US 20030196615A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0196615 A1**
Asano et al. (43) **Pub. Date: Oct. 23, 2003**

(54) **ELECTROMAGNETIC VALVE CONTROL APPARATUS AND CONTROL METHOD THEREOF**

(76) Inventors: **Masahiko Asano**, Toyota-shi (JP); **Takashi Izuo**, Toyota-shi (JP); **Kiyoharu Nakamura**, Seto-shi (JP); **Takeshi Sakuragi**, Toyota-shi (JP)

Correspondence Address:
KENYON & KENYON
1500 K STREET, N.W., SUITE 700
WASHINGTON, DC 20005 (US)

(21) Appl. No.: **10/412,208**

(22) Filed: **Apr. 14, 2003**

(30) **Foreign Application Priority Data**

Apr. 22, 2002 (JP) 2002-118806

Publication Classification

(51) **Int. Cl.**[7] **F01L 9/04**
(52) **U.S. Cl.** **123/90.11**

(57) **ABSTRACT**

A control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a pair of spring means for energizing the valve element toward the valve-opening side and the valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, is provided with a controller which increases the energizing force of the spring means for energizing the valve element toward the valve-closing side immediately before seating of the valve element. By this type of the control apparatus of the electromagnetic valve, an increase in power consumption of the electromagnetic valve is suppressed.

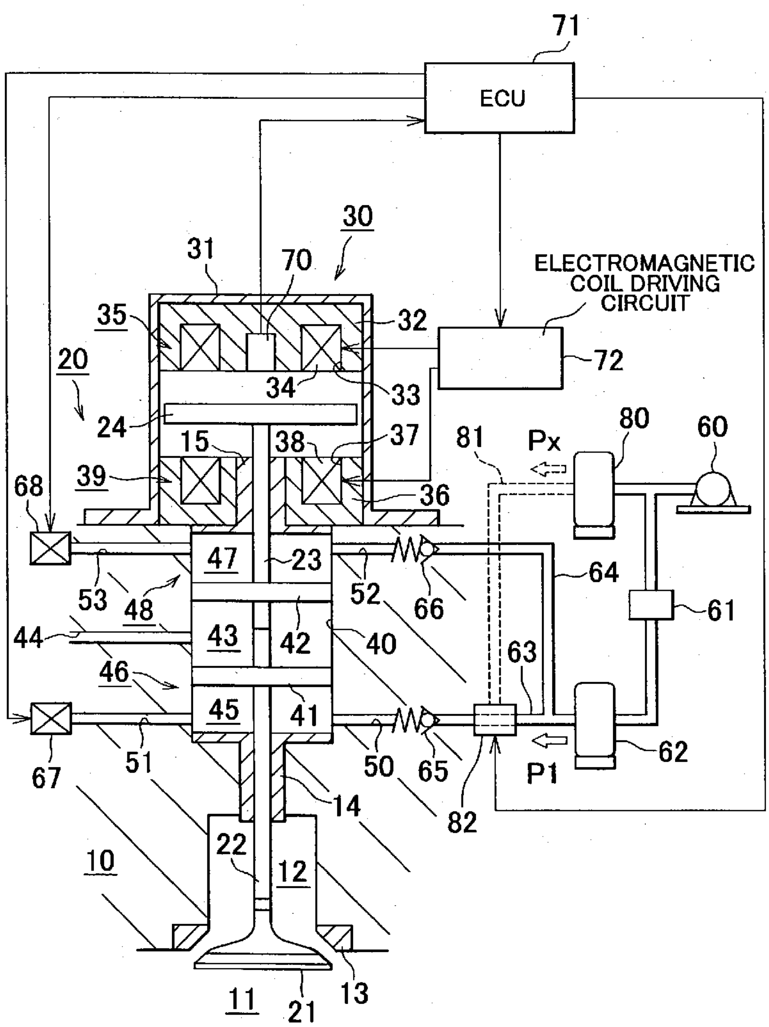


FIG. 1

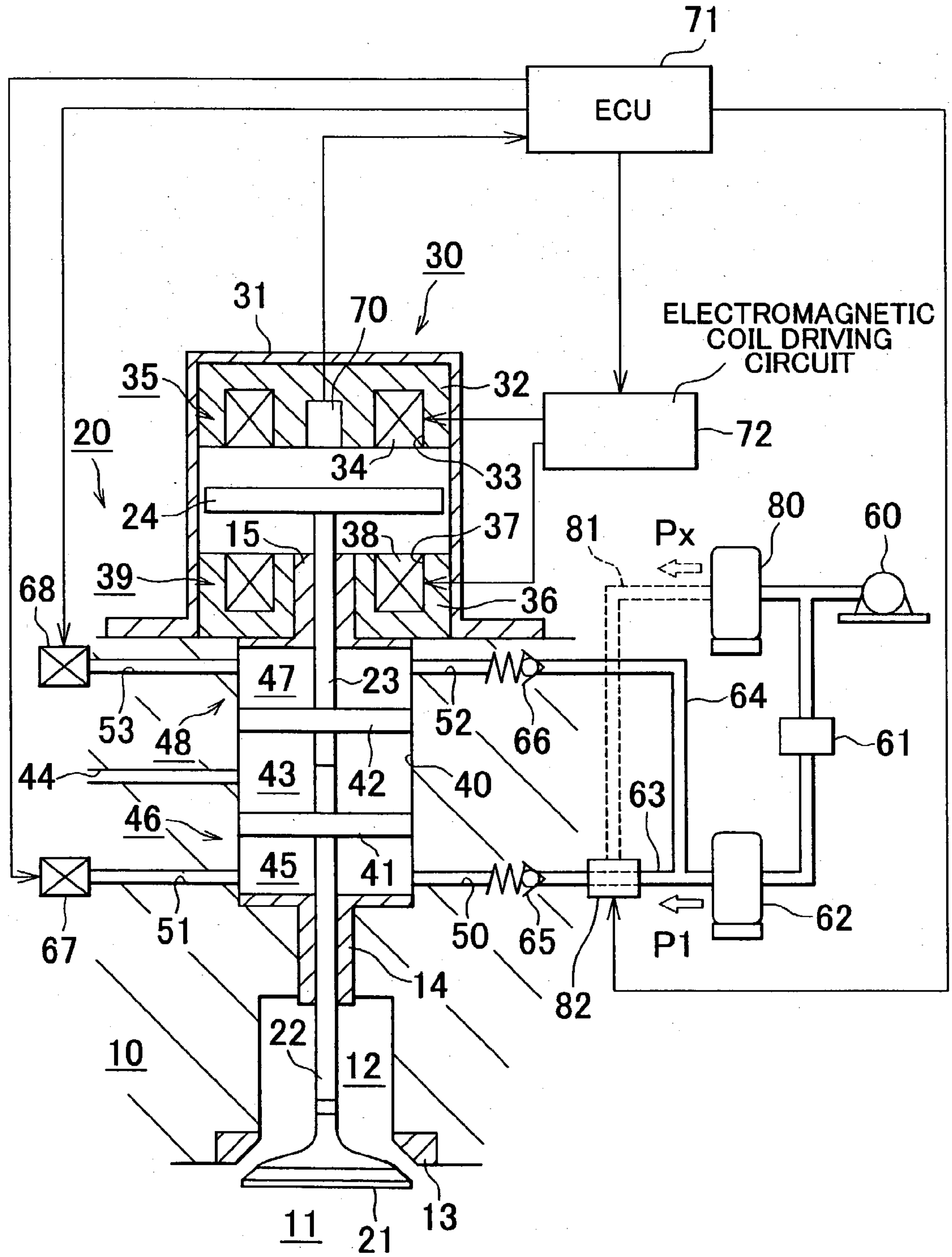

71
ECU
30
31
70
ELECTROMAGNETIC COIL DRIVING CIRCUIT
35
32
20
72
34
33
24
15
38
37
81
Px
80
60
68
39
36
47
23
53
48
52
66
64
61
44
43
42
40
63
46
45
41
67
51
50
65
62
P1
14
82
22
12
10
13
11
21

FIG. 2a

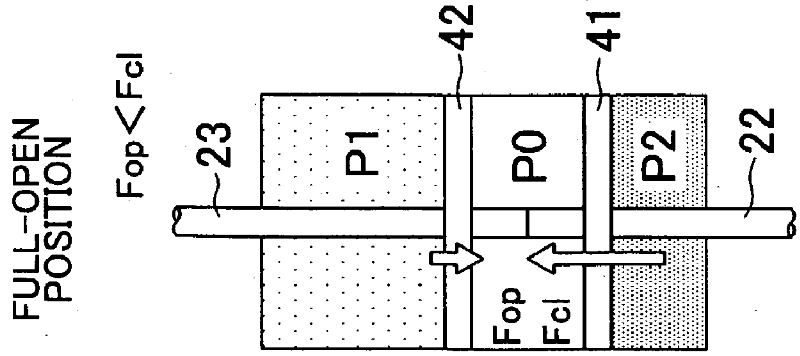


FIG. 2b

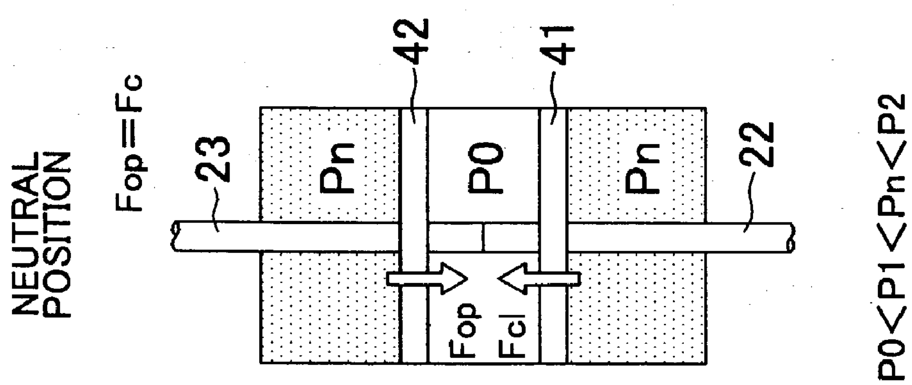


FIG. 2c

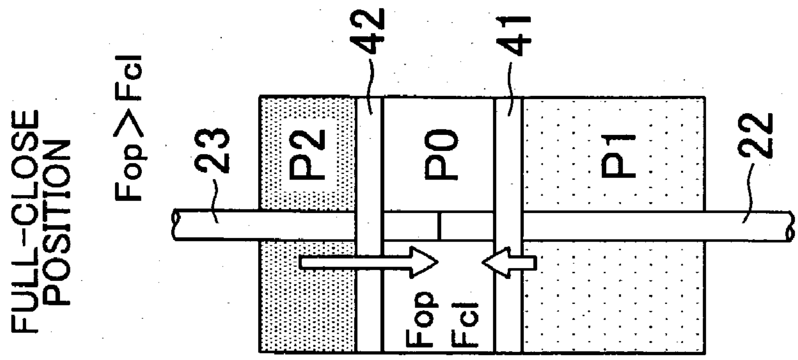
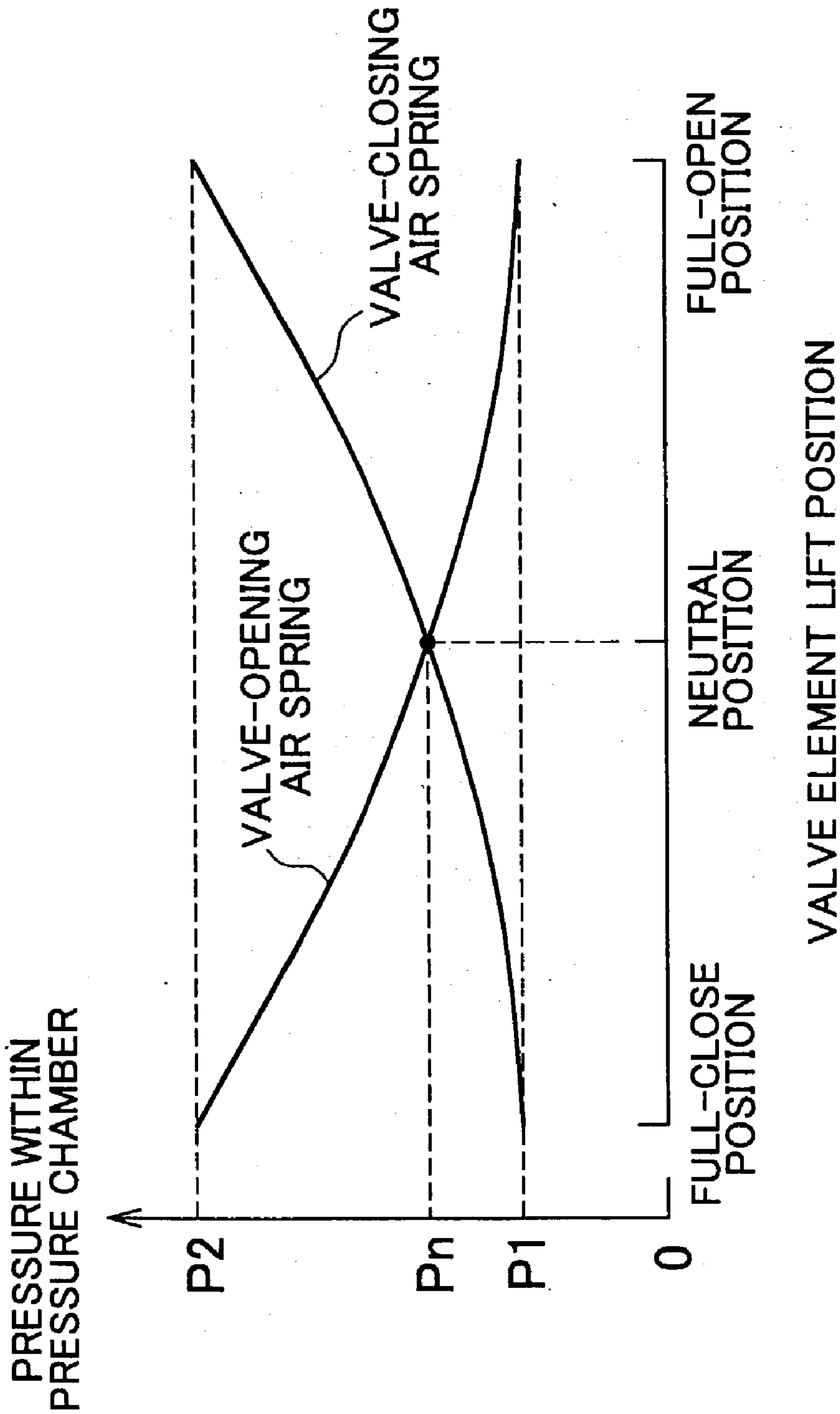
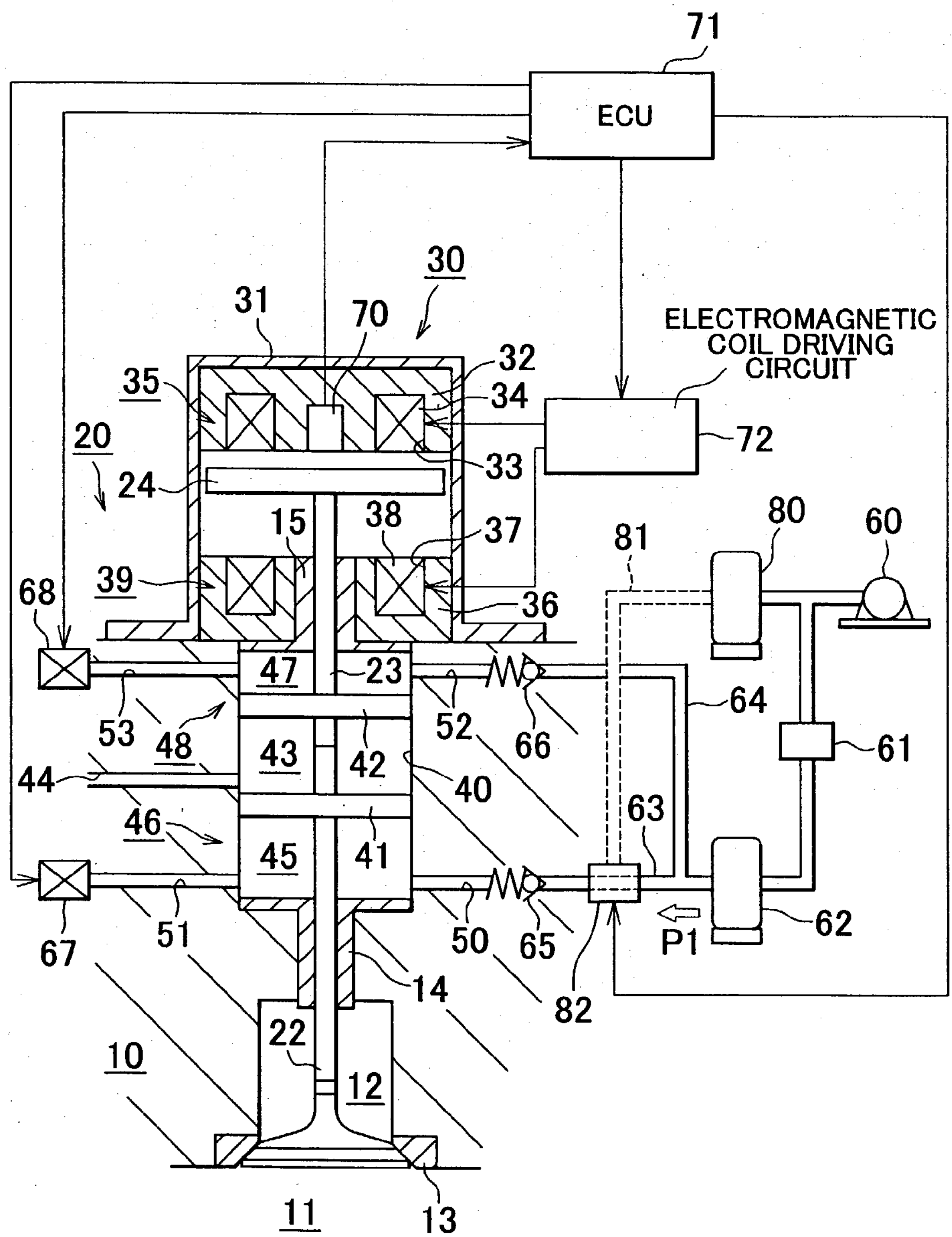


FIG. 3

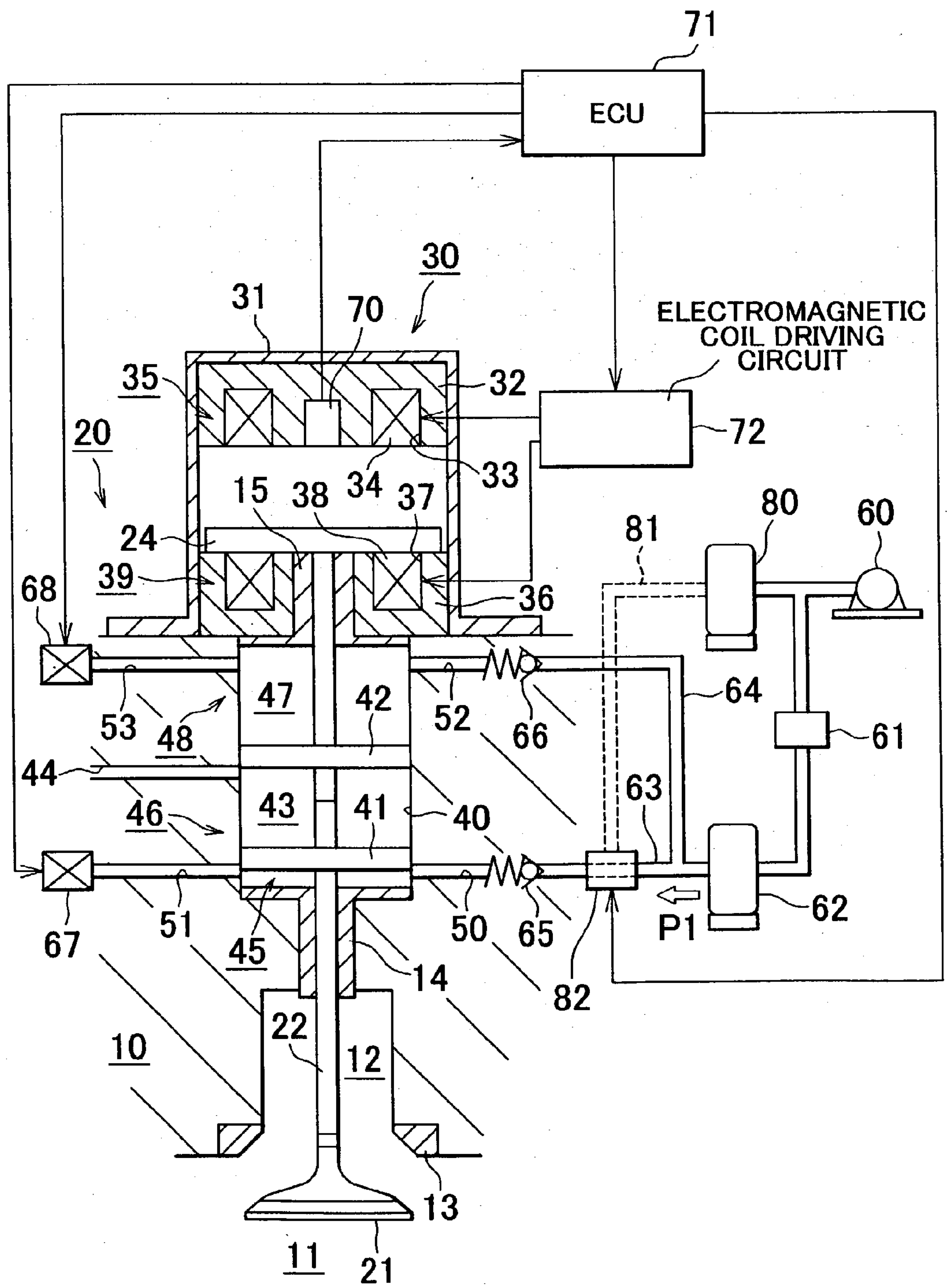


PRESSURE WITHIN PRESSURE CHAMBER
P2
Pn
P1
0
VALVE-CLOSING AIR SPRING
VALVE-OPENING AIR SPRING
FULL-CLOSE POSITION
NEUTRAL POSITION
FULL-OPEN POSITION
VALVE ELEMENT LIFT POSITION

FIG. 4

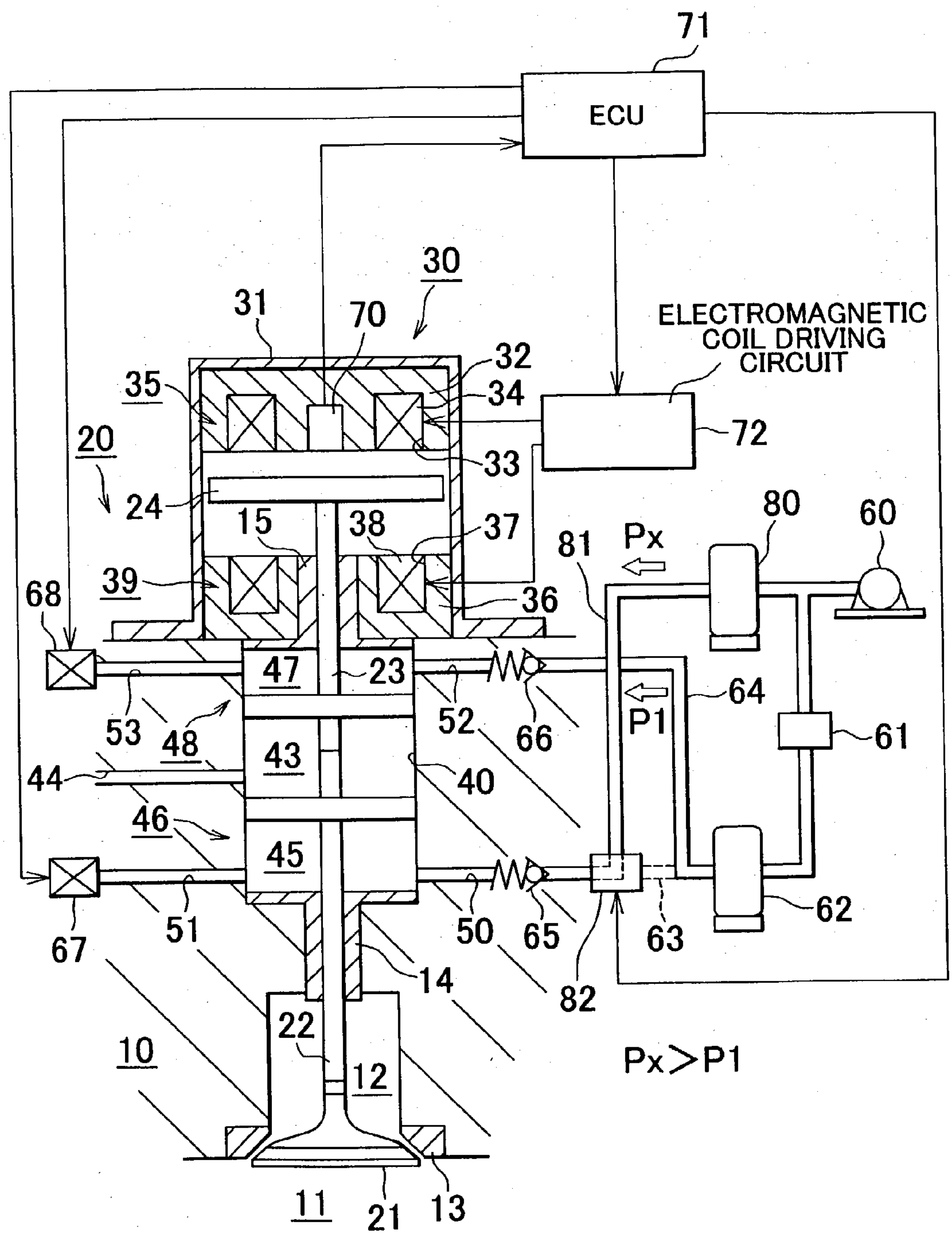

71
ECU
30
31
70
32
35
34
ELECTROMAGNETIC COIL DRIVING CIRCUIT
72
20
24
33
15
38
37
81
80
60
68
39
36
47
23
53
48
52
66
64
61
43
42
44
40
46
63
45
41
67
51
50
65
82
P1
62
14
22
10
12
11
13

F I G. 5



71
ECU
30
31
70
ELECTROMAGNETIC COIL DRIVING CIRCUIT
35
32
72
20
34
33
15
38
37
24
80
60
81
39
36
68
47
42
64
53
48
52
66
61
44
63
43
41
40
46
67
51
50
65
62
45
P1
14
82
22
10
12
13
11
21

FIG. 6



71
ECU
30
31
70
ELECTROMAGNETIC COIL DRIVING CIRCUIT
32
35
34
72
20
33
24
15
38
37
80
60
81
Px
39
68
36
47
23
53
48
52
66
P1
64
61
43
44
40
46
45
67
51
50
65
82
63
62
14
22
12
10
Px>P1
11
21
13

FIG. 7a

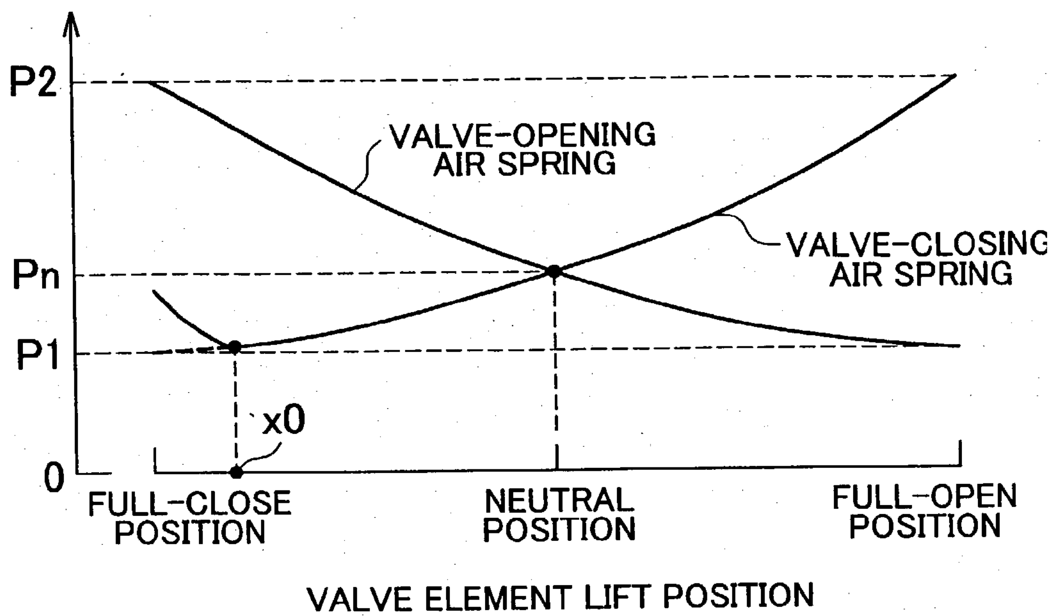
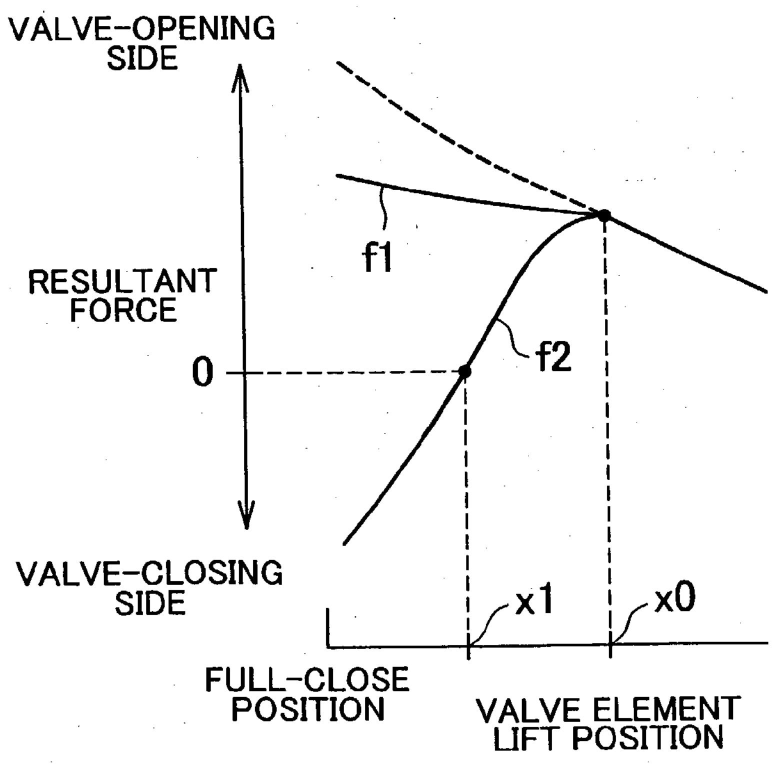
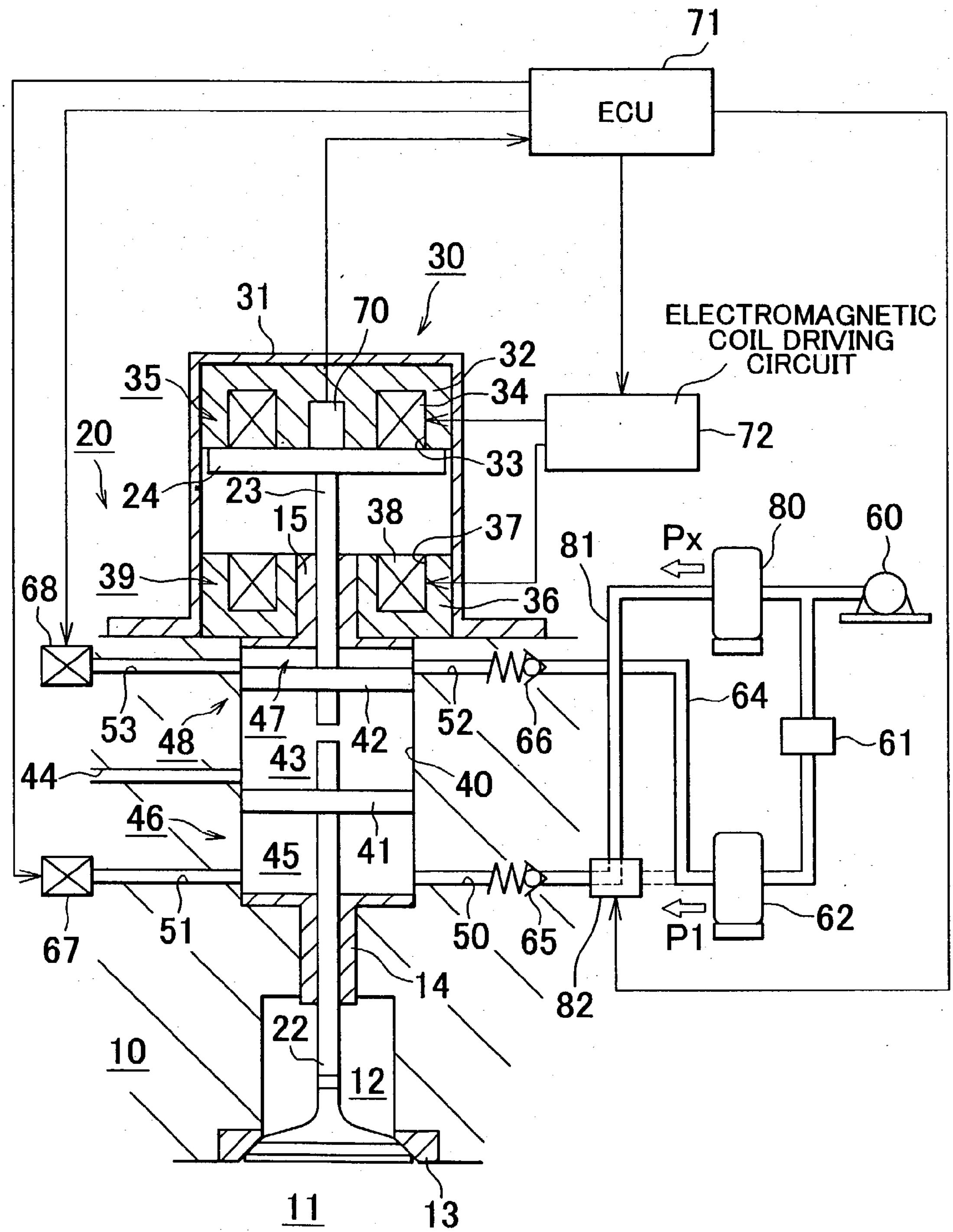

P2
Pn
P1
0
VALVE-OPENING AIR SPRING
VALVE-CLOSING AIR SPRING
x0
FULL-CLOSE POSITION
NEUTRAL POSITION
FULL-OPEN POSITION
VALVE ELEMENT LIFT POSITION

FIG. 7b


VALVE-OPENING SIDE
RESULTANT FORCE
0
VALVE-CLOSING SIDE
f1
f2
x1
x0
FULL-CLOSE POSITION
VALVE ELEMENT LIFT POSITION

F I G. 8


71
ECU
30
31
70
32
34
35
ELECTROMAGNETIC
COIL DRIVING
CIRCUIT
72
20
33
24
23
15
38
37
80
60
81
Px
39
36
68
53
48
47
42
52
66
64
61
44
43
40
46
45
41
67
51
50
65
82
P1
62
14
22
10
12
11
13

F I G. 9

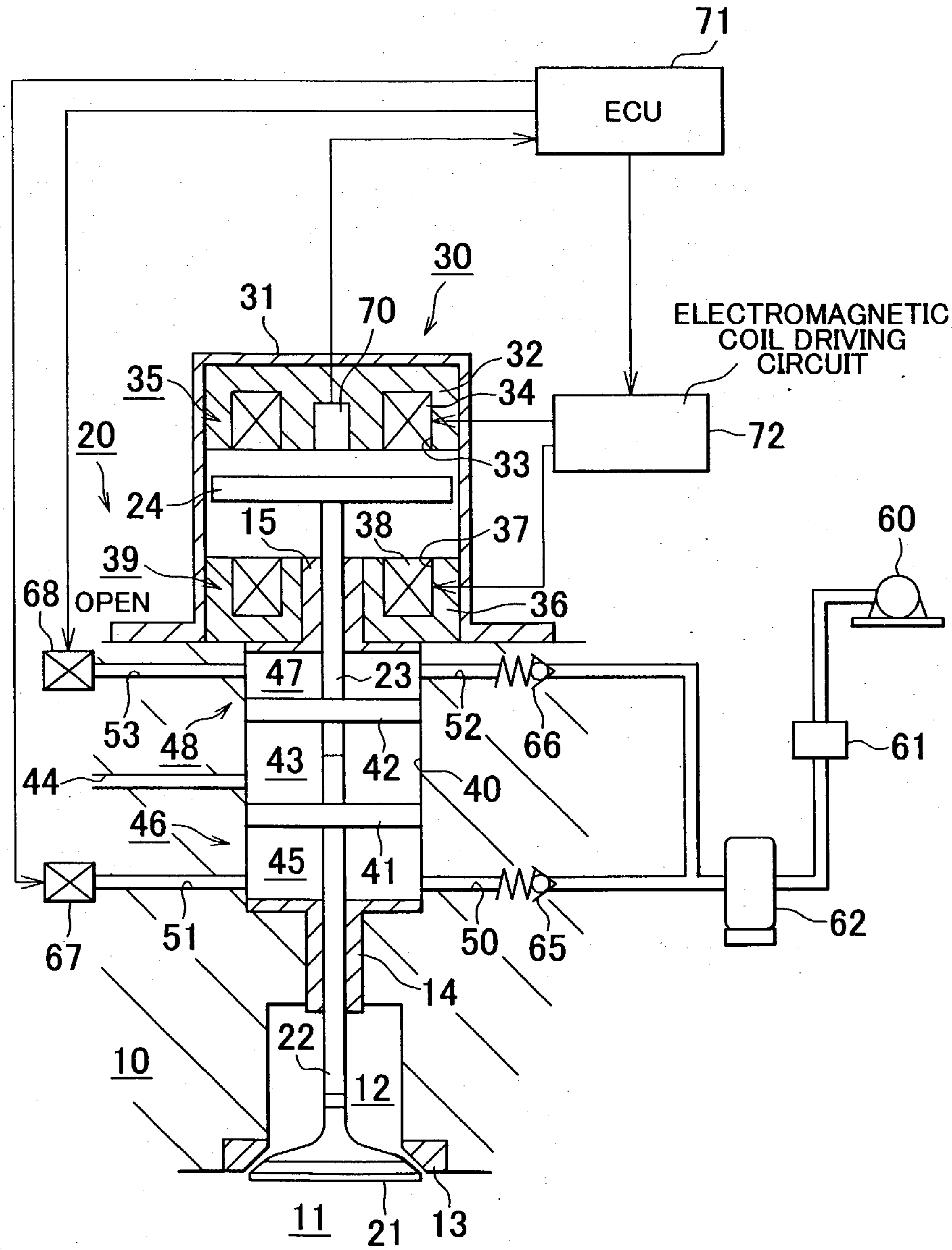

71
ECU
30
31
70
ELECTROMAGNETIC COIL DRIVING CIRCUIT
32
35
34
20
33
72
24
15
38
37
60
39
OPEN
68
36
47
23
53
48
52
66
61
43
42
44
40
46
45
41
67
51
50
65
62
14
22
10
12
11
21
13

FIG. 10a

PRIOR ART

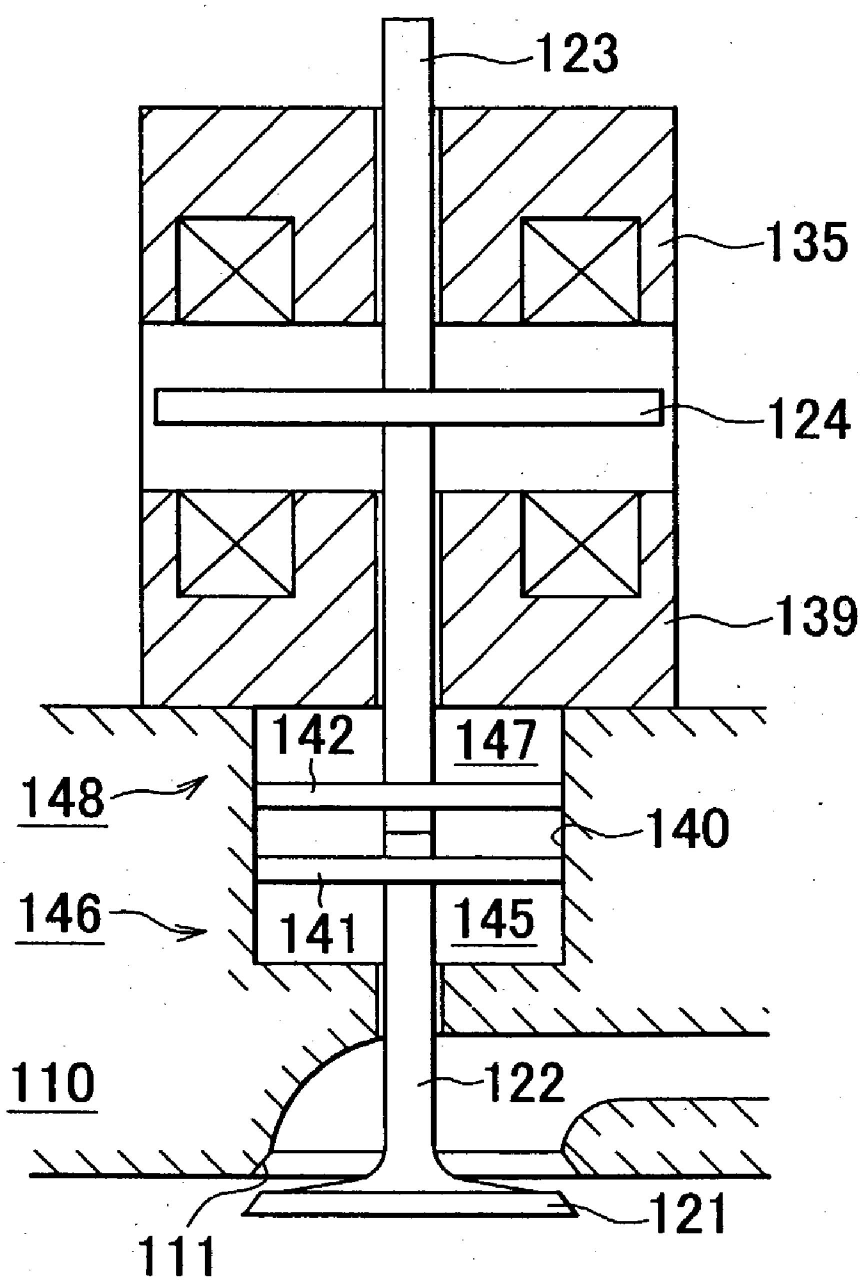
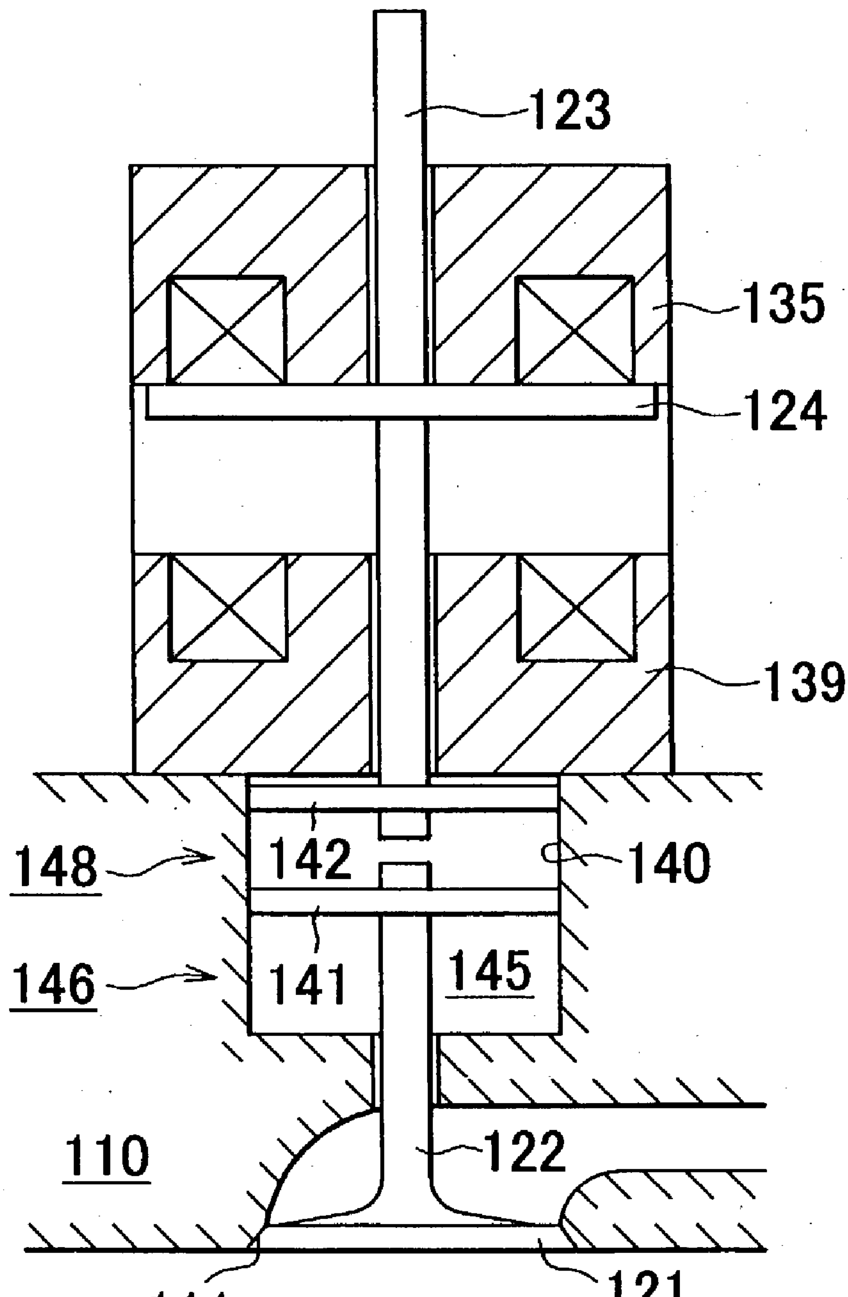


FIG. 10b

PRIOR ART



ELECTROMAGNETIC VALVE CONTROL APPARATUS AND CONTROL METHOD THEREOF

INCORPORATION BY REFERENCE

[**0001**] The disclosure of Japanese Patent Application No. 2002-118806 filed on Apr. 22, 2002, including the specification, drawings and abstract is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[**0002**] 1. Field of the Invention

[**0003**] The invention relates to a control apparatus of an electromagnetic valve for operating a valve element to open and close by an electromagnetic force of an electromagnet and an energizing force of a spring, and a control method of the same.

[**0004**] 2. Description of Related Art

[**0005**] **FIG. 10***a* shows an example of a configuration of the aforementioned type of the electromagnetic valve. In this electromagnetic valve, a cylinder **140** is formed in a cylinder head **110** of an internal combustion engine, and an upper end of an opening of the cylinder **140** is covered with an electromagnet (valve-opening electromagnet) **139** for energizing a valve element **121** which functions as an intake and exhaust valve of the engine. In addition, a valve-closing air spring (pneumatic spring) **146** and a valve-opening air spring (pneumatic spring) **148** are formed in the cylinder **140**. In this case, the valve-closing air spring **146** is disposed against the bottom face of the cylinder **140**, and is provided with a piston **141** connected to a valve shaft **122** of the valve element **121**. Furthermore, the structure is such that the compressed air within a pressure chamber **145** defined by the piston **141**, cylinder **140**, and the bottom face thereof applies to the piston **141** an energizing force in a direction for closing the valve element **121**. Meanwhile, the valve-opening air spring **148** is disposed against the opening face of the cylinder **140**, that is, the bottom face of the valve-opening electromagnet **139**, and is provided with a piston **142** connected to a supporting shaft (armature shaft **123**) of an armature **124** on which the electromagnetic force of the valve-opening electromagnet **139** acts. Furthermore, the structure is such that the compressed air within a pressure chamber **147** defined by the piston **141**, cylinder **140**, and the bottom face of the valve-opening electromagnet **139** which covers the opening face of the cylinder **140** applies to the piston **142** the energizing force in a direction for opening the valve element **121**.

[**0006**] Moreover, the armature shaft **123** connected to the piston **142** of the valve-opening air spring **148** and the valve shaft **122** connected to the piston **142** of the valve-closing air spring **146** are connected to their corresponding pistons **141** and **141** in such a manner as to pass through and protrude from the pistons, such that the armature shaft **123** and the valve shaft **122** oppose with each other. Accordingly, a tappet for transmitting power is constituted by the armature shaft **123** and the valve shaft **122** which protrude and oppose with each other.

[**0007**] On the other hand, at a position opposing the valve-opening electromagnet **139** which covers the cylinder **140**, an electromagnet (valve-closing electromagnet) **135** for energizing the valve element **121** in the valve closing direction is disposed with the armature **124** provided between the electromagnet **139** and the electromagnet **135**. By cooperative operation of the electromagnetic force of the valve-closing electromagnet **135** and the valve-opening electromagnet **139** and the valve-closing air spring **146** and the valve-opening air spring **148**, the valve element **121** is operated to open and close against a valve seat **111** provided in the cylinder head **110**.

[**0008**] Meanwhile, with respect to such electromagnetic valve having the air springs as mentioned above, if a speed (contact speed) at which the armature **124** contacts the valve-closing electromagnet **135** and the valve-opening electromagnet **139** is high, a problem such as a loud contact noise may arise. Therefore, conventionally, as indicated in the Japanese Patent laid-Open Publication No. 2000-27616 for example, it has been suggested that the elastic force of the valve-closing air spring **146** is increased in the vicinity of a full-open position of the valve element **121** during valve opening operation, whereas the elastic force of the valve-opening air spring **148** is increased in the vicinity of the full-close position of the valve element **121** during valve closing operation. This may relieve the impact upon contact of the armature **124** against the valve-closing electromagnet **135** or the valve-opening electromagnet **139**, thereby allowing to lessen the contact noise involved with such contact operation.

[**0009**] According to the electromagnetic valve described in the aforementioned publication, the contact noise generated when the armature **124** contacts the valve-closing electromagnet **135** and the valve-opening electromagnet **139** can certainly be reduced. However, particularly during opening of the valve element **121**, the following inconvenience also occurs when the armature **124** is attracted to the valve-opening electromagnet **135**.

[**0010**] That is, since the tappet between the valve shaft **122** and the armature shaft **123** is normally provided with a predetermined clearance, after the valve element **121** is seated on the valve seat **111**, the armature shaft **123** separates from the valve shaft **122** and the armature **124** continues to be further attracted by the valve-closing electromagnet **135**. Meanwhile, after the valve element **121** is seated on the valve seat **111**, the energizing force of the valve-closing air spring **146** toward the valve-closing side is not applied to the armature **124**, in correlation with the separation of the armature shaft **123**. Therefore, in order to certainly attract (attach) the armature **124** to the valve-closing electromagnet **135**, in a manner shown in **FIG. 10***b*, against the energizing force of the valve-opening air spring **148** toward the valve-opening side, the amount of power supplied to the valve-closing electromagnet **135** must be increased. Moreover, the electromagnetic force by which the valve-closing electromagnet **135** attracts the armature **124** suddenly increases as a gap between the valve-closing electromagnet **135** and the armature **124** becomes small. As a result, a speed at which the armature **124** contact the valve-closing electromagnet **135** increases, thereby also increasing the contact noise involved with such contact operation.

SUMMARY OF THE INVENTION

[**0011**] The invention has been made in view of the aforementioned conditions, and it is an object of the invention to provide a control apparatus of an electromagnetic valve by which an armature connected to an armature shaft which transmits power in relation to the valve shaft can be certainly attracted to an electromagnet which attracts the armature in the valve-closing direction of a valve element, while suppressing an increase in power consumption and the like.

[0012] Therefore, according to an exemplary embodiment, with respect to an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, a control apparatus is provided that is equipped with a controller for increasing, immediately before the valve element is seated, the energizing force of the spring means which energizes the valve element toward the valve-closing side.

[0013] Furthermore, according to an exemplary embodiment, a control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprises the following steps of:

[0014] supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and

[0015] increasing, immediately before seating of the valve element, the energizing force of the spring means which energizes the valve element toward the valve-closing side.

[0016] According to the control apparatus of the electromagnetic valve and the control method thereof as described above, the energizing force of the spring means for energizing the valve element toward the valve-closing side is increased immediately before seating of the valve element. Therefore, compared to a case where the energizing force is not increased, the energizing force for energizing the armature toward the valve-opening side by a resultant force of a pair of spring means is reduced. In addition, if the amount of increase in the energizing force is large, displacement of the armature toward the valve-closing side is accelerated. Accordingly, the degree of decrease in the inertia force of the armature due to the energizing force for energizing the armature toward the valve-opening side by the resultant force of the pair of spring means is reduced immediately before the valve element is seated. Furthermore, if the amount of increase in the energizing force of the spring means for energizing the valve element toward the valve-closing side is large, the inertia force of the armature increases. Consequently, the armature can certainly be attracted to the electromagnet which energizes (attracts) the armature in the valve-closing direction of the valve element while suppressing an increase in power consumption and the like.

[0017] Furthermore, according to an exemplary embodiment, according to an exemplary embodiment, with respect to an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, a control apparatus is provided that is equipped with a controller for reducing, immediately before the valve element is seated, the energizing force of the spring means which energizes the valve element toward the valve-opening side.

[0018] Furthermore, according to an exemplary embodiment, a control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprises the following steps of:

[0019] supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and

[0020] reducing, immediately before seating of the valve element, the energizing force of the spring means which energizes the valve element toward the valve-opening side.

[0021] According to the control apparatus of the electromagnetic valve and the control method thereof as described above, the energizing force of the spring means for energizing the valve element toward the valve-opening side is reduced immediately before seating of the valve element. Therefore, compared to a case where the energizing force is not reduced, the energizing force for energizing the armature toward the valve-opening side by a resultant force of a pair of spring means is reduced. In addition, if the amount of decrease in the energizing force of the spring means for energizing the valve element toward the valve-opening side is large, displacement of the armature toward the valve-closing side is accelerated. Accordingly, the degree of decrease in the inertia force of the armature due to the energizing force for energizing the armature toward the valve-opening side by the resultant force of the pair of spring means is reduced immediately before the valve element is seated. Furthermore, if the amount of decrease in the energizing force of the spring means for energizing the valve element toward the valve-opening side is large, the inertia force of the armature increases. Consequently, the armature can certainly be attracted to the electromagnet which energizes (attracts) the armature in the valve-closing direction of the valve element while suppressing an increase in power consumption and the like.

[0022] Moreover, according to an exemplary embodiment, with respect to an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a valve-opening air spring for energizing the valve element toward a valve-opening side, a valve-closing air spring for energizing the valve element toward a valve-closing side, and a pair of electromagnets for energizing the armature in both axial directions of the armature shaft, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of each electromagnet and an energizing force of each air spring, a control apparatus is provided that is equipped with a controller for forcibly reducing, immediately before the valve element is seated, the degree of increase in the energizing force by which the valve-opening air spring and the valve-closing air spring energize the valve element toward the valve-opening side in accordance with displacement of the valve element toward the valve-closing side.

[**0023**] Furthermore, according to yet another exemplary embodiment, a control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which engages with the valve element, a valve-opening air spring for energizing the valve element toward a valve-opening side, a valve-closing air spring for energizing the valve element toward a valve-closing side, and a pair of electromagnets for energizing the armature in both axial directions of the armature shaft, and which operates the valve element to open and close by cooperative operation of an electromagnetic force of each electromagnet and an energizing force of each air spring, comprises the following steps of:

- [**0024**] supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and
- [**0025**] forcibly reducing, immediately before seating of the valve element, the degree of increase in the energizing force by which the valve-opening air spring and the valve-closing air spring energize the valve element toward the valve-opening side in accordance with displacement of the valve element toward the valve-closing side.

[**0026**] Immediately before the valve element is seated, the inertia force of the armature is reduced by the energizing force which energizes the armature toward the valve-opening side by the resultant force of the valve-opening air spring and the valve-closing air spring.

[**0027**] In this case, according to the control apparatus of the electromagnetic valve and the control method thereof as described above, the degree of increase in the energizing force by which the valve-opening air spring and the valve-closing air spring energize the valve element toward the valve-opening side in accordance with displacement of the valve element toward the valve-closing side is forcibly reduced immediately before seating of the valve element. Accordingly, the degree of decrease in the inertia force of the armature due to the energizing force for energizing the armature toward the valve-opening side by the resultant force of the valve-opening air spring and the valve-closing air spring is reduced immediately before seating of the valve element. Consequently, the armature can certainly be attracted to the electromagnet which energizes (attracts) the armature in the valve-closing direction of the valve element while suppressing an increase in power consumption and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0028**] The above mentioned embodiment and other embodiments, objects, features, advantages, technical and industrial significances of this invention will be better understood by reading the following detailed description of the exemplary embodiments of the invention, when considered in connection with the accompanying drawings, in which:

[**0029**] **FIG. 1** is a drawing of a first exemplary embodiment of a control apparatus of an electromagnetic valve according to the invention;

[**0030**] **FIGS. 2***a*, **2***b*, and **2***c* are cross-sectional views which schematically show operation modes of an air spring according to the exemplary embodiment;

[**0031**] **FIG. 3** is a drawing which shows a relationship between a lift position of a valve element and a pressure of the air spring according to the exemplary embodiment;

[**0032**] **FIG. 4** is a drawing which shows a valve-closed state of the valve element according to the exemplary embodiment;

[**0033**] **FIG. 5** is a drawing which shows a valve-open state of the valve element according to the exemplary embodiment;

[**0034**] **FIG. 6** is a drawing which shows a state immediately before seating of the valve element according to the exemplary embodiment;

[**0035**] **FIGS. 7***a* and **7***b* are drawings which show control modes of the air spring according to the exemplary embodiment;

[**0036**] **FIG. 8** is a drawing which show a state in which an armature is seated according to the exemplary embodiment;

[**0037**] **FIG. 9** is a drawing which shows a control mode immediately before seating of the valve element according to a second exemplary embodiment of the control apparatus of the electromagnetic valve of the invention; and

[**0038**] **FIGS. 10***a* and **10***b* are drawings which show control modes of a conventional electromagnetic valve.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[**0039**] In the following description and the accompanying drawings, the invention will be described in more detail in terms of exemplary embodiments.

[**0040**] (First Exemplary Embodiment)

[**0041**] A control apparatus of an electromagnetic valve according to a first exemplary embodiment will be described at first. Each of an intake valve and exhaust valve of an internal combustion engine is configured as an electromagnetic valve which is opened and closed by cooperative operation of an electromagnetic force of an electromagnet and an elastic force (energizing force) of a pair of air springs. More specifically, the electromagnetic valve is equipped with a pair of electromagnets for energizing an armature connected to an armature shaft in both armature axial directions. Furthermore, the electromagnetic valve includes a valve-opening air spring for energizing a piston connected to the armature shaft toward the valve-opening side of a valve element by a pressure in a pressure chamber, and a valve-closing air spring for energizing a piston connected to a valve shaft which is an axis of the valve element toward the valve-closing side of the valve element by a pressure in a pressure chamber. The valve element is operated to open and close by cooperative operation of the electromagnetic force which acts on the armature by the pair of electromagnets and the energizing force of the pair of air springs. Since the intake valve and the exhaust valve have the same basic structure, the intake valve is taken as an example herein to describe its internal structure.

[**0042**] A cylinder head **10** of an internal combustion engine shown in **FIG. 1** is formed with an intake port **12** which is connected to a combustion chamber **11**, and is provided with an electromagnetic valve **20** for opening and closing the intake port **12**.

[**0043**] The electromagnetic valve **20** generally includes a valve element **21** provided at one end of a valve shaft **22**, an electromagnetic drive portion **30** which generates an electromagnetic force for opening and closing the valve element **21**, and a pair of air springs **46** and **48** which energize the valve element **21** toward a valve-closing side displacement end and a valve-opening side displacement end, respectively.

[**0044**] The valve element **21** is arranged in an opening of the intake port **12** in such a manner as to be exposed to the inside of the combustion chamber **11**. A valve seat **13** is provided at the outer edge of the opening of the intake port **12**. The intake port **12** is opened and closed as the valve element **21** is separated from or seated on the valve seat **13**. That is, as the valve element **21** is displaced upward in **FIG. 1** to be seated on the valve seat **13**, the intake port **12** is closed with respect to the combustion chamber **11**. Furthermore, as the valve element **21** seated on the valve seat **13** is displaced downward in **FIG. 1** to be separated from the valve seat **13**, the intake port **12** is opened with respect to the combustion chamber **11**.

[**0045**] The valve shaft **22** whose one end is provided with the valve element **21** is supported by a valve guide **14** fixed to the cylinder head **10** in such a manner as to allow reciprocating motion in an axial direction. The upper end of the valve shaft **22** is placed in contact with the lower end of an armature shaft **23**. The armature shaft **23** is supported by an armature guide **15** fixed to the cylinder head **10** in such a manner as to allow reciprocating motion coaxially with the valve shaft **22**.

[**0046**] On the upper end of the armature shaft **23**, an armature **24** that is made of high permeable material and generally formed in a disc shape is fixed. Furthermore, the upper portion of the armature shaft **23** on which the armature **24** is fixed is housed within a casing **31** of the electromagnetic drive portion **30**.

[**0047**] In the casing **31**, an upper core **32** made of high permeable material is fixed above the armature **24**. An annular groove **33** is formed on a face of the upper core **32** that faces the armature **24**, and a cylindrically-wound electromagnetic coil **34** is housed within the groove **33**. The upper core **32** and the electromagnetic coil **34** constitute a valve-closing electromagnet **35** for operating the valve element **21** in a valve-closing direction.

[**0048**] On the other hand, under the armature **24** in the casing **31**, a lower core **36** also made of high permeable material is fixed at a predetermined distance from the upper core **32**. Also on the lower core **36**, an annular groove **37** is formed on a face that faces the armature **24**, and a cylindrically-wound electromagnetic coil **38** is housed within the groove **37**. The lower core **36** and the electromagnetic coil **38** constitute a valve-opening electromagnet **39** for operating the valve element **21** in a valve-opening direction.

[**0049**] Furthermore, in the casing **31**, a displacement sensor **70** is provided for detecting displacement of the armature **24**. A lift position of the valve element **21** can be confirmed based on a detection result of the displacement sensor **70**.

[**0050**] Meanwhile, in the cylinder head **10**, a cylinder **40** with an open circular shape is formed between the valve guide **14** and the armature guide **15**. Furthermore, a generally disc shaped piston **42** is fixed to the valve shaft **22**, and also a generally disc shaped piston **42** is fixed to the armature shaft **23**. These pistons **41** and **42** are disposed in such a manner allowing reciprocating motion in an axial direction of the valve shaft **22** and the armature shaft **23** while being slidably in contact with a side wall of the cylinder **40**.

[**0051**] Inside the cylinder **40** is divided into three spaces by the piston **41** and the piston **42**. Of these three spaces, a middle space **43** formed between the piston **41** and the piston **42** is open to the outside via a communicating passage **44**. Furthermore, a valve-closing air spring **46** and a valve-opening air spring **48** are constituted with the space **43** provided therebetween.

[**0052**] That is, the valve-closing air spring **46** is constituted of the piston **41** and a portion of the cylinder **40** on the valve guide **14** side. In this case, within the cylinder **40**, a space **45** formed between the valve guide **14** and the piston **41** fixed to the valve shaft **22** is supplied with compressed air via an air supply passage **50**, and the compressed air within the space **45** is discharged through an exhaust passage **51**. In this case, the space **45**, the air supply passage **50**, and the exhaust passage **51** constitute a pressure chamber of the valve-closing air spring **46**. The air pressure within the pressure chamber (more accurately, a pressure difference between the air pressure within the pressure chamber and that within the space **43**, or the atmospheric pressure) energizes the valve shaft **22** toward the valve-closing side (upward in **FIG. 1**) of the valve element **21** via the piston **41**.

[**0053**] Furthermore, the valve-opening air spring **48** is constituted of the piston **42** and a portion of the cylinder **40** on the armature guide **15** side. In this case, within the cylinder **40**, a space **47** formed between the armature guide **15** and the piston **42** fixed to the armature shaft **23** is supplied with compressed air via an air supply passage **52**, and the compressed air within the space **47** is discharged through an exhaust passage **53**. In this case, the space **47**, the air supply passage **52**, and the exhaust passage **53** constitute a pressure chamber of the valve-opening air spring **48**. The air pressure within the pressure chamber (more accurately, a pressure difference between the air pressure within the pressure chamber and that within the space **43**, or the atmospheric pressure) energizes the armature shaft **23** toward the valve-opening side (downward in **FIG. 1**) of the valve element **21** via the piston **42**.

[**0054**] Next, a structure of an air pressure circuit for the valve-closing air spring **46** and the valve-opening air spring

48 will be described with reference to **FIG. 1**. The air pressure circuit is provided with an air pump **60** and a reservoir tank **62**.

[**0055**] The air pump **60** compresses air taken in from outside and supplies the compressed air to the reservoir tank **62** via a throttle **61**. The compressed air supplied from the air pump **60** is accumulated in the reservoir tank **62**. A pressure of the compressed air accumulated in the reservoir tank **62** is maintained constant by a regulator or the like (not shown).

[**0056**] The reservoir tank **62** is connected to the pressure chamber of the valve-closing air spring **46** via a supply passage **63**. Furthermore, the reservoir tank **62** is connected to the pressure chamber of the valve-opening air spring **48** via a supply passage **64**.

[**0057**] More specifically, the supply passage **63** is connected to the air supply passage **50** via a non-return valve **65**. Furthermore, the supply passage **64** is connected to the air supply passage **52** via a non-return valve **66**.

[**0058**] The non-return valves **65** and **66** are differential pressure operating valves of normally closed type, and open when the pressures within the pressure chambers of the valve-closing air spring **46** and the valve-opening air spring **48** become lower than the pressures of the supply passages **63** and **64**, so as to supply compressed air to the pressure chambers.

[**0059**] Moreover, the exhaust passage **51** of the valve-closing air spring **46** and the exhaust passage **53** of the valve-opening air spring **48** are provided with a relief valves **67** and **68**, respectively. The relief valves **67** and **68** normally function as pressure operating valves of normally closed type which open when the air pressure of the exhaust passages **51** and **53** has become equal to or higher than a predetermined level, so as to discharge extra compressed air from the pressure chamber. Furthermore, the relief valves **67** and **68** are also structured so as to be forcibly opened or closed by a command from outside. The downstream of the relief valves **67** and **68** is open to the air.

[**0060**] The amount of compressed air filled within the pressure chambers of the valve-closing air spring **46** and the valve-opening air spring **48** is regulated through the non-return valves **65** and **66**, the relief valves **67** and **68**, and the like, so as to obtain a desired elastic force.

[**0061**] Although not shown in **FIG. 1**, each of intake valve and exhaust valve of the internal combustion chamber is provided with the non-return valves **65** and **66**, the relief valves **67** and **68**, and the supply passages **63** and **64**. According to this structure, the air pressure of the air spring provided for each intake valve and exhaust valve of the internal combustion engine can also be adjusted individually.

[**0062**] Next, the structure of a control system of the electromagnetic valve **20** described above will be explained with reference to **FIG. 1**.

[**0063**] To an input port of an electronic control unit (ECU) **71** which executes various controls of the internal combustion engine, detection signals of various sensors, such as a crank angle sensor and an accelerator sensor, that detect an operation state of the engine, in addition to a detection signal of the displacement sensor **70** are input. Furthermore, an electromagnetic coil driving circuit **72** is connected to an output port of the electronic control unit **71**.

[**0064**] The electronic control unit **71** generates a control signal for supplying power to both electromagnetic coils **34** and **38** on the basis of the engine operation state identified based on the detection signals of each sensor mentioned above, and outputs the control signal to the electromagnetic coil driving circuit **72**. The electromagnetic coil driving circuit **72** amplifies the control signal to generate an electromagnetic coil driving current, and supplies power to each of the electromagnetic coils **34** and **38**.

[**0065**] Furthermore, the electronic control unit **71** controls the relief valves **67** and **68** so as to adjust the air pressure within the pressure chambers of the valve-closing air spring **46** and the valve-opening air spring **48** according to the engine operation state.

[**0066**] In the electromagnetic valve **20** as structured as above according to the exemplary embodiment, the valve element **21** which is displaced along with the valve shaft **22** and the armature shaft **23** is capable of reciprocating between a position at which the valve element **21** seats on the valve seat **13** and a position at which the armature **24** contacts the lower core **36**.

[**0067**] In this case, at a lift position of the valve element **21** at which the valve element is seated on the valve seat **13**, that is, at the valve-closing side displacement end of the valve element **21**, the electromagnetic valve **20** is fully closed. The lift position of the valve element **21** in this state is called a "full-close position."

[**0068**] Furthermore, at a lift position of the valve element **21** at which the armature **24** contacts the lower core **36**, that is, at the valve-opening side displacement end of the valve element **21**, the valve element **21** is kept apart from the valve seat **13** to the maximum, and thus the electromagnetic valve **20** is fully opened. The lift position of the valve element **21** in this state is called a "full-open position."

[**0069**] In the electromagnetic valve **20**, when no electromagnetic force is generated by the electromagnets **35** and **39**, the valve element **21** which is displaced along with the valve shaft **22** and the armature shaft **23** is placed at a position at which an elastic force Fcl of the valve-closing air spring **46** and an elastic force Fop of the valve-opening air spring **48** are equal. Herein, a lift position of the valve element **21** at which the elastic force Fcl of the valve-closing air spring **46** and the elastic force Fop of the valve-opening air spring **48** are balanced is called a "neutral position."

[**0070**] In addition, when the elastic forces of the valve-closing air spring **46** and the valve-opening air spring **48** are equal, and the external environments of both springs are the same, the air pressure in the valve-closing air spring **46** and that in the valve-opening air spring **48** assume the same pressure Pn, as shown in **FIG. 2***b*. In this exemplary embodiment, on the basis of a position (reference position) at which the elastic forces of the valve-closing air spring **46** and the valve-opening air spring **48** become equal under the same external environments, forces (elastic forces) applied to pressure-receiving surfaces of the pistons **41** and **42** in accordance with displacement of the pistons are set to be equal with each other. This can be achieved by equalizing, at the aforementioned reference position, the capacities of the pressure chambers of the valve-closing air spring **46** and the valve-opening air spring **48**, and the pressure-receiving areas of the pistons **41** and **42**.

[**0071**] As the valve element **21** is displaced from the neutral position, the pistons **41** and **42** are also displaced within the cylinder **40**, and accordingly the capacity of each pressure chamber of the valve-closing air spring **46** and the valve-opening air spring **48** changes, thereby causing the air pressure therein to change. **FIG. 3** illustrates a pattern of such air pressure change within the pressure chamber based on the lift position of the valve element **21**.

[**0072**] After being minimized at the full-open position, the capacity of the pressure chamber of the valve-closing air spring **46** is increased as the lift position of the valve element **21** moves toward the full-close position. Therefore, as shown in **FIG. 3**, the air pressure within the pressure chamber increases from a minimum pressure P1 at the full-close position as the lift position moves toward the valve-opening side, and becomes a maximum pressure P2 at the full-open position.

[**0073**] In contrast to the pressure chamber of the valve-closing air spring **46** as mentioned above, the capacity of the pressure chamber of the valve-opening air spring **48** is, after being maximized at the full-open position, reduced as the lift position of the valve element **21** moves toward the full-close position. Therefore, the air pressure within the pressure chamber of the valve-opening air spring **48** is increased from a minimum pressure P1 at the full-open position as the lift position moves toward the valve-closing side, and becomes a maximum pressure P2 at the full-close position.

[**0074**] Accordingly, as shown in **FIG. 2***a*, at the full-open position, since the air pressure within the pressure chamber of the valve-closing air spring **46** becomes the maximum pressure P2, whereas the air pressure within the pressure chamber of the valve-opening air spring **48** becomes the minimum pressure P1, the valve element **21** is energized toward the valve-closing side by the elastic force of both air springs **46** and **48** (Fcl>Fop). On the other hand, at the full-close position, the air pressure within the pressure chamber of the valve-opening air spring **48** becomes the maximum pressure P2, whereas the air pressure within the pressure chamber of the valve-closing air spring **46** becomes the minimum pressure P1, as shown in **FIG. 2***c*. Therefore, the valve element **21** is energized toward the valve-opening side by the elastic force of both air springs **46** and **48** (Fop>Fcl).

[**0075**] In addition, the air pressure within each pressure chamber when the capacity thereof is at its maximum, that is, the minimum pressure P1 is sufficiently higher than an atmospheric pressure P0. In order to secure the minimum pressure P1, a pressure of the compressed air within the reservoir tank **62** is set to the minimum pressure P1.

[**0076**] Next, a description will be given of an operation mode of the electromagnetic valve **20** during normal valve opening and closing operation, In a state where the valve element **21** is placed at the full-close position, the valve element **21** is, as described above, energized toward the valve-opening side by the resultant force of the elastic forces of the valve-closing air spring **46** and the valve-opening air spring **48**. The valve element **21** is held at the full-close position by supplying a holding current to the electromagnetic coil **34** of the valve-closing electromagnet **35** to generate an electromagnetic force which attracts and holds the armature **24** to the upper core **32**. In this case, the magnitude of holding current supplied to the electromagnetic coil **34** is set so as to maintain the state in which the armature **24** is attracted to the upper core **32** against the resultant force of the elastic forces of the valve-closing air spring **46** and the valve-opening air spring **48**.

[**0077**] Next, to operate the valve element **21** maintained at the full-close position to open toward the full-open position, supply of holding current to the electromagnetic coil **34** is stopped. As a result, as shown in **FIG. 4**, the armature **24** is released from the upper core **32**, and the valve element **21** is displaced from the full-close position toward the valve-opening side by the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** that acts toward the valve-opening side.

[**0078**] Thereafter, in accordance with the displacement of the valve element **21** toward the valve-opening side, the resultant force of the elastic forces of the valve-closing air spring **46** and the valve-opening air spring **48** decreases. When the valve element **21** is displaced beyond the neutral position to the valve-opening side, the resultant force of the elastic forces starts to act in a direction to pull the valve element **21** back. However, the valve element **21** continues to move further toward the valve-opening side, to some extent by its own inertia force, against the resultant force of the elastic forces.

[**0079**] Then, when the valve element **21** reaches a predetermined position, an attracting current is supplied to the electromagnetic coil **38** of the valve-opening electromagnet **39**. An electromagnetic force generated in the valve-opening electromagnet **39** due to the supply of the attracting current attracts the armature **24** toward the lower core **36**. Accordingly, the valve element **21** continues to move, by its own inertia force and the electromagnetic force of the electromagnet **39**, toward the valve-opening side against the resultant force of the elastic forces the valve-closing air spring **46** and the valve-opening air spring **48**. In this case, the magnitude of the attracting current is set, for example, according to the lift position of the valve element **21** or the like that is detected by the displacement sensor **70**, so that the armature **24** is certainly attracted to the lower core **36**.

[**0080**] Accordingly, as shown in **FIG. 5**, as the armature **24** is attracted to the lower core **36** and the valve element **21** reaches the full-open position, a holding current is supplied to the electromagnetic coil **38** of the valve-opening electromagnet **39**. The electromagnetic force generated thereby attracts and holds the armature **24** to the lower core **36**.

[**0081**] Also, to operate the valve element **21**, which is maintained at the full-open position, to close toward the full-close position, as in the same manner as the opening operation of the valve element **21** from the full-close position to the full-open position as described above, power supply to the valve-closing electromagnet **35** and the valve-opening electromagnet **39** is controlled. That is, by stopping the supply of holding current to the electromagnetic coil **38** of the valve-opening electromagnet **39**, the valve element **21** starts to move toward the valve-closing side, and by supplying the attracting current to the electromagnetic coil **34** of the valve-closing electromagnet **35**, the armature **24** is attracted to the upper core **32**.

[**0082**] After the valve element **21** reaches the full-close position, opening and closing operation of the electromagnetic valve **20** is continued by sequentially repeating the aforementioned current supply control. The above are the descriptions of the operation mode of the electromagnetic valve **20** during normal valve opening and closing operation.

[**0083**] Meanwhile, even after the valve element **21** is seated on the valve seat **13**, the armature **24** is attracted to the valve-closing electromagnet **35** and is displaced toward the valve-closing electromagnet **35** side. Such displacement continues until the armature **24** contacts the valve-closing electromagnet **35**. However, since the armature shaft **23** separates form the valve shaft **22** after the valve element **21** is seated on the valve seat **13**, the armature **24** is not applied with the energizing force by the valve-closing air spring **46**. At this time, to displace the armature **24** toward the valve closing side against the energizing force of the valve-opening air spring **48** toward the valve-opening side, the amount of current supplied to the valve-closing electromagnet **35** is increased, thereby causing the inconvenience such as increasing power consumption, as mentioned earlier.

[**0084**] Therefore, in this exemplary embodiment, a pressure within the pressure chamber of the valve-closing air spring **46** is increased immediately before the valve element **21** is seated. In other words, the pressure within the pressure chamber of the valve-closing air spring **46** is increased during a predetermined period immediately before the armature shaft **23** starts separate from the valve shaft **22** to move toward the valve-closing electromagnet **35** side upon seating of the valve element **21** on the valve seat **13**.

[**0085**] Accordingly, compared to a case in which the pressure is not increased as described above, the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the elastic forces the valve-closing air spring **46** and the valve-opening air spring **48** is reduced. In other words, an increase, involved with displacement of the valve element **21** toward the valve-closing side, in the energizing force toward the valve-opening side that is applied to the valve element **21** by the valve-opening air spring **48** and the valve-closing air spring **46** in accordance with such displacement, is at least suppressed immediately before the valve element **21** is seated.

[**0086**] As a result, the degree of decrease in the inertia force of the armature **24** due to the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** is at least reduced immediately before the valve element **21** is seated. Consequently, the armature **24** can appropriately be attracted to be brought into contact with the valve-closing electromagnet **35** without increasing the energizing force of the valve-closing electromagnet **35** for energizing the armature **24** toward the valve-closing side.

[**0087**] Furthermore, if the amount of increase in the pressure within the pressure chamber of the valve-closing air spring **46** immediately before seating of the valve element **21** is large, the inertia force of the armature **24** is also increased. In other words, displacement of the armature **24** toward the valve-closing electromagnet **35** side is also accelerated.

[**0088**] More specifically, in order to execute such control as mentioned above, in this exemplary embodiment, as shown in **FIG. 1, a** high-pressure reservoir tank **80** which accumulates compressed air with a pressure (Px) higher than a pressure (P1) of compressed air accumulated in the reservoir tank **62** is provided. The high-pressure reservoir tank **80** also accumulates the compressed air supplied from the air pump **60**. Moreover, a pressure of the compressed air accumulated in the high-pressure reservoir tank **80** is also maintained constant by a regulator or the like (not shown). However, the throttle **61** is not provided between the air pump **60** and the high-pressure reservoir tank **80**, thereby making it easier to accumulate, in the high-pressure reservoir tank **80**, the compressed air with a pressure higher than the pressure of the compressed air accumulated in the reservoir tank **62**.

[**0089**] The high-pressure reservoir tank **80** is connected to the pressure chamber of the valve-closing air spring **46** through a supply passage **81**. Furthermore, a switching valve **82** is provided in the supply valve **63** in order to selectively supply the pressure chamber of the valve-closing air spring **46** with the compressed air in the high-pressure reservoir tank **80** and that in the reservoir tank **62**. The switching valve **82** switches, based on a command from the electronic control unit **71**, between communication between the upstream and downstream of the supply passage **63** and that between the supply passage **81** and the downstream of the supply passage **63**. In other words, the switching valve **82** switches between communication between the reservoir tank **62** and the pressure chamber of the valve-closing air spring **46** via the non-return valve **65**, and that between the high-pressure reservoir tank **80** and the pressure chamber of the valve-closing air spring **46** via the non-return valve **65**.

[**0090**] Furthermore, the switching valve **82** is switched so as to increase the pressure within the pressure chamber of the valve-closing air spring **46** immediately before the valve element **21** is seated on the valve seat **13**. That is, as shown in **FIG. 6**, the switching valve **82** is switched so as to supply the compressed air accumulated in the high-pressure reservoir tank **80** to the pressure chamber of the valve-closing air spring **46**. Accordingly, the non-return valve **65** is closed and the compressed air accumulated in the high-pressure reservoir tank **80** flows into the pressure chamber of the valve-closing air spring **46**. As a result, the pressure within the pressure chamber of the valve-closing air spring **46** immediately before the valve element **21** is seated on the valve seat **13** can be increased compared to that theretofore. In this case, when the compressed air accumulated in the high-pressure reservoir tank **80** is supplied to the pressure chamber of the valve-closing air spring **46**, a control such as forcibly closing the relief valve **67** is executed.

[**0091**] By supplying the compressed air accumulated in the high-pressure reservoir tank **80** as mentioned above, as shown in **FIG. 7***a*, the pressure within the pressure chamber of the valve-closing air spring **46** is forcibly increased during displacement of the valve element **21** toward the valve-closing side from a predetermined displacement x**0** in the vicinity of the full-close position. Before the predetermined displacement x**0**, the valve element **21** is energized toward the valve-opening side by the resultant force of the elastic forces of the valve-opening air spring **48** and the valve-closing air spring **46**. This energizing force increases in accordance with displacement of the valve element **21** toward the valve-closing side as shown in **FIG. 7***b*. After the predetermined displacement x**0** in the vicinity of the full-close position, however, since the pressure within the pressure chamber of the valve-closing air spring **46** is forcibly increased, the actual energizing force mentioned above is suppressed in relation to the degree of increase in the energizing force indicated by a dotted line in **FIG.** 7*b*. That is, in this case, the resultant force of the elastic forces of the valve-opening air spring **48** and the valve-closing air spring **46** becomes, for example, a resultant force f1. Consequently, the degree of decrease in the inertia force of the armature **24** due to the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the elastic forces of the valve-opening air spring **48** and the valve-closing air spring **46** is reduced.

[**0092**] Furthermore, when the degree of forced increase in the pressure within the pressure chamber of the valve-closing air spring **46** is high, and the pressure within the pressure chamber of the valve-closing air spring **46** exceeds the pressure within the pressure chamber of the valve-opening air spring **48**, the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** is directed toward the valve-closing direction as indicated by a resultant force f2 in **FIG.** 7*b*. In this case, displacement of the armature **24** toward the valve-closing side is also accelerated. Accordingly, the inertia force in accordance with displacement of the armature **24** toward the valve-closing side is increased.

[**0093**] By forcibly increasing the pressure within the pressure chamber of the valve-closing air spring **46**, the armature **24** can be brought into contact with the valve-closing electromagnet **35** as shown in **FIG. 8**.

[**0094**] According to the exemplary embodiment as described above, the following effects can be obtained.

[**0095**] (1) A pressure within the pressure chamber of the valve-closing air spring **46** is forcibly increased immediately before the valve element **21** is seated. Consequently, the degree of decrease in the inertia force of the armature **24** due to the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** can be sufficiently reduced immediately before the valve element **21** is seated. Furthermore, if the amount of increase in the pressure within the pressure chamber of the valve-closing air spring **46** immediately before seating of the valve element is large, the inertia force of the armature can also be increased. In other words, displacement of the armature **24** toward the valve-closing electromagnet **35** side is also accelerated. As a result, the armature **24** can certainly be attracted to and brought into contact with the valve-closing electromagnet **35**.

[**0096**] (2) As reservoir tanks for supplying compressed air to the pressure chambers of the valve-closing air spring **46** and the valve-opening air spring **48**, the reservoir tank **62** and the high-pressure reservoir tank **80** which accumulates compressed air with a pressure higher than that of the reservoir tank **62** are provided. Accordingly, the pressure within the pressure chamber of the valve-closing air spring **46** can forcibly increased immediately before seating of the valve element **21** in a suitable manner.

[**0097**] (Second Exemplary Embodiment)

[**0098**] A second exemplary embodiment of a control apparatus of an electromagnetic valve according to the invention will be described hereinafter with reference to the accompanying drawings, with a focus directed on differences from the first exemplary embodiment.

[**0099**] In the first exemplary embodiment, the pressure within the pressure chamber of the valve-closing air spring **46** is forcibly increased immediately before the valve element **21** is seated on the valve seat **13**. To the contrary, in the second exemplary embodiment, the pressure within the pressure chamber of the valve-opening air spring **48** is reduced immediately before the valve element **21** is seated. Therefore, compared to a case in which the pressure is not forcibly reduced as descried above, the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** is reduced. As a result, the degree of decrease in the inertia force of the armature **24** due to the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of a pair of spring means is reduced immediately before the valve element **21** is seated. Furthermore, if the amount of the aforementioned pressure reduction is large, the inertia force in accordance with the displacement of the armature **24** toward the valve-closing side is increased. Accordingly, the armature **24** can certainly be attracted to and brought into contact with the valve-closing electromagnet **35** without increasing the energizing force of the valve-closing electromagnet **35** that energizes the armature **24** toward the valve-opening side.

[**0100**] More specifically, according to this exemplary embodiment, in a structure as shown in **FIG. 9**, the relief valve **68** is opened by a predetermined degree so as to reduce the pressure within the pressure chamber of the valve-opening air spring **48** immediately before the valve element **21** is seated. Consequently, the armature **24** can be brought into contact with the valve-closing electromagnet **35** just like in the case of the first exemplary embodiment.

[**0101**] According to the aforementioned exemplary embodiment, the following effects can be obtained.

[**0102**] (3) A pressure within the pressure chamber of the valve-opening air spring **48** is forcibly reduced immediately before the valve element **21** is seated. Accordingly, the degree of decrease in the inertia force of the armature **24** due to the energizing force for energizing the armature **24** toward the valve-opening side by the resultant force of the valve-closing air spring **46** and the valve-opening air spring **48** can be sufficiently reduced immediately before the valve element **21** is seated. Furthermore, if the amount of decrease in the pressure within the pressure chamber of the valve-opening air spring **48** immediately before seating of the valve element is large, the inertia force of the armature **24** can also be increased. In other words, displacement of the armature **24** toward the valve-closing electromagnet **35** side is also accelerated. As a result, the armature **24** can certainly be attracted to and brought into contact with the valve-closing electromagnet **35**.

[**0103**] Each exemplary embodiment described above may be modified as follows.

[**0104**] The invention is not limited to the control by which the pressure within the pressure chamber of the valve-closing air spring **46** is forcibly increased immediately before the valve element **21** is seated, as described in the first exemplary embodiment. Any control will do as long as the degree of decrease in the pressure within the pressure chamber of the valve-closing air spring **46** involved with displacement of the valve element **21** toward the valve-closing side is forcibly reduced immediately before the valve element **21** is seated. That is, for example, the pressure may assume a larger value than the pressure within the pressure chamber of the valve-opening air spring represented by a curve in **FIG. 3**, so as to reduce the degree of decrease in the pressure within the pressure chamber involved with displacement of the valve element toward the valve-closing side.

[**0105**] In this case, control means for forcibly reducing, immediately before the valve element **21** is seated on the valve seat **13**, the degree of decrease in the pressure within the pressure chamber of the valve-closing air spring **46** involved with displacement of the valve element **21** toward the valve-opening side, may be configured to include the high-pressure reservoir tank **80**, the relief valve **67**, and the electronic control unit **71**. Furthermore, this control means may be provided with, in place of the non-return valve **65**, for example, a pressure controller or the like which regulates a pressure of compressed air supplied to the pressure chamber of the valve-closing air spring **46**. In this case, by increasing by the pressure controller the pressure of the compressed air supplied to the pressure chamber, the degree of decrease in the pressure within the pressure chamber immediately before seating of the valve element is reduced.

[**0106**] The invention is not limited to the control by which the pressure within the pressure chamber of the valve-opening air spring **48** is forcibly reduced immediately before the valve element **21** is seated, as described in the second exemplary embodiment. Any control will do as long as the degree of increase in the pressure within the pressure chamber of the valve-opening air spring **48** involved with displacement of the valve element **21** toward the valve-closing side is forcibly reduced immediately before the valve element **21** is seated. That is, for example, the pressure may assume a smaller value than the pressure within the pressure chamber of the valve-opening air spring represented by a curve in **FIG. 3**, so as to reduce the degree of increase in the pressure within the pressure chamber involved with displacement of the valve element toward the valve-closing side.

[**0107**] In this case, control means for forcibly reducing, immediately before the valve element **21** is seated on the valve seat **13**, the degree of increase in the pressure within the pressure chamber of the valve-opening air spring **48** involved with displacement of the valve element **21** toward the valve-closing side, may be configured to include, for example, the relief valve **68** and the electronic control unit **71**.

[**0108**] The control means for increasing the pressure within the pressure chamber of the valve-closing air spring **46** immediately before the valve element **21** is seated on the valve seat **13** is not limited those configured to include the high-pressure reservoir tank **80**, the relief valve **67**, and the electronic control unit **71**. For example, this control means may be provided with, in place of the non-return valve **65**, a pressure controller or the like which regulates a pressure of compressed air supplied to the pressure chamber of the valve-closing air spring **46**. In this case, by increasing by the pressure controller the pressure of the compressed air supplied to the pressure chamber, the pressure within the pressure chamber is increased immediately before seating of the valve element.

[**0109**] The control means for reducing, immediately before the valve element **21** is seated on the valve seat **13**, the pressure within the pressure chamber of the valve-opening air spring **48** in accordance with displacement of the valve element **21** toward the valve-closing side, is not limited to those configured to include the relief valve **68** and the electronic control unit **71**.

[**0110**] The structure of the air pressure circuit, the arrangement of the air springs **46** and **48** in the electromagnetic valve **20**, the structure of the control system, and the like according to the aforementioned exemplary embodiments may be arbitrarily changed.

[**0111**] In the exemplary embodiments above, an air spring that generates an elastic force by the pressure of the compressed air filled in the pressure chamber is adopted as a spring for energizing the valve element **21** toward the displacement ends on the valve-opening side and valve-closing side. However, any gas other than the atmospheric air may also be used as a source for generating the elastic force.

[**0112**] Furthermore, spring means other than a pneumatic spring may be adopted as long as the energizing force can be arbitrarily changed.

[**0113**] While the invention has been described with reference to exemplary embodiments thereof, it is to be understood that the invention is not limited to the exemplary embodiments or constructions. To the contrary, the invention is intended to cover various modifications and equivalent arrangements. In addition, while the various elements of the exemplary embodiments are shown in various combinations and configurations, which are exemplary, other combinations and configurations, including more, less or only a single element, are also within the spirit and scope of the invention.

What is claimed is:

1. A control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprising:

a controller which increases, immediately before seating of the valve element, the energizing force of the spring means for energizing the valve-element toward the valve-closing side.

2. The control apparatus of the electromagnetic valve according to claim 1, wherein

at least one of the pair of the spring means is configured as a valve-closing pneumatic spring, wherein the valve closing pneumatic spring energizes a piston connected to a valve shaft of the valve element toward the valve-closing side by a pressure within a pressure chamber of the valve-closing pneumatic spring, and the controller has a function to control the pressure within the pressure chamber for adjusting an energizing force of the valve-closing pneumatic spring.

3. The control apparatus of the electromagnetic valve according to claim 2, wherein

the controller increases the pressure within the pressure chamber of the valve-closing pneumatic spring immediately before seating of the valve element.

4. The control apparatus of the electromagnetic valve according to claim 2, wherein

the controller forcibly reduces, immediately before seating of the valve element, a degree of decrease in the pressure within the pressure chamber of the valve-closing pneumatic spring involved with displacement toward the valve-closing side.

5. A control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprising:

a controller which reduces, immediately before seating of the valve element, the energizing force of the spring means for energizing the valve-element toward the valve-opening side.

6. The control apparatus of the electromagnetic valve according to claim 5, wherein

at least one of the pair of the spring means is configured as a valve-opening pneumatic spring, wherein the valve-opening pneumatic spring energizes a piston connected to a valve shaft of the valve element toward the valve-opening side by a pressure within a pressure chamber of the valve-opening pneumatic spring, and the controller has a function to control the pressure within the pressure chamber for adjusting an energizing force of the valve-opening pneumatic spring.

7. The control apparatus of the electromagnetic valve according to claim 6, wherein

the controller reduces the pressure within the pressure chamber of the valve-opening pneumatic spring immediately before seating of the valve element.

8. The control apparatus of the electromagnetic valve according to claim 6, wherein

the controller forcibly reduces, immediately before seating of the valve element, a degree of increase in the pressure within the pressure chamber of the valve-opening pneumatic spring involved with displacement toward the valve-closing side.

9. A control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a valve-opening pneumatic spring for energizing the valve element toward a valve-opening side, a valve-closing pneumatic spring for energizing the valve element toward a valve-closing side, and a pair of electromagnets for energizing the armature in both axial directions of the armature shaft, respectively, and operates the valve element to open and close by cooperative operation of an electromagnetic force of each electromagnet and an energizing force of each pneumatic spring, comprising:

a controller which forcibly reduces, immediately before seating of the valve element, a degree of increase in the energizing force by which the valve-opening pneumatic spring and the valve-closing pneumatic spring energize the valve element toward the valve-opening side in accordance with displacement of the valve element toward the valve-closing side.

10. A control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprising the following steps of:

supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and

increasing, immediately before seating of the valve element, the energizing force of the spring means for energizing the valve element toward the valve-closing side.

11. The control method according to claim 10, wherein

at least one of the pair of the spring means is configured as a valve-closing pneumatic spring, wherein the valve-closing pneumatic spring energizes a piston connected to a valve shaft of the valve element toward the valve-closing side by a pressure within a pressure chamber of the valve-closing pneumatic spring, and the pressure within a pressure chamber of the valve-closing pneumatic spring is increased immediately before seating of the valve element.

12. The control method according to claim 10, wherein

a degree of decrease in the pressure within the pressure chamber of the valve-closing pneumatic spring involved with displacement toward the valve-closing side is forcibly reduced immediately before seating of the valve element.

13. A control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a pair of spring means for energizing the valve element toward a valve-opening side and a valve-closing side, respectively, and an electromagnet for energizing the armature toward the valve-closing side of the valve element, and operates the valve element to open and close by cooperative operation of an electromagnetic force of the electromagnet and an energizing force of the spring means, comprising the following steps of:

supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and

reducing, immediately before seating of the valve element, the energizing force of the spring means for energizing the valve element toward the valve-opening side.

14. The control method according to claim 13, wherein

at least one of the pair of the spring means is configured as a valve-opening pneumatic spring, wherein the valve-opening pneumatic spring energizes a piston connected to a valve shaft of the valve element toward the valve-opening side by a pressure within a pressure chamber of the valve-opening pneumatic spring, and a pressure within a pressure chamber of a valve-opening pneumatic spring is reduced immediately before seating of the valve element.

15. The control method according to claim 13, wherein

a degree of increase in the pressure within the pressure chamber of the valve-opening pneumatic spring involved with displacement toward the valve-closing side is forcibly reduced immediately before seating of the valve element.

16. A control method of a control apparatus of an electromagnetic valve which includes a valve element, an armature connected to an armature shaft which is engaged with the valve element, a valve-opening pneumatic spring for energizing the valve element toward a valve-opening side, a valve-closing pneumatic spring for energizing the valve element toward a valve-closing side, and a pair of electromagnets for energizing the armature in both axial directions of the armature shaft, respectively, and operates the valve element to open and close by cooperative operation of an electromagnetic force of each electromagnet and an energizing force of each pneumatic spring, comprising the following steps of:

supplying an electric current to the electromagnet so as to energize the valve element toward the valve-closing side; and

forcibly reducing, immediately before seating of the valve element, a degree of increase in the energizing force by which the valve-opening pneumatic spring and the valve-closing pneumatic spring energize the valve element toward the valve-opening side in accordance with displacement of the valve element toward the valve-closing side.

* * * * *