then, the valve element **32** is moved to a position (the valve close position) where the valve element **32** is brought into contact with the valve seat **33** only by the urging force of the spring **52**.

[0065] Under the normal temperature, the origin position of the servomotor **6** corresponds to the valve close position, but when the valve seat **33** is expanded, the valve close position is displaced from the origin position in the opening direction by the amount of the thermal expansion amount Δt**11** (see FIG. **2**). Namely, the valve element **32** and the valve seat **33** come to contact with each other before the servomotor **6** reaches the origin position. However, the valve element **32** is driven only by the urging force of the spring **52** from the switching position, and thus the servomotor **6** would not try to return to the origin thereafter even if the valve seat **33** is expanded, and the valve element **32** and the valve seat **33** come to contact before the servomotor **6** reaches the origin position. Accordingly, the servomotor **6** is free from high load and breakage in the servomotor **6** such as burn damage of the coil **64** can be prevented.

[0066] Further, the switching position from the position control mode to the thrust control mode is determined to be a position where the valve element **32** advances from the valve open position to the valve close position by 90 to 95% in the stroke from the valve open position to the valve close position of the valve element **32**. Accordingly, the responsivity in driving the valve element **32** from the valve open position to the valve close position is improved. The fluid control valve **1** placed in a gas supply system of a semiconductor manufacturing device is small-sized, and thus the urging force of the spring **52** is lower than that of an ordinary air-operated-type valve. Therefore, in order to improve the responsivity, it is preferable to make the switching position as close as possible to the valve seat **33** and to reduce a range of relying only on the urging force of the spring **52** from the valve open position to the valve close position as narrow as possible. By setting the switching position as above, the valve element **32** is driven under the position control mode of the servomotor **6** directly before contacting with the expanded valve seat **33**, so that the valve can be closed with high responsivity.

[0067] On the other hand, when the valve seat **33** is abraded or creeps and a position of the contact surface **331** is lowered, the valve close position is displaced to the closing direction from the origin position by the amount of its contraction amount Δt**2** (see FIG. **2**). Namely, even when the servomotor **6** reaches the origin position, the valve element **32** fails to be in contact with the valve seat **33**. However, the valve element **32** is driven only by the urging force of the spring **52** from the switching position, and therefore the valve element **32** is assuredly driven to the valve close position to be in contact with the valve seat **33** without stopping at the origin position even after the servomotor **6** has reached the origin position. Therefore, occurrence of fluid leakage due to sealing failure can be prevented.

[0068] Herein, the time point t**2** in FIG. **6** is the timing when the valve element **32** has reached the switching position, and also the timing when control of the servomotor **6** has been switched from the position control mode to the thrust control mode. When the mode is switched to the thrust control mode, the thrust of the drive shaft **62** becomes zero based on the set target thrust. Then, the travel speed of the valve element **32** is decelerated since the time point t**2** at which the mode has been switched to the thrust control mode (an inclination of a graph in FIG. **6** (*b*) becomes gentle). This is because the valve element **32** is moved only by the urging force of the spring **52**. Then, the time point t**3** in FIG. **6** is the timing when the valve element **32** has reached the valve close position. Herein, whether the valve element **32** has reached the valve close position is monitored by confirming whether a change amount of the current position of the drive shaft **62** is within a range of the deviation pulse. When the change amount is within the range, the valve element **32** is determined to have reached the valve close position.

[0069] Subsequently, when the valve element **32** has reached the valve close position, the valve element **32** is held at the valve close position (S**27** in FIG. **5**). A period of time for this holding is carried out based on the recession time of the servomotor **6** at the valve close position (see S**16** in FIG. **4**) that has been set by the initial setting. While the valve element **32** is held in the valve close position, the servomotor **6** is controlled by the thrust control mode with the target thrust of zero. In other words, the servomotor **6** is not subjected to any load and the valve closed state is maintained only by the urging force of the spring **52**. Thereby, the load applied to the servomotor **6** can be reduced and a lifespan can be extended. Further, for example, even when the fluid control valve **1** gets broken down or electric supply to the fluid control valve **1** is shut off due to power outage and others, the valve closed state is maintained only by the urging force of the spring **52**, achieving high safety in view of fail safe.

[0070] As the above-mentioned recession time has elapsed, subsequently, the mode is switched to the position control mode (S**28** in FIG. **5**), and thereafter, the valve closing operation under the position control mode is performed (S**24** in FIG. **5**). As mentioned above, by repeating the processes of S**22** to S**28** in FIG. **5**, opening and closing operation of the fluid control valve **1** is performed.

[0071] As explained above, the fluid control valve **1** according to the present embodiment is configured as (1) being provided with a motor (for example, the servomotor **6**), the valve element **32**, the valve seat **33**, and a passage (a series of passages constituted of the input passage **313**, the valve chamber **311**, and the output passage **314**), and configured to perform controlling of a control fluid (for example, process gas) to flow through the passage by moving the valve element **32** with the motor (the servomotor **6**) between the valve open position at which the valve element **32** is separated from the valve seat **33** and a valve close position at which the valve element **32** is contacted with the valve seat **33**. The fluid control valve **1** is provided with an elastic member (for example, the spring **52**) to apply an urging force to the valve element **32** in a closing direction, the motor (the servomotor **6**) is provided with a drive shaft **62** to operate the valve element **32**, a position control mode to control the drive shaft **62** to move to a target position and a thrust control mode to control the drive shaft **62** to obtain a target thrust are provided, and while the valve element moves **32** moves from the valve open position to the valve close position, the fluid control valve **1** is provided with a control program configured to control the motor (the servomotor **6**) with the position control mode until the valve element **32** reaches a predetermined position (a switching position) before reaching the valve close position from the valve open position and to switch control of the motor (the servomotor **6**) from the position control mode to the thrust control mode with the target thrust of zero to bring the valve element **32** to reach the valve close position from the predetermined position (the switching position) only by the urging force.

[0072] According to the fluid control valve **1** described in (1), when the valve element **32** is operated from the valve open position to the valve close position, the motor (the servomotor **6**) is controlled by the position control mode until the valve element **32** reaches the predetermined position from the valve open position before reaching the valve close position. Control of the motor (the servomotor **6**) is switched from the position control mode to the thrust control mode in which the target thrust is set as zero at the predetermined position so that the valve element re is controlled to reach the valve close position only by the urging force of the elastic member. Namely, the valve element **32** is driven only by the urging force of the elastic member (the spring **52**) from the predetermined position (the switching position) to the valve close position. Accordingly, even when the valve element **32** and the valve seat **33** are brought into contact with each other before the motor (the servomotor **6**) reaches the origin position due to expansion of the valve seat **33**, the motor (the servomotor **6**) would not return to the original position thereafter. Therefore, no high load is applied to the motor (the servomotor **6**), and thus breakdown of the motor (the servomotor **6**) such as burn damage of the motor coil **4** can be prevented.

[0073] Further, even when the valve element **32** and the valve seat **33** fail to be in contact after the motor (the servomotor **6**) has reached the origin position due to decrease in a size of the valve seat **33** that gets abraded, the valve element **32** is assuredly driven to the valve close position to be in contact with the valve seat **33** without stopping at the origin position since the valve element **32** is driven only by the urging force of the elastic member (the spring **52**) from the predetermined position (the switching position). Therefore, occurrence of fluid leakage due to sealing failure can be prevented.

[0074] (2) In the fluid control valve **1** described in (1), preferably, the control program (steps S**21** to S**28** in FIG. **5**) is configured to maintain a state in which the valve element

32 is at the valve close position after the valve element **32** reaches the valve close position by the thrust control mode with the target thrust of zero.

[0075] According to the fluid control valve **1** described in (2), a case of maintaining the valve closed state, namely, a state where the valve element **32** is in the valve close position is maintained by the thrust control mode with the target thrust of zero. Specifically, the motor (the servomotor **6**) is not applied with any load but applied only with the urging force of the elastic member (the spring **52**) to maintain the valve closed state. Thereby, the load applied to the motor (the servomotor **6**) is reduced and the lifespan can be extended. Furthermore, for example, even when the fluid control valve **1** gets broken down or the electric supply to the fluid control valve **1** is shut off due to power outage and others, the valve closed state can be maintained only by the urging force of the elastic member (the spring **52**), thus achieving high safety in view of fail safe.

[0076] (3) In the fluid control valve **1** described in (1) or (2), preferably, the predetermined position (the switching position) is determined based on a thermal expansion amount Δ**t11** of the valve seat **33** in an opening/closing direction of the valve element **32**.

[0077] In order to improve responsivity while the valve element **32** is driven from the valve open position to the valve close position, it is preferable to arrange the predetermined position (the switching position) as close as possible to the valve seat **33** so that a range of relying only on the urging force of the elastic member (the spring **52**) from the valve open position to the valve close position is made as narrow as possible. Accordingly, the predetermined position (the switching position) is determined based on the thermal expansion amount Δ**t11** of the valve seat **33** in the opening/closing direction of the valve element **32**. Specifically, for example, the predetermined position is set in a position behind the origin position of the motor (the servomotor **6**) by the amount Δ**t11** and an additional several micrometers. This position is a position at which the valve element **32** is moved ahead from the valve open position to the closing direction by 90 to 95% in the stroke of the valve element **32** from the valve open position to the valve close position. By setting the predetermined position (the switching position) as mentioned above, the valve element **32** is driven by the position control mode of the motor (the servomotor **6**) by the position directly before contacting with the expanded valve seat **33**, so that the valve can be closed with high responsivity.

[0078] The above embodiment is only an illustration and gives no limitation to the present invention. Accordingly, the present invention can naturally be made with various improvements and modifications without departing from the scope of the subject matter. For example, opening and closing operation of the fluid control valve **1** according to the present embodiment is performed by bringing a lower end face of the main body **321** of the valve element **32** into or out of contact with the valve seat **33**. Alternatively, as disclosed in JP2017-223318A, a fluid control valve may be configured that opening and closing operation is performed by bringing a diaphragm into or out of contact with a valve seat.

REFERENCE SIGNS LIST

[0079] **1** Fluid control valve
[0080] **6** Servomotor (one example of a motor)
[0081] **32** Valve element
[0082] **33** Valve seat
[0083] **52** Spring (one example of an elastic member)
[0084] **62** Drive shaft

1. A fluid control valve

provided with a motor, a valve element, a valve seat, and a passage, and

configured to perform controlling of a control fluid to flow through the passage by moving the valve element with the motor between a valve open position at which the valve element is separated from the valve seat and a valve close position at which the valve element is contacted with the valve seat, wherein

the fluid control valve is provided with an elastic member to apply an urging force to the valve element in a closing direction,

the motor is provided with a drive shaft to operate the valve element,

a position control mode to control the drive shaft to move to a target position and a thrust control mode to control the drive shaft to obtain a target thrust are provided, and

while the valve element moves from the valve open position to the valve close position, the fluid control valve is provided with a control program configured to control the motor with the position control mode until the valve element reaches a predetermined position before reaching the valve close position from the valve open position and to switch control of the motor from the position control mode to the thrust control mode with the target thrust of zero to bring the valve element to reach the valve close position from the predetermined position only by the urging force.

2. The fluid control valve according to claim **1**, wherein

the control program is configured to maintain a state in which the valve element is at the valve close position after the valve element reaches the valve close position by the thrust control mode with the target thrust of zero.

3. The fluid control valve according to claim **1**, wherein the predetermined position is determined based on a thermal expansion amount of the valve seat in an opening/closing direction of the valve element.

4. The fluid control valve according to claim **2**, wherein the predetermined position is determined based on a thermal expansion amount of the valve seat in an opening/closing direction of the valve element.

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