US 20030161733A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0161733 A1**

Kabasawa et al. (43) **Pub. Date: Aug. 28, 2003**

(54) **PUMP APPARATUS**

(76) Inventors: **Takashi Kabasawa**, Narashino-shi (JP); **Manabu Nonaka**, Narashino-shi (JP)

Correspondence Address:
ADAMS & WILKS
31st Floor
50 Broadway
New York, NY 10004 (US)

(21) Appl. No.: **10/370,985**

(22) Filed: **Feb. 20, 2003**

(30) **Foreign Application Priority Data**

Feb. 28, 2002 (JP) 053198/2002

Publication Classification

(51) **Int. Cl.^{7}** **F04B 49/10**

(52) **U.S. Cl.** **417/32**; 417/423.4

(57) **ABSTRACT**

A pump apparatus in accordance with the present invention is used to discharge a process gas from, for example, a semiconductor manufacturing system, and is constructed so that a rotor is pivotally supported by a magnetic bearing. To decrease the solidification and deposition of process gas in a tube of the pump apparatus, heat is generated in a bearing electromagnet of magnetic bearing to keep the temperature of tube at a high temperature. Heat is generated in the bearing electromagnet, for example, by causing a bias current to flow together with a control current, or by causing a high frequency current to flow. Also, a motor is heated by repeating the increase and decrease of rotational speed of motor, whereby the temperature of tube can be raised.

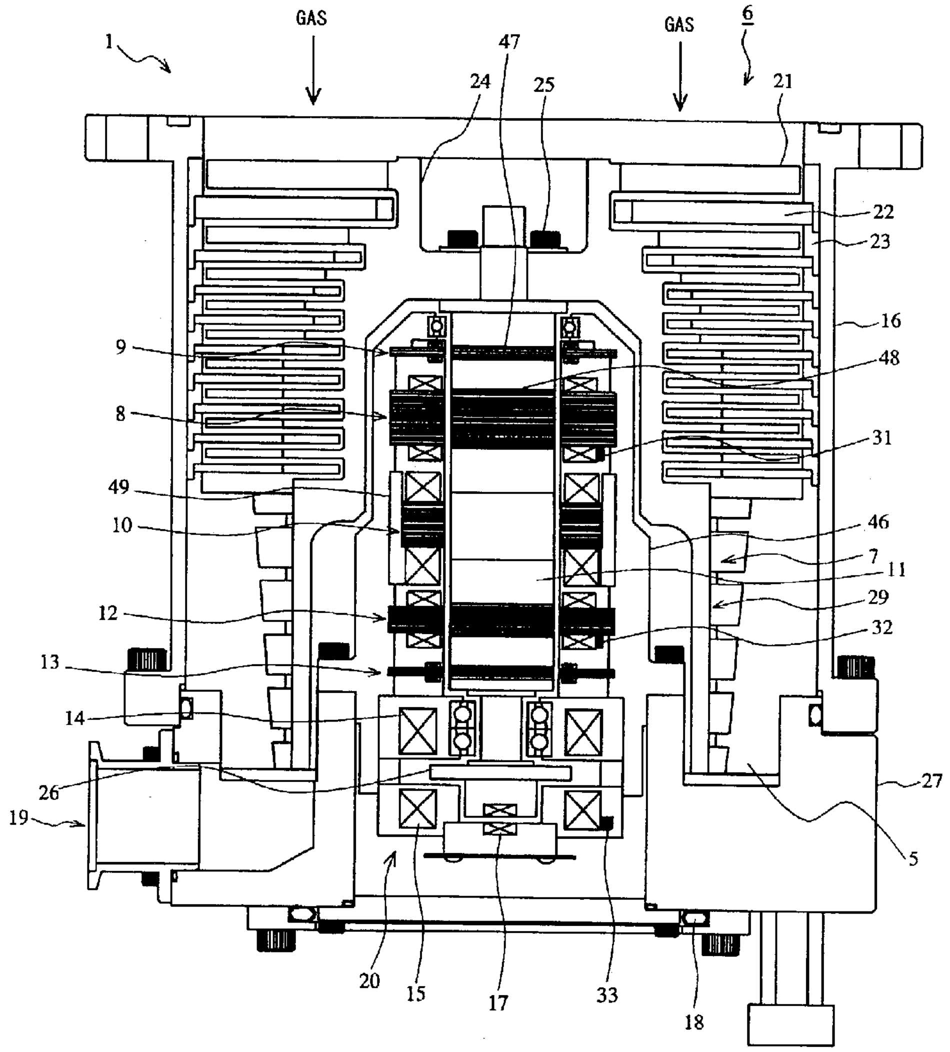


Fig.1

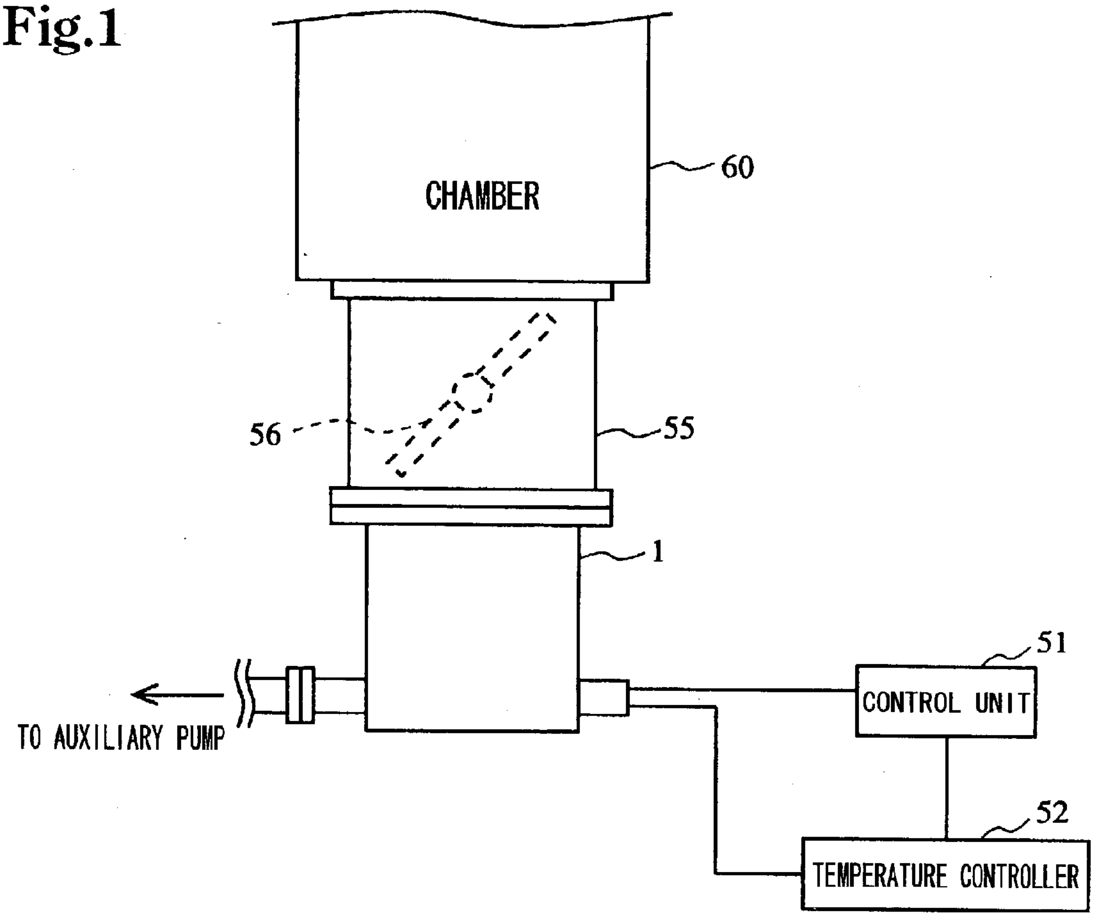

CHAMBER
60
56
55
1
TO AUXILIARY PUMP
51
CONTROL UNIT
52
TEMPERATURE CONTROLLER

Fig.2

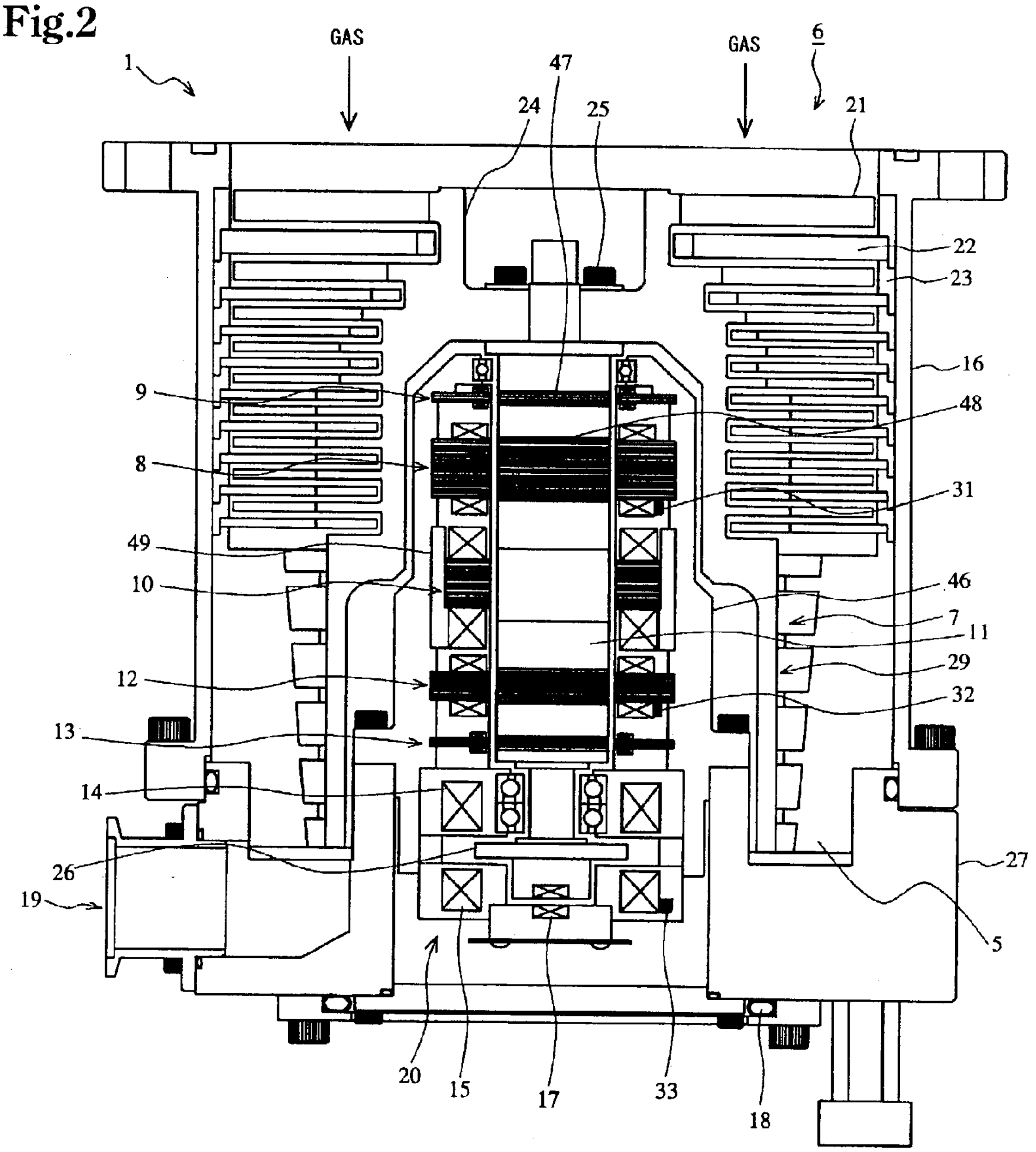

GAS
GAS
6
1
47
24
25
21
22
23
16
9
48
8
31
49
46
10
7
11
29
12
32
13
14
27
26
19
5
20
15
17
33
18

Fig.3

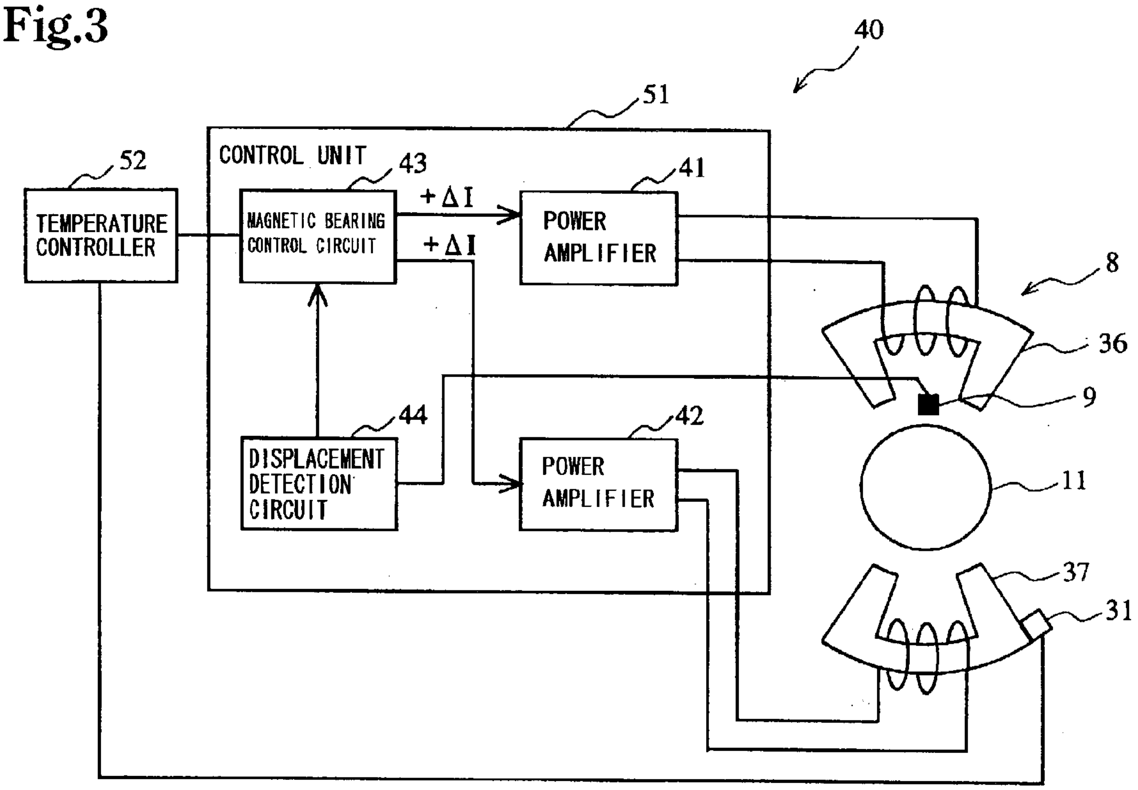

40
51
CONTROL UNIT
52
TEMPERATURE CONTROLLER
43
MAGNETIC BEARING CONTROL CIRCUIT
+ΔI
+ΔI
41
POWER AMPLIFIER
44
DISPLACEMENT DETECTION CIRCUIT
42
POWER AMPLIFIER
8
36
9
11
37
31

Fig.4

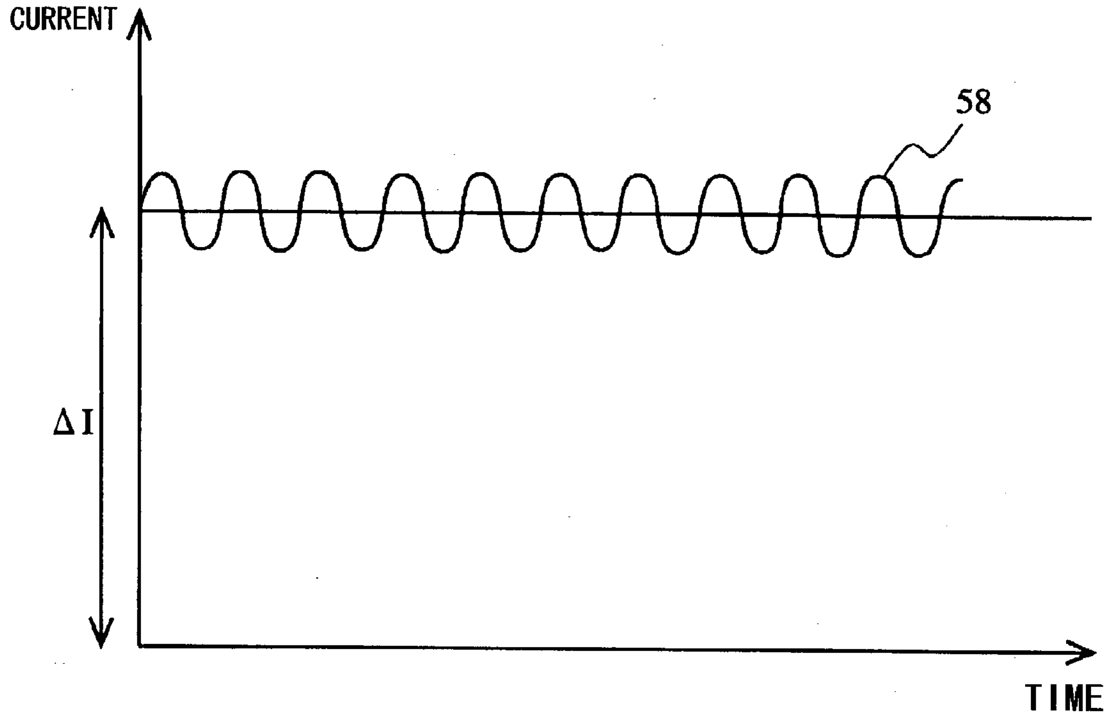


Fig.5

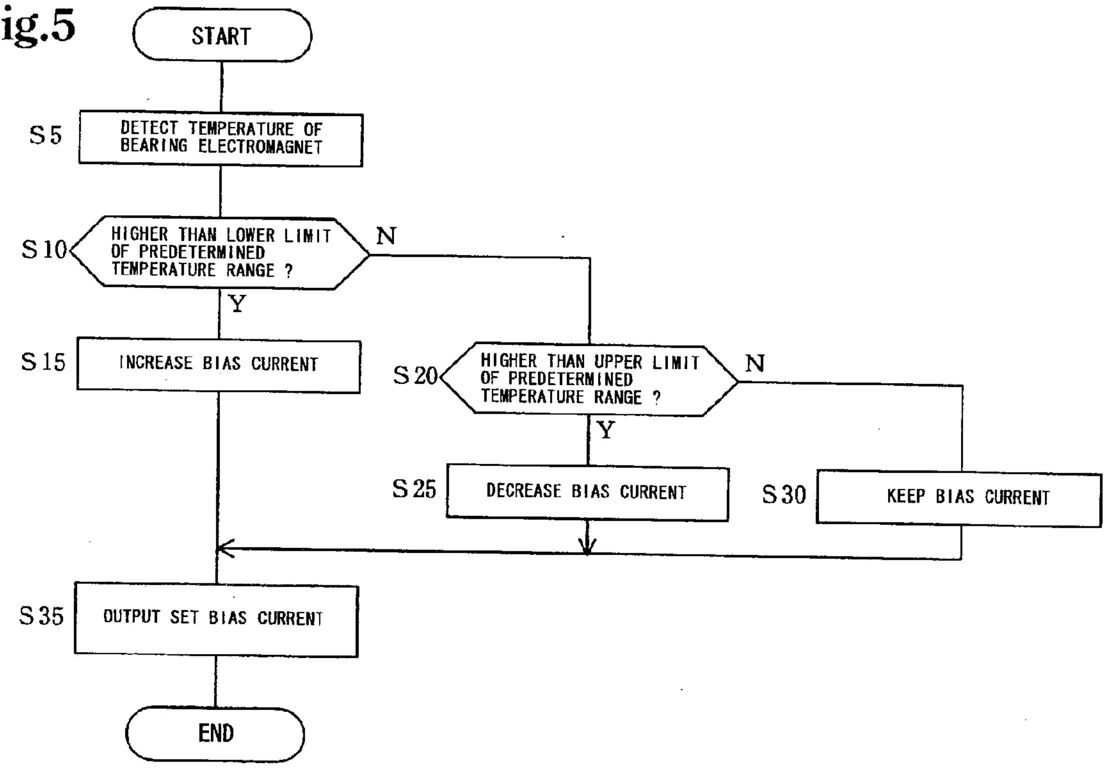
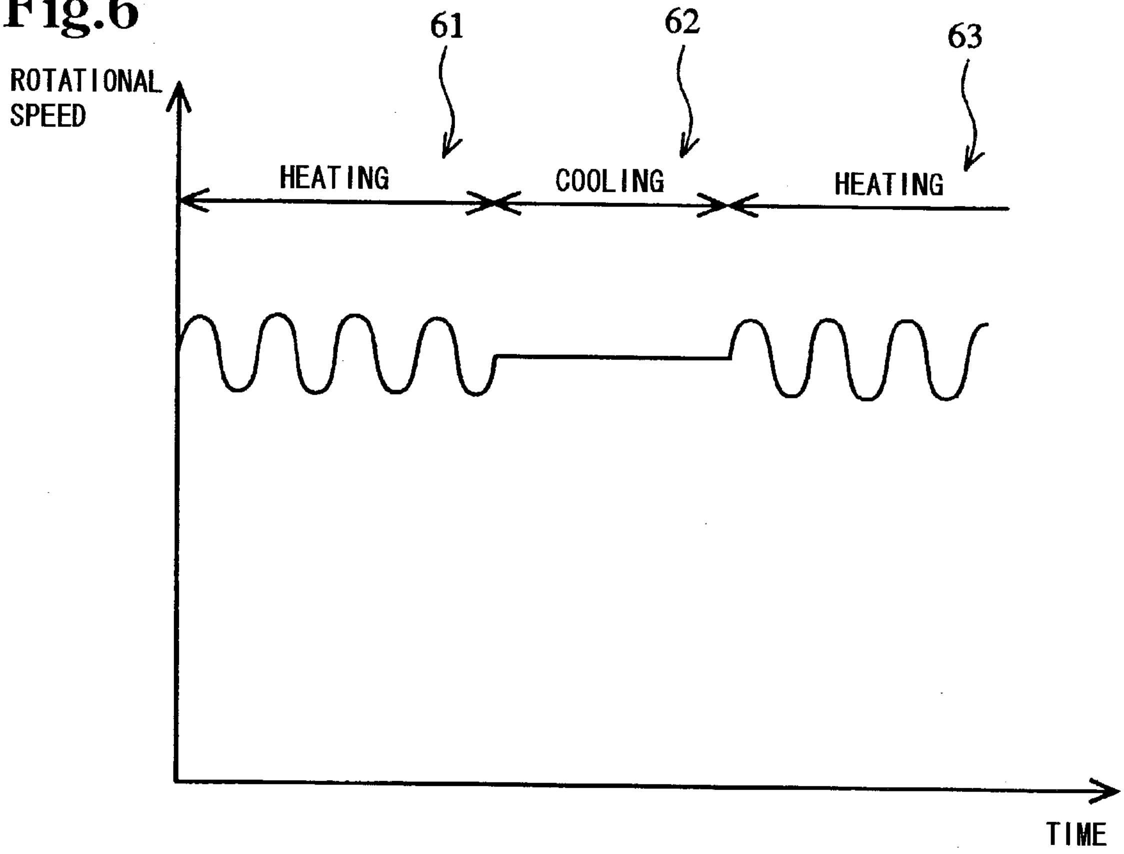

START
S5
DETECT TEMPERATURE OF BEARING ELECTROMAGNET
S10
HIGHER THAN LOWER LIMIT OF PREDETERMINED TEMPERATURE RANGE ?
N
Y
S15
INCREASE BIAS CURRENT
S20
HIGHER THAN UPPER LIMIT OF PREDETERMINED TEMPERATURE RANGE ?
N
Y
S25
DECREASE BIAS CURRENT
S30
KEEP BIAS CURRENT
S35
OUTPUT SET BIAS CURRENT
END

Fig.6



PUMP APPARATUS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a pump apparatus and, more particularly, to a turbo-molecular pump used, for example, to manufacture semiconductors.

[0003] 2. Description of the Related Art

[0004] Semiconductors are manufactured while a process gas is applied to a substrate in a chamber. To discharge the process gas in the chamber, a turbo-molecular pump has been used widely for the reason of requirement for discharge capacity and degree of vacuum.

[0005] The turbo-molecular pump is used not only to discharge the process gas etc. in the chamber but also to keep the interior of chamber at a predetermined pressure.

[0006] Various kinds of process gases are used for manufacturing semiconductors, and some kind of process gas solidifies and deposits in a tube portion depending on conditions such as temperature and pressure.

[0007] Therefore, if the turbo-molecular pump is operated for a certain period of time, in some cases, deposits are built up in a tube portion, so that the tube is clogged and hence the performance of pump is decreased, or the rotor comes into contact with the deposits and hence an adverse influence is exerted on the operation of pump.

[0008] In order to prevent the process gas from solidifying in the tube, a heater is commonly provided around the pump to keep the tube at a high temperature.

[0009] By controlling the temperature of pump so as to be a predetermined value by using the heater, the solidification of process gas in the pump can be decreased.

SUMMARY OF THE INVENTION

[0010] When the temperature of turbo-molecular pump is controlled by using a heater, additional parts such as the heater, a controller for controlling the heater, and a power cable are needed, which results in an increase in cost.

[0011] Accordingly, an object of the present invention is to provide a pump apparatus capable of reducing the cost required for additional parts for temperature control such as a heater.

[0012] To achieve the above object, an invention of a first aspect provides a pump apparatus including a casing formed with a gas intake port on one end side thereof and a gas discharge port on the other end side thereof; a base member forming a bottom on the other side of the casing; a cylindrical member which is fixed to the base member and contains a bearing and a motor; a rotor shaft which is rotatably contained in the cylindrical member via the bearing and is rotated by the motor; a rotor disposed on the rotor shaft; a stator disposed on the inner peripheral surface of the casing with a predetermined space provided with respect to the rotor; gas transfer means formed in the space between the rotor and the stator; and heat generation control means for controlling the amount of heat generated in the cylindrical member.

[0013] In an invention of a second aspect, the bearing is a magnetic bearing, and the heat generation control means controls a bias current superimposed on a control current of the magnetic bearing.

[0014] In an invention of a third aspect, the bearing is a magnetic bearing, and the heat generation control means controls a high frequency current superimposed on a control current of the magnetic bearing.

[0015] In an invention of a fourth aspect, the heat generation control means controls the amount of generated heat of the motor by changing the rotational speed of the motor.

[0016] In an invention of a fifth aspect, a cylindrical member, the base member, the rotor, and the stator are formed of aluminum or aluminum alloy.

[0017] In an invention of a sixth aspect, a reinforcing member disposed around the motor or a housing member for the bearing is formed of aluminum or aluminum alloy.

[0018] In an invention of a seventh aspect, at least a part of opposing surfaces of the stator and the rotor is coated to enhance heat radiation efficiency.

[0019] In an invention of an eighth aspect, at least a part of the outer peripheral surface of the cylindrical member is opposed to the inner peripheral surface of the rotor with a predetermined space there between, and at least a part of opposing surfaces of the cylindrical member and the rotor is coated to enhance heat radiation efficiency.

[0020] In an invention of a ninth aspect, the pump apparatus further includes cooling means formed in the pump apparatus; and cooling control means for controlling the cooling means in relation to a temperature detected by temperature detecting means provided at a predetermined location of the pump apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] **FIG. 1** is a schematic view showing a turbo-molecular pump attached to a chamber;

[0022] **FIG. 2** is a sectional view in the axial direction of a turbo-molecular pump in accordance with the invention;

[0023] **FIG. 3** is a schematic view for illustrating a control system for a bias current;

[0024] **FIG. 4** is chart showing one example of current supplied to a bearing electromagnet by a power amplifier;

[0025] **FIG. 5** is a flowchart for illustrating a control procedure for a bias current; and

[0026] **FIG. 6** is a chart showing one example of a change in motor rotational speed in the case where the temperature of a motor section is controlled.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] (1) Outline of Embodiment

[0028] A turbo-molecular pump **1** in accordance with an embodiment pivotally supports a rotor shaft **11** by magnetic levitation using magnetic bearing portions **8**, **12** and **20** as shown in **FIG. 2**.

[**0029**] The magnetic bearing portions **8**, **12** and **20** each are mounted with temperature sensors **31**, **32** and **33**, respectively, so that the temperature of bearing electromagnet of the magnetic bearing portions **8**, **12** and **20** is monitored by a temperature controller **52** (**FIG. 1**).

[**0030**] On a current supplied to the bearing electromagnet, a dc bias current is superimposed in addition to a displacement control current for controlling the displacement of the rotor shaft **11**. Due to this bias current, the bearing electromagnet generates heat.

[**0031**] The temperature controller **52** (**FIG. 1**) sets the value of bias current by using detection signals sent from the temperature sensors **31**, **32** and **33** so that the temperatures of electromagnets of the magnetic bearing portions **8**, **12** and **20** can be kept in a preset range.

[**0032**] A control unit **51** supplies the bias current set by the temperature controller **52**, in addition to the displacement control current, to the electromagnets of the magnetic bearing portions **8**, **12** and **20**.

[**0033**] Specifically, by the detection signals from the temperature sensors **31**, **32** and **33**, the bias current is feedback controlled.

[**0034**] Since the bearing electromagnets are heated by the bias current, the temperature of tube for the turbo-molecular pump **1** rises, so that the solidification of process gas in the pump can be decreased.

[**0035**] (2) Details of Embodiment

[**0036**] **FIG. 1** is a schematic view showing the turbo-molecular pump **1** attached to a chamber **60**.

[**0037**] The chamber **60** is a vessel having gas tightness, and is constructed so that various operations for manufacturing semiconductors, such as dry etching and laminating, can be performed in the interior thereof. Although not shown in **FIG. 1**, the chamber **60** is provided with a discharge port for a process gas used for manufacturing semiconductors. By the process gas discharged through this discharge port, the interior of the chamber **60** can be made in a predetermined atmosphere.

[**0038**] The turbo-molecular pump **1** is installed in a state of being hung from the lower end of the chamber **60** via a conductance valve **55**.

[**0039**] The conductance valve **55** is a valve provided with a valve element formed of, for example, a butterfly valve. The butterfly valve is provided with a disk-shaped valve element **56** with a diameter equal to the inside diameter of a flow path in a cylindrical valve casing, and is opened/closed by the turning of the valve element **56** around the diameter axis. By turning the valve element **56** from the outside of the conductance valve **55**, the cross-sectional area of flow path can be regulated. In **FIG. 1**, the valve element **56** arranged in the conductance valve **55** is indicated by a dotted line.

[**0040**] The conductance valve **55**, which is a valve for regulating conductance (ease of gas flow), is installed to regulate the degree to which exhaust gas is sucked by the turbo-molecular pump **1**.

[**0041**] Thus, by opening/closing the conductance valve **55** for regulating the degree to which exhaust gas is sucked from a vacuum system by the turbo-molecular pump **1**, the pressure in the chamber **60** can be regulated.

[**0042**] The turbo-molecular pump **1** is a pump for discharging the gas in the chamber **60** to the auxiliary pump side by rotating a rotor section pivotally supported by the magnetic bearing portions at a high speed.

[**0043**] The magnetic bearing portion is a device for magnetically levitating the rotor shaft and holding it at a predetermined position by the attraction force of a plurality of electromagnets (hereinafter referred to as bearing electromagnets) provided around the rotor shaft and in the bottom portion.

[**0044**] The control unit **51** is a device for controlling a motor section provided on the magnetic bearing portion and rotor shaft.

[**0045**] The magnetic bearing portion detects the displacement of the rotor shaft by a sensor, and supplies a displacement control current to the bearing electromagnet to regulate magnetic force so that the rotor shaft is held at the predetermined position.

[**0046**] The motor section detects the rotational speed of rotor shaft by a sensor, and regulates the current supplied to a stator coil constituting the motor section (hereinafter referred simply as to a stator coil).

[**0047**] The control unit **51** can supply not only the displacement control current to the magnetic bearing portion but also the dc bias current in accordance with the a control signal sent from the temperature controller **52** (hereinafter referred to as a bias signal). Due to this bias current, the bearing electromagnet generates heat, and thus the tube of the turbo-molecular pump **1** is heated.

[**0048**] By the detection signals sent from the temperature sensors installed on the bearing electromagnets, the temperature controller **52** detects temperatures of these locations. The value of current is set so that the detected temperature is kept in a preset predetermined range, and this current value is sent to the control unit **51**. The control unit **51** supplies a bias current corresponding to this current value to the magnetic bearing portion.

[**0049**] **FIG. 2** is a sectional view in the axial direction of the turbo-molecular pump **1** in accordance with this embodiment.

[**0050**] In this embodiment, as an example of molecular pump, a turbo-molecular pump having a turbo-molecular pump section and a screw groove pump section is used.

[**0051**] A casing **16** forming a housing for the turbo-molecular pump **1** has a cylindrical shape, and the rotor shaft **11** is provided in the center thereof. The casing **16** forms, together with a base **27**, described later, the housing for the turbo-molecular pump **1**.

[**0052**] In the center of the base **27**, a stator column **46**, which is a cylindrical member having a substantially cylindrical shape, is formed on the side of a gas intake port **6**.

[**0053**] On the inner peripheral surface of the stator column **46**, a motor section **10** is housed to rotate the magnetic bearing portions **8** and **12** and the rotor shaft **11**.

[**0054**] The magnetic bearing portions **8** and **12** are provided at the upper and lower parts in the axial direction of the rotor shaft **11**, respectively. Also, in the bottom portion of the rotor shaft **11**, the magnetic bearing potion **20** is provided.

[**0055**] The rotor shaft **11** is supported in the radial direction (radial direction of the rotor shaft **11**) by the magnetic bearing portions **8** and **12** in a non-contact manner, and is supported in the thrust direction (axial direction of the rotor shaft **11**) by the magnetic bearing portion **20** in a non-contact manner. These magnetic bearing portions constitute what is called a five-axis control type magnetic bearing, and the rotor shaft **11** rotates around the axis.

[**0056**] In the magnetic bearing portion **8**, for example, four bearing electromagnets are arranged so as to be opposed every 90 degrees around the rotor shaft **11**.

[**0057**] At a position forming the magnetic bearing portion **8** on the rotor shaft **11**, an electromagnet target **48** is formed. The electromagnet target **48** is formed of laminated steel sheets in which many steel sheets such as silicon steel having insulation film formed on the surface thereof are laminated. The electromagnet target **48** is arranged to restrain an eddy current produced on the rotor shaft **11** by a magnetic field generated by the magnetic bearing portion **8**.

[**0058**] If an eddy current is produced on the rotor shaft **11**, the rotor shaft **22** generates heat and an eddy current loss is yielded, by which the efficiency is decreased. However, this phenomenon can be prevented by forming the electromagnet target **48** of laminated steel sheets.

[**0059**] In the magnetic bearing portion **8**, the electromagnet target **48** is attracted by a magnetic force of electromagnet, by which the rotor shaft **11** magnetically levitated in the radial direction.

[**0060**] The bearing electromagnet of the magnetic bearing portion **8** is provided with the temperature sensor **31** so that the temperature of that bearing electromagnet can be detected.

[**0061**] In the vicinity of the magnetic bearing portion **8**, a radial sensor **9** is formed. The radial sensor **9** is composed of, for example, a coil arranged around the rotor and a radial sensor target **47** formed on the rotor shaft **11**.

[**0062**] The coil, which forms a part of oscillator circuit of the control unit **51**, detects displacement of the rotor shaft **11** because the amplitude of signal is changed by a distance between the coil and the radial sensor target **47**.

[**0063**] The radial sensor target **47** is formed of laminated steel sheets as in the case of the electromagnet target **48**.

[**0064**] Based on the signal of the radial sensor **9**, the control unit **51** feedback controls the magnetic force generated by the magnetic bearing portion **8**.

[**0065**] As a sensor for detecting the displacement of the rotor shaft **11**, a capacitance type sensor or an optical sensor can be used.

[**0066**] The construction and operation of the magnetic bearing portion **12** and a radial sensor **13** are the same as those of the magnetic bearing portion **8** and the radial sensor **9**, and therefore the explanation thereof is omitted.

[**0067**] The bearing electromagnet of the magnetic bearing portion **12** is mounted with the temperature sensor **32** so that the temperature of that bearing electromagnet can be detected.

[**0068**] The magnetic bearing portion **20** provided at the lower end of the rotor shaft **11** is composed of a disk-shaped metallic disk **26**, bearing electromagnets **14** and **15**, and a thrust sensor **17**.

[**0069**] The metallic disk **26** is formed of a material having high magnetic permeability, such as iron, and is fixed perpendicularly to the rotor shaft **11** in the center thereof. The bearing electromagnet **14** is provided above the metallic disk **26**, and the bearing electromagnet **15** is provided below the metallic disk **26**. The bearing electromagnet **14** attracts the metallic disk **26** upward by the magnetic force, and the bearing electromagnet **15** attracts the metallic disk **26** downward.

[**0070**] The bearing electromagnet **15** is mounted with the temperature sensor **33** so that the temperature of the bearing electromagnet **15** can be detected.

[**0071**] The thrust sensor **17**, which is formed of, for example, a coil like the radial sensors **9** and **13**, detects the displacement in the thrust direction of the rotor shaft **11**, and sends it to the control unit **51**.

[**0072**] The control unit **51** can detect the displacement in the thrust direction of the rotor shaft **11** by the signal received from the radial sensor **13**.

[**0073**] If the rotor shaft **11** is moved in either thrust direction and is displaced from the predetermined position, the control unit **51** regulates the exciting current of the bearing electromagnets **14** and **15** so as to correct this displacement, and operates so as to return the rotor shaft **11** to the predetermined position.

[**0074**] The control unit **51** can magnetically levitate the rotor shaft **11** to the predetermined position in the thrust direction by this feedback control and can hold it.

[**0075**] As described above, the rotor shaft **11** is held in the radial direction by the magnetic bearing portions **8** and **12**, and is held in the thrust direction by the magnetic bearing portion **20**. Therefore, the rotor shaft **11** is pivotally supported so as to have the degree of freedom of rotation around the axis.

[**0076**] The motor section **10** is provided in a middle portion between the magnetic bearing portions **8** and **12** of the rotor shaft **11**.

[**0077**] In this embodiment, the motor section **10** is assumed to be formed of a dc brushless motor as an example.

[**0078**] Around a portion constituting the motor section **10** of the rotor shaft **11**, a permanent magnet is fixed. This permanent magnet is fixed so that the N pole and S pole are arranged 180° apart around the rotor shaft **11**. Around this permanent magnet, for example, six electromagnets are arranged symmetrically and opposingly with respect to the axis of the rotor shaft **11** every 60° with a predetermined clearance provided with respect to the rotor shaft **11**.

[**0079**] On the other hand, the turbo-molecular pump **1** has a sensor, not shown, for detecting the rotational speed and rotational angle (phase) of the rotor shaft **11**. Thus, the control unit **51** can detect the position of magnetic pole of the permanent magnet fixed to the rotor shaft **11**.

[**0080**] The control unit **51** successively changes the current of electromagnet of the motor section **10** according to the detected position of magnetic pole to yield a rotating magnetic field around the permanent magnet of the rotor shaft **11**.

[**0081**] The permanent magnet fixed to the rotor shaft **11** follows this rotating magnetic field, and thereby the rotor shaft **11** is rotated.

[**0082**] On the outer peripheral surface of the motor section **10**, a collar **49**, which is a cylindrical member made of stainless steel, is provided to protect the motor section **10**. The collar **49** is a reinforcing member for protecting the motor section **10**.

[**0083**] At the upper end of the rotor shaft **11** is installed a rotor **24** with a plurality of bolts **25**.

[**0084**] In this embodiment, the construction is assumed to be, as one example, such that a portion ranging from a substantially middle position of the rotor **24** to the gas intake port **6**, that is, a substantially upper half portion in **FIG. 2** is a turbo-molecular pump section composed of rotor blades **21**, stator blades **22**, and the like, and a substantially lower half portion in the figure is a screw groove pump section composed of a spacer **5**, which is a threaded spacer, and the like. The construction of the turbo-molecular pump is not limited to the above-described one. For example, the construction may be such that the portion ranging from the gas intake port **6** to the gas discharge port **19** may be configured by a screw groove pump.

[**0085**] In the turbo-molecular pump section, the rotor **24** has the rotor blades **21** which are formed of aluminum, aluminum alloy, etc. and are installed at a plurality of stages radially from the rotor **24** so as to be inclined through a predetermined angle from a plane perpendicular to the axis of the rotor shaft **11**. The rotor blade **21** is fixed to the rotor **24** so as to be rotated at a high speed together with the rotor shaft **11**.

[**0086**] On the gas intake port side of the casing **16**, the stator blades **22**, which are formed of aluminum, aluminum alloy, etc., are arranged on the inside of the casing **16** alternately with the rotor blades **21** so as to be inclined through a predetermined angle from a plane perpendicular to the axis of the rotor shaft **11**.

[**0087**] The spacer **23** is a ring-shaped member, and is formed of metal such as aluminum, iron, or stainless steel.

[**0088**] The spacer **23** is disposed between stages formed by the stator blades **22** to keep the stator blade **22** at a predetermined position.

[**0089**] When the rotors **24** are driven by the motor section **10** and are rotated together with the rotor shaft **11**, exhaust gas is sucked through the gas intake port **6** by the action of the rotor blades **21** and the stator blades **22**.

[**0090**] The exhaust gas sucked through the gas intake port **6** passes between the rotor blade **21** and the stator blade **22**, and is sent to the screw groove pump section.

[**0091**] The screw groove pump section is formed by a rotor lower portion **29**, the spacer **5**, and the like. In this embodiment, the screw groove is formed by the spacer **5**.

[**0092**] The rotor lower portion **29** is formed by a portion having a cylindrical outer peripheral surface formed in a substantially lower half portion of the rotor **24**, and projects to a region close to the inner peripheral surface of the spacer **5**.

[**0093**] A stator in the screw groove pump section is formed by the spacer **5**. The spacer **5** is a cylindrical member formed of metal such as aluminum, stainless steel, or iron, and has a plurality of spiral screw grooves **7** formed in the inner peripheral surface thereof.

[**0094**] The direction of spiral of the screw groove **7** is a direction such that when molecules of exhaust gas move in the rotation direction of the rotor **24**, the molecules are transferred to the gas discharge port **19**.

[**0095**] When the rotor **24** is driven and rotated by the motor section **10**, the exhaust gas sent from the turbo-molecular pump section is transferred toward the gas discharge port **19** while being guided by the screw groove **7**.

[**0096**] The pressure of gas in the turbo-molecular pump **1** increases from the gas intake port **6** toward the gas discharge port **19**. By configuring the gas intake port side by the turbo-molecular pump **1** and configuring the gas discharge port side by the screw groove pump section, a high compression ratio can be achieved.

[**0097**] In this embodiment, the threaded spacer in which a screw groove **7** is formed on the stator side is arranged, and the outer peripheral surface of the rotor lower portion **29** has a cylindrical shape. However, inversely, the turbo-molecular pump may be constructed so that the screw groove is formed on the outer peripheral surface of the rotor.

[**0098**] The base **27**, which is a disk-shaped member constituting a bottom portion of the turbo-molecular pump **1**, is formed of metal such as stainless steel, aluminum, or iron.

[**0099**] The upper end in the outer edge portion of the base **27** is connected with the casing **16**, and on the inside thereof is provided the spacer **5**. In the center of the base **27**, there is provided a mechanism for holding the rotor shaft **11** including the magnetic bearings **8**, **12** and **20**, the motor section **10**, and the like.

[**0100**] In a lower portion of the base **27**, a water-cooled tube **18** for circulating cooling water is installed so that heat exchange is accomplished efficiently between the water-cooled tube **18** and the base **27**. The water-cooled tube **18** constitutes cooling means.

[**0101**] The heat transmitted to the base **27** can be dissipated efficiently to the outside of the turbo-molecular pump **1** by the cooling water circulating in the water-cooled tube **18**, which prevents the turbo-molecular pump **1** from being overheated and becoming at a temperature not lower than the allowable temperature.

[**0102**] The water-cooled tube **18** constitutes a water cooling system together with a water feed pump, not shown, and a heat exchanger, not shown. The cooling water in the water-cooled tube **18** is circulated in the water cooling system by the water feed pump.

[**0103**] The heat which the cooling water obtains by means of heat exchange with the base **27** is dissipated to the outside of the water cooling system, for example, into the atmosphere, by the heat exchanger.

[**0104**] As a result, the cooling water is cooled, and is sent out again to the turbo-molecular pump **1** by the water feed pump.

[**0105**] **FIG. 3** is a schematic view for illustrating a bearing controls system **40**, showing the magnetic bearing portion **8** viewed in the axial direction.

[**0106**] The bearing control system **40** is a system for controlling a current supplied to bearing electromagnets **36** and **37** constituting the magnetic bearing portion **8**. This current includes a displacement control current for controlling the position of the rotor shaft **11** and a bias current for generating heat in the bearing electromagnets **36** and **37**.

[**0107**] Although the bearing magnets **36** and **37** are disposed in the vertical direction in the figure with respect to the rotor shaft **11**, in addition to these bearing electromagnets, there are also bearing electromagnets disposed transversely in the figure with respect to the rotor shaft **11**, the explanation of which is omitted for simplicity of explanation.

[**0108**] The bearing control system **40** is composed of the temperature controller **52**, a magnetic bearing control circuit **43**, a displacement detection circuit **44**, a power amplifier **41**, a power amplifier **42**, the bearing electromagnets **36** and **37**, the radial sensor **9**, the temperature sensor **31**, the rotor shaft **11**, and the like. Of these elements, the magnetic bearing control circuit **43**, the displacement detection circuit **44**, the power amplifier **41**, and the power amplifier **42** are included in the control unit **51**.

[**0109**] The temperature sensor **31** detects the temperature of the bearing electromagnet **37**, and sends a temperature detection signal to the temperature controller **52**.

[**0110**] The temperature controller **52** arithmetically operates the temperature of the bearing electromagnet **37** from the temperature detection signal sent from the temperature sensor **31**. Then, the temperature controller **52** judges whether or not the arithmetically operated temperature is within a preset temperature range (for example, 70 to 85° C.).

[**0111**] If the arithmetically operated temperature is lower than the lower limit of the preset temperature range, a bias signal is sent to the magnetic bearing control circuit **43** so that the bias current is increased by a predetermined amount. On the other hand, if the arithmetically operated temperature is higher than the upper limit of the preset temperature range, a bias signal is sent to the magnetic bearing control circuit **43** so that the bias current is decreased by a predetermined amount.

[**0112**] The displacement detection circuit **44** receives a displacement signal from the radial sensor **9**, arithmetically operates the displacement of the rotor shaft **11**, and sends the arithmetically operated displacement to the magnetic bearing control circuit **43**.

[**0113**] The magnetic bearing control circuit **43** receives a bias signal from the temperature controller **52**, further receives a displacement signal from the displacement detection circuit **44**, and arithmetically operates the amount of current to be sent to the bearing electromagnets **36** and **37** for each of bearing electromagnets **36, 37**. Then, the magnetic bearing control circuit **43** sends a current signal representing the arithmetically operated amount of current to the power amplifiers **41** and **42**.

[**0114**] In this embodiment, the current values of bias currents supplied to the bearing electromagnets **36** and **37** are made the same. The reason for this is that since the bearing electromagnets **36** and **37** are opposed to each other, magnetic forces that the magnetic fields generated in the bearing electromagnets **36** and **37** by the bias current apply to the rotor shaft **11** are offset. Thereby, the influence of bias current on the control of displacement of the rotor shaft **11** can be decreased.

[**0115**] The magnetic bearing control circuit **43** sets a displacement control current by the displacement signal, sets a bias current by the bias signal, and outputs, as a current signal, the amount of current on which the displacement control current and the bias current are superimposed.

[**0116**] The displacement control current is a current for generating a magnetic field for correcting the displacement of the rotor shaft **11** and for generating magnetic field on the bearing electromagnet **36, 37** in order to return the rotor shaft **11** to the predetermined position.

[**0117**] The power amplifiers **41** and **42** supply a predetermined current to the bearing electromagnets **36** and **37**, respectively, according to the current signal received from the magnetic bearing control circuit **43**. The current supplied to the bearing electromagnet **36, 37** is a current on which the displacement control current and the bias current are superimposed. The rotor shaft **11** is held at the predetermined position by the magnetic field generated by the displacement control current, and the bearing electromagnet **36, 37** is heated by the bias current.

[**0118**] Thus, the bias current is feedback controlled by the detection signal of the temperature sensor **31** to keep the temperature of the bearing electromagnet **37** in a fixed range. The temperature of the bearing electromagnet **36** is also kept in a fixed range, like the bearing electromagnet **37**. By the heat generation in the bearing electromagnets **36** and **37**, the temperature in the turbo-molecular pump **1** is raised, so that the solidification of process gas in a discharge path can be decreased.

[**0119**] As described above, the control unit **51** constitutes heat generation control means together with the temperature controller **52**.

[**0120**] Although not shown in the figure, the temperatures of the bearing electromagnets disposed transversely in the figure with respect to the rotor shaft **11** are controlled in the same way. Also, the temperatures of the magnetic bearing electromagnets constituting the magnetic bearing portion **12** are controlled in the same way.

[**0121**] In this embodiment, no bias current is supplied to the bearing electromagnets **14** and **15** constituting the magnetic bearing portion **20**. However, the configuration may be such that a temperature sensor is provided on the bearing electromagnets **14** and **15**, and temperature control is carried out in the same way.

[**0122**] **FIG. 4** is chart showing one example of a current **58** supplied to the bearing electromagnet **36** by the power amplifier **41**, in which the ordinates represent current value, and the abscissas represent time.

[**0123**] The current **58** outputted to the bearing electromagnet **36** by the power amplifier **41** is a current on which a bias current for heating the bearing electromagnet **36** and a displacement control current for controlling the displacement of the rotor shaft **11** are superimposed.

[**0124**] In **FIG. 4**, of the current **58**, a dc component ΔI is the bias current, and an ac component is the displacement control current.

[**0125**] In this embodiment, the bias current ΔI is also supplied, in addition to the bearing electromagnet **36**, to the bearing electromagnet **37** constituting the magnetic bearing portion **8**, and the bearing electromagnets, not shown, disposed transversely in **FIG. 3** with respect to the rotor shaft **11**.

[**0126**] The configuration may also be such that the value of bias current ΔI is changed for each bearing electromagnet, or the value is changed according to the displacement of the rotor shaft **11**.

[**0127**] **FIG. 5** is a flowchart for illustrating a control procedure for a bias current, of the operations that the bearing control system **40** performs.

[**0128**] First, the temperature controller **52** measures the temperature of the bearing electromagnet **37** by using a temperature detection signal sent from the temperature sensor **31** (Step **5**).

[**0129**] Next, the temperature controller **52** judges whether or not the measured temperature is lower than the lower limit of the preset temperature range (Step **10**).

[**0130**] If the measured temperature is lower than the lower limit of the preset temperature range (Step **10**: Y), the temperature controller **52** produces a bias signal so that the bias current increases by a preset amount (for example, 20%) and sends it to the magnetic bearing control circuit **43** (Step **15**).

[**0131**] If the measured temperature is not lower than the lower limit of the preset temperature range (Step **10**: N), the temperature controller **52** further judges whether or not the measured temperature is higher than the upper limit of the preset temperature range (Step **20**).

[**0132**] If the measured temperature is higher than the upper limit of the preset temperature range (Step **20**: Y), the temperature controller **52** produces a bias signal so that the bias current decreases by a preset amount (for example, 20%) and sends it to the magnetic bearing control circuit **43** (Step **25**).

[**0133**] If the measured temperature is not higher than the upper limit of the preset temperature range (Step **20**: N) the temperature controller **52** produces a bias signal so that the present bias current is kept and sends it to the magnetic bearing control circuit **43** (Step **30**).

[**0134**] Next, the magnetic bearing control circuit **43** sets a bias current from the bias signal received from the temperature controller **52**, and sends it to the power amplifier **41** together with a signal for setting the displacement control current.

[**0135**] The power amplifier **41** outputs a predetermined bias current based on the control signal received from the magnetic bearing control circuit **43** (Step **35**).

[**0136**] By repeating the above-described procedure at specified time intervals (for example, every one second) the temperatures of the bearing electromagnets **36** and **37** can be kept in a fixed range.

[**0137**] Although the above procedure has been explained for the case where a bias current is supplied to the bearing electromagnets **36** and **37**, the control unit **51** and the temperature controller **52** supply a bias current similarly to other bearing electromagnets constituting the magnetic bearing portions **8**, **12** and **20** and carry out temperature control.

[**0138**] In the above-described embodiment, heat is generated by supplying a bias current to the magnetic bearing portions **8** and **12**, and thereby the temperature of the tube in the pump can be raised.

[**0139**] The amount of heat generation is controlled by increasing/decreasing the bias current of the magnetic bearing, and hence the temperature of the tube in the pump can be kept. Thereby, the solidification of process gas in the tube can be decreased.

[**0140**] Since heat is generated using a portion that the turbo-molecular pump **1** inherently has to achieve the pump function (magnetic bearing portion), there is no need for installing accessories such as a heater wound on the turbo-molecular pump **1**, so that the manufacturing cost can be reduced.

[**0141**] Although heat is generated in the magnetic bearing portion by supplying a bias current to this portion in this embodiment, heat can also be generated by two other methods.

[**0142**] (1) A High Frequency Current With a Frequency Higher Than a Predetermined One is Superimposed on the Displacement Control Current.

[**0143**] The frequency in this case is made higher than the natural frequency (for example, 1 kHz) of a rotor section (a rotating body consisting of the rotor shaft **11** and the rotor **24**). If the frequency is set so as to be larger than the natural frequency of the rotor section, the displacement of the rotor section cannot follow a component caused by high frequency of the magnetic field generated by the bearing electromagnet. Therefore, the displacement of the rotor section is not affected by high frequency, and heat is generated in the bearing electromagnet by the high frequency current.

[**0144**] (2) The Rotational Speed of Rotor Section is Increased/Decreased Within a Fixed Range.

[**0145**] Generally, when the rotor section is accelerated or decelerated, a large current flows in the stator coil. On the other hand, at the time of steady operation, the amount of current flowing in the stator coil is small.

[**0146**] Therefore, by alternately repeating the acceleration and deceleration of the rotor section within the range in which the discharge of gas is not affected, heat is generated in the motor section **10**, by which the temperature of the tube in the pump can be raised.

[**0147**] In the case where the temperature is controlled by this method, a temperature sensor is installed on the motor section **10**, and when it is desired to raise the temperature of the motor section **10** while the temperature is monitored, the acceleration and deceleration of the rotor section are repeated, and when it is desired to lower the temperature of the motor section **10**, the rotational speed of the rotor section is kept constant.

[**0148**] **FIG. 6** is a chart showing one example of a change in motor rotational speed in the case where the temperature of the motor section **10** is controlled by the method (2).

[**0149**] The ordinates represent rotational speed of the rotor shaft **11** and the abscissas represent time. When heat is generated in the motor section **10**, as shown in intervals **61** and **63**, the increase and decrease of motor rotational speed are repeated.

[**0150**] On the other hand, when it is desired to lower the temperature of the motor section **10**, as shown in interval **62**, ordinary operation is performed while the rotation of the motor section **10** is kept constant.

[**0151**] The amount of heat generation per unit time of the motor section **10** can be controlled, for example, by increasing the frequency of increase/decrease of motor rotational speed or by widening a difference between the upper limit of rotational speed and the value of increase/decrease.

[**0152**] A system configuration for operating the turbo-molecular pump **1** in this manner will be described with reference to **FIG. 1**.

[**0153**] In **FIG. 1**, the temperature controller **52** monitors the temperature of the motor section **10** by using the temperature sensor installed in the motor section **10**. It is judged whether or not the monitored temperature is higher than the upper limit of the predetermined range, or is lower than the increase/decrease, and the judgment result is sent to the control unit **51**.

[**0154**] The control unit **51** can operate the motor section **10** in a heating mode in which the increase/decrease (fluctuation) of motor rotational speed is repeated and in a cooling mode in which the motor rotational speed is constant.

[**0155**] The control unit **51** operates the motor section **10** in the cooling mode when the temperature of the motor section **10** is higher than the upper limit of the predetermined range, from the judgment result of the temperature controller **52**, and operates it in the heating mode when the temperature of the motor section **10** is lower than the lower limit.

[**0156**] The above-described methods can be used combinedly. For example, a combined method can be used in which a bias current or a high frequency current is superimposed on the bearing electromagnet, and the motor section is heated by the method (2).

[**0157**] Also, if the flow rate or temperature of cooling water supplied to the water-cooled tube **18** is controlled in addition to the control of heat generation amount in the magnetic bearing portions **8**, **12** and **20**, the temperature of the turbo-molecular pump **1** can be controlled more effectively.

[**0158**] In this case, temperature detecting means composed of, for example, a thermocouple is provided on the stator column **46**, the spacer **5**, the base **27**, etc., by which the temperatures of these elements are monitored. On the other hand, there is provided cooling control means for controlling the flow rate of cooling water in accordance with the detected temperature. When the detected temperature exceeds a predetermined preset value, the flow rate of cooling water is increased, and when it is lower than a predetermined temperature range, the flow rate of cooling water is decreased, or the supply of cooling water is stopped.

[**0159**] Thus, when it is desired to raise the temperature of the turbo-molecular pump **1**, the flow rate of cooling water is decreased, or the supply of cooling water is stopped, which saves consumed energy required for heating.

[**0160**] The installation position of the water-cooled tube **18** is not limited to the bottom portion of the base **27**. The water-cooled tube **18** may be provided at the outer periphery of the base **27** or in the casing **16**.

[**0161**] (Modification of Embodiment)

[**0162**] In the above-described embodiment, a mechanism for generating heat in the turbo-molecular pump **1** has been described. In this modification, a mechanism for rapidly transmitting the generated heat to the tube in the pump is explained.

[**0163**] In this modification, the following three methods are used so that the heat generated in the magnetic bearing portions **8**, **12** and **20** can be transmitted to the tube efficiently.

[**0164**] (1) A member in a portion which is in contact with the tube in the turbo-molecular pump **1** is formed of a material with high thermal conductivity.

[**0165**] More specifically, a case for containing the magnetic bearing portions **8**, **12** and **20**, the collar **49**, and the like are formed of, for example, aluminum, aluminum alloy, or metal having thermal conductivity equal to or higher than that of aluminum alloy (copper, silver, etc.)

[**0166**] The case is a housing member constituting the housing for the magnetic bearing portions **8**, **12** and **20**, and is contained on the inner periphery side of the stator column **43** together with the magnetic bearing body.

[**0167**] The rotor **24** is also formed of a material having high thermal conductivity so that the heat generated in the magnetic bearing portions **8**, **12** and **20** is rapidly transmitted to the tube.

[**0168**] Also, if the stator column **46**, the spacer **5**, the base **27**, and the rotor **24** are formed of aluminum or aluminum alloy at the same time, heat can be transmitted more efficiently.

[**0169**] (2) At least a part of the outer peripheral surface of the stator column **46**, the inner peripheral surface of the rotor **24**, the rotor blade **21** and the rotor lower portion **29**, the opposing surface thereof, etc. is coated.

[**0170**] The outer peripheral surface of the stator column **46** and the inner peripheral surface of the rotor **24** are usually nickel-plated. The plated surfaces have high reflection factor of light, so that the heat from the surface is less liable to radiate. Therefore, at least a part of the inner peripheral surface of the rotor **24**, the rotor blade **21**, the surface of the rotor lower portion **29**, and the opposing surface thereof is coated with a substance from which heat is liable to radiate. Thereby, the transmission of heat by radiation can be performed efficiently.

[**0171**] For example, the following types of coatings can be thought. Carbon or black ceramics are mixed with fluorocarbon resin and the mixture is applied. Chemical conversion treatment such as chromating is performed. Anodic oxidation is accomplished to yield black alumite.

[**0172**] For a portion that is in direct contact with process gas, a less-corrosive coating method must be selected. Since the outer peripheral surface of the stator column **46** and the inner peripheral surface of the rotor **24** are not in direct contact with process gas, there is no fear of corrosion, so that any coating method can be used.

[**0173**] Also, only a portion that is not in direct contact with process gas may be coated.

[**0174**] As described above, according to this modification, the thermal conductivity in the turbo-molecular pump **1** is improved, and thus the temperature control can be carried out effectively.

[**0175**] Also, the temperature of the rotor **24** which is raised as a result of temperature control of the magnetic bearing portions **8**, **12** and **20** can be transmitted to the stator side effectively.

[**0176**] The above is a description of one embodiment and one modification of the present invention. The present invention is not limited to the above-described embodiment and modification, and various changes can be made within a scope described in claims.

[**0177**] According to the present invention, the cost required for additional parts for temperature control, such as a heater, can be reduced.

What is claimed is:

1. A pump apparatus comprising:

a casing formed with a gas intake port on one end side thereof and a gas discharge port on the other end side thereof;

a base member forming a bottom on the other side of said casing;

a cylindrical member which is fixed to said base member and contains a bearing and a motor;

a rotor shaft which is rotatably contained in said cylindrical member via said bearing and is rotated by said motor;

a rotor disposed on said rotor shaft;

a stator disposed on the inner peripheral surface of said casing with a predetermined space provided with respect to said rotor;

gas transfer means formed in the space between said rotor and said stator; and

heat generation control means for controlling the amount of heat generated in said cylindrical member.

2. The pump apparatus according to claim 1, wherein

said bearing is a magnetic bearing, and

said heat generation control means controls a bias current superimposed on a control current of said magnetic bearing.

3. The pump apparatus according to claim 1, wherein

said bearing is a magnetic bearing, and

said heat generation control means controls a high frequency current superimposed on a control current of said magnetic bearing.

4. The pump apparatus according to claim 1, wherein

said heat generation control means controls the amount of generated heat of said motor by changing the rotational speed of said motor.

5. The pump apparatus according to claim 2, wherein

said heat generation control means controls the amount of generated heat of said motor by changing the rotational speed of said motor.

6. The pump apparatus according to claim 3, wherein

said heat generation control means controls the amount of generated heat of said motor by changing the rotational speed of said motor.

7. The pump apparatus according to claim 1, wherein

said cylindrical member, said base member, said rotor, and said stator are formed of aluminum or aluminum alloy.

8. The pump apparatus according to claim 2, wherein

said cylindrical member, said base member, said rotor, and said stator are formed of aluminum or aluminum alloy.

9. The pump apparatus according to claim 3, wherein

said cylindrical member, said base member, said rotor, and said stator are formed of aluminum or aluminum alloy.

10. The pump apparatus according to claim 4, wherein

said cylindrical member, said base member, said rotor, and said stator are formed of aluminum or aluminum alloy.

11. The pump apparatus according to claim 7, wherein

a reinforcing member disposed around said motor or a housing member for said bearing is formed of aluminum or aluminum alloy.

12. The pump apparatus according to claim 1, wherein

at least a part of opposing surfaces of said stator and said rotor is coated to enhance heat radiation efficiency.

13. The pump apparatus according to claim 2, wherein

at least a part of opposing surfaces of said stator and said rotor is coated to enhance heat radiation efficiency.

14. The pump apparatus according to claim 3, wherein

at least a part of opposing surfaces of said stator and said rotor is coated to enhance heat radiation efficiency.

15. The pump apparatus according to claim 1, wherein

at least a part of the outer peripheral surface of said cylindrical member is opposed to the inner peripheral surface of said rotor with a predetermined space there between, and

at least a part of opposing surfaces of said cylindrical member and said rotor is coated to enhance heat radiation efficiency.

16. The pump apparatus according to claim 2, wherein

at least a part of the outer peripheral surface of said cylindrical member is opposed to the inner peripheral surface of said rotor with a predetermined space there between, and

at least a part of opposing surfaces of said cylindrical member and said rotor is coated to enhance heat radiation efficiency.

17. The pump apparatus according to claim 3, wherein

at least a part of the outer peripheral surface of said cylindrical member is opposed to the inner peripheral surface of said rotor with a predetermined space there between, and

at least a part of opposing surfaces of said cylindrical member and said rotor is coated to enhance heat radiation efficiency.

18. The pump apparatus according to claim 1, wherein

said pump apparatus further comprises:

cooling means formed in said pump apparatus; and

cooling control means for controlling said cooling means in relation to a temperature detected by temperature detecting means provided at a predetermined location of said pump apparatus.

19. The pump apparatus according to claim 2, wherein

said pump apparatus further comprises:

cooling means formed in said pump apparatus; and

cooling control means for controlling said cooling means in relation to a temperature detected by temperature detecting means provided at a predetermined location of said pump apparatus.

20. The pump apparatus according to claim 3, wherein

said pump apparatus further comprises:

cooling means formed in said pump apparatus; and

cooling control means for controlling said cooling means in relation to a temperature detected by temperature detecting means provided at a predetermined location of said pump apparatus.

* * * * *