(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 202 227 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
28.06.2023 Bulletin 2023/26

(21) Application number: **21858144.5**

(22) Date of filing: **30.07.2021**

(51) International Patent Classification (IPC):
F04D 19/04 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F04D 19/04

(86) International application number:
PCT/JP2021/028253

(87) International publication number:
WO 2022/038996 (24.02.2022 Gazette 2022/08)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **21.08.2020 JP 2020140495**

(71) Applicant: **Edwards Japan Limited**
Yachiyo-shi, Chiba 276-8523 (JP)

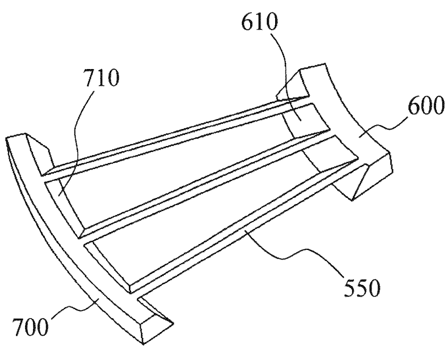
(72) Inventors:
- **MIWATA, Tooru**
  Yachiyo-shi Chiba 276-8523 (JP)
- **SHI, Yongwei**
  Yachiyo-shi Chiba 276-8523 (JP)

(74) Representative: **Openshaw & Co.**
8 Castle Street
Farnham, Surrey GU9 7HR (GB)

(54) VACUUM PUMP, FIXED BLADE, AND SPACER

(57) A vacuum pump with enhanced exhaustion performance achieved by innovating stator blades (inner and outer rims) and spacers installed in the vacuum pump is provided. In the vacuum pump in which the rotor blade in one stage has an outer diameter that is smaller at an outlet port side, or the rotor blade in one stage has an inner diameter that is larger at an outlet port side, at least one of an outer circumference portion or an inner circumference portion of the stator blade that is located immediately above the rotor blade having a smaller outer diameter or immediately above the rotor blade having a larger inner diameter has a tapered surface sloping down to an outlet port side. By providing the tapered surface, entering molecules are reflected at a right angle, sent toward an inner circumference side, and hit by the rotor blade in the upper stage. The molecules are thus sent to a next exhaustion stage.

FIG. 9



EP 4 202 227 A1

Description

[0001] The present invention relates to a vacuum pump, a stator blade, and a spacer, and more particularly to a structure for improving exhaustion efficiency of a vacuum pump.

[0002] Conventionally, a vacuum pumps is widely used such as a turbomolecular pump that exhausts gas by rotating at high speed a rotor potion (a shaft and a rotor) and a rotating portion, which includes rotor blades and a rotating cylinder, in a casing having an inlet port and an outlet port.

[0003] Such a vacuum pump exhausts gas through interaction between rotor blades in multiple stages rotating at high speed and stator blades in multiple stages fixed to the casing.

[0004] As shown in FIG. 30, a stator blade 123 used in this vacuum pump includes a plurality of blades 550, an inner rim 600, which holds and fixes inner sides (sides corresponding to the rotor portion when installed) of the plurality of blades 550, and an outer rim 700, which holds and fixes outer sides (sides corresponding to the casing when installed) of the blades 550. FIG. 31 is a partially enlarged view of a circle section indicated by a broken line of the stator blade 123 shown in FIG. 30.

[0005] As shown in FIG. 32, a stator blade 123 of a type without an outer rim 700 (type that holds and fixes the blades 550 only by the inner rim 600) may also be used.

[0006] FIG. 32 is a diagram showing a stator blade 123 cut in half, and FIG. 33 is a partially enlarged view of a circle section indicated by a broken line in FIG. 32.

[0007] In this vacuum pump, due to design requirements, a rotor blade in one stage of rotor blades in multiple stages has an outer diameter that is smaller at an outlet port side than at an inlet port side, or a rotor blade in one stage of rotor blades in multiple stages has an inner diameter that is larger at the outlet port side than at the inlet port side.

[0008] FIGS. 34 and 35 are diagrams for illustrating a conventional technique.

[0009] FIG. 34 is a cross-sectional view for illustrating a configuration of a conventional turbomolecular pump including stator blades 123 each including an inner rim 600 and an outer rim 700 (of the type shown in FIG. 30).

[0010] FIG. 35 is a partially enlarged view of FIG. 34.

[0011] As shown in FIG. 35, a flow of exhaust gas is in a direction indicated by the arrow from the inlet port side to the outlet port side.

[0012] As shown in FIG. 35, the inner rim 600 (outer side) and the outer rim 700 (inner side) of the installed stator blades 123 are arranged horizontally with respect to the exhaust direction and thus do not particularly contribute to exhaustion operation of the turbomolecular pump.

[0013] Also, an upper surface of a stator blade spacer located at a position where the outer diameter of the rotor blade is reduced has a section extending perpendicular to the exhaust direction. This configuration reflects gas molecules transferred from the upstream s
ide rotor blade directly toward the inlet port, whereby exhaustion performance is lowered.

[0014]

Patent Document 1: Japanese Patent Application Publication No. 2007-2692
Patent Document 2: Japanese Patent Application Publication No. 2018-35718

[0015] In a vacuum pumps disclosed in Patent Document 1 and Patent Document 2, outer and inner rims of stator blades are arranged horizontally with respect to the gas exhaust direction and therefore do not contribute to exhaustion efficiency.

[0016] In recent years, there has been a need for further improving exhaustion efficiency of a vacuum pump without increasing the size of a pump or increasing a rotation speed of a rotor portion.

[0017] In view of the above, it is an object of the present invention to provide a vacuum pump with enhanced exhaustion performance achieved by innovating stator blades (inner and outer rims) and spacers installed in the vacuum pump.

[0018] The present invention according to claim 1 provides a vacuum pump including: a casing that has an inlet port and an outlet port; a rotating shaft that is rotationally supported inside the casing; rotor blades in multiple stages that are fixed to the rotating shaft and rotatable together with the rotating shaft; and stator blades in multiple stages that are fixed to the casing and located between the rotor blades, the rotor blade in at least one stage of the rotor blades in multiple stages being configured to have an outer diameter that is smaller at an outlet port side than at an inlet port side, or the rotor blade in at least one stage of the rotor blades in multiple stages being configured to have an inner diameter that is larger at the outlet port side than at the inlet port side, wherein an outer circumference portion or an inner circumference portion of the stator blade that is located immediately above the rotor blade having a smaller outer diameter or immediately above the rotor blade having an larger inner diameter has a tapered surface sloping down to the outlet port side.

[0019] The invention according to claim 2 provides the vacuum pump according to claim 1, wherein the stator blade includes a plurality of radially arranged blades and an inner rim or an outer rim that holds the plurality of blades, and an outer circumference surface of the inner rim or an inner circumference surface of the outer rim has a tapered surface sloping down to the outlet port side.

[0020] The invention according to claim 3 provides the vacuum pump according to claim 1, wherein the stator blade includes a plurality of radially arranged blades and a spacer portion that holds the plurality of blades and enables positioning of the stator blade in a height direction, and an inner circumference surface of the spacer portion has a tapered surface sloping down to the outlet port side.

[0021] The invention according to claim 4 provides the vacuum pump according to claim 2 or 3, wherein the stator blade is undercut to surfaces of the plurality of blades facing the outlet port side.

[0022] The invention according to claim 5 provides the vacuum pump according to claim 2 or 3, wherein the stator blade has a vertical surface or a tapered surface on a rear side of the plurality of blades.

[0023] The invention according to claim 6 provides the vacuum pump according to claim 1, wherein a protrusion is provided that extends within a range of the stator blade in a height direction from a spacer portion that holds a casing side of the stator blade and enables positioning of the stator blade in the height direction, and at least a part of an inner circumference surface of the spacer portion and the protrusion has a tapered surface sloping down to the outlet port side.

[0024] The invention according to claim 7 provides a stator blade for a vacuum pump including a casing having an inlet port and an outlet port, the spacer including: a plurality of radially arranged blades; and an inner rim or an outer rim that holds the plurality of blades, wherein an outer circumference surface of the inner rim or an inner circumference surface of the outer rim has a tapered surface sloping down to the outlet port side.

[0025] The invention according to claim 8 provides a spacer for a vacuum pump including a casing having an inlet port and an outlet port, the spacer including: a spacer portion that is configured to, when a stator blade having a plurality of radially arranged blades is placed, hold a casing side of the stator blade and enable positioning of the stator blade in a height direction; and a protrusion that extends from the spacer portion within a range of the stator blade in the height direction, wherein at least a part of an inner circumference surface of the spacer portion and the protrusion has a tapered surface sloping down to the outlet port side.

[0026] According to the present invention, the exhaustion performance of a vacuum pump is enhanced by improving the shape of an inner rim, an outer rim, or a spacer of a stator blade of the vacuum pump.

FIG. 1 is a schematic view showing an example of the configuration of a turbomolecular pump of an embodiment according to the present invention;

FIG. 2 is a circuit diagram of an amplifier circuit used in an embodiment of the present invention;

FIG. 3 is a time chart showing control performed when a current command value is greater than a detected value in an embodiment of the present invention;

FIG. 4 is a time chart showing control performed when a current command value is less than a detected value in an embodiment of the present invention;

FIG. 5 is a schematic view showing an example of the configuration of a turbomolecular pump according to a first embodiment of the present invention;

FIG. 6 is a partially enlarged view of the turbomolecular pump according to the first embodiment shown in FIG. 5;

FIG. 7 is a diagram showing a stator blade according to the first embodiment A in which the inner rim has a tapered surface;

FIG. 8 is a diagram showing a stator blade according to the first embodiment B in which the inner rim has a tapered surface, vertical surfaces, and circumference surfaces;

FIG. 9 is a diagram showing a stator blade according to the first embodiment C in which the inner rim and the outer rim have tapered surfaces;

FIG. 10 is a diagram showing a stator blade according to the first embodiment D in which the inner rim and the outer rim have tapered surfaces, vertical surfaces, and circumference surfaces;

FIGS. 11A and 11B are diagrams showing a stator blade according to the first embodiment E in which the inner rim and the outer rim have tapered surfaces and the outer rim has a tapered surface above (below) the blades;

FIG. 12 is a diagram showing a stator blade according to the first embodiment F in which the inner rim and the outer rim have tapered surfaces and an inner circumference surface is provided above (below) the blades;

FIG. 13 is a diagram showing a stator blade according to the first embodiment G in which the inner rim and the outer rim have tapered surfaces and vertical surfaces, and an inner circumference surface is provided above (below) the blades of the outer rim;

FIGS. 14A and 14B are diagrams showing a stator blade according to the first embodiment H in which the inner rim and the outer rim have tapered surfaces and vertical surfaces and a tapered surface is provided above (below) the blades of the outer rim;

FIG. 15 is a diagram showing a stator blade according to the first embodiment I in which the inner rim and the outer rim have tapered surfaces and a flange is provided;

FIG. 16 is a diagram showing a stator blade according to the first embodiment J in which the inner rim and the outer rim have tapered surfaces and vertical surfaces and a flange is provided;

FIG. 17 is a partially enlarged view showing an example of a schematic configuration of a turbomolecular pump according to a second embodiment of the invention;

FIG. 18 is a diagram showing a stator blade according to the second embodiment A in which the outer rim has a tapered surface and an inner circumference surface;

FIG. 19 is a diagram showing a stator blade according to the second embodiment B in which the outer rim has a tapered surface, an inner circumference surface, and a flange;

FIG. 20 is a diagram showing a stator blade according to the second embodiment C in which the outer rim has a tapered surface and an inner circumference surface and inner rim vertical surfaces and outer rim vertical surfaces are provided;

FIG. 21 is a diagram showing a stator blade according to the second embodiment D in which the outer rim has a tapered surface, an inner circumference surface, and a flange;

FIG. 22 is a partially enlarged view of a turbomolecular pump according to a third embodiment;

FIG. 23 is a partially enlarged view of a turbomolecular pump according to a fourth embodiment;

FIG. 24 is a diagram showing a stator blade according to the fourth embodiment A in which the inner rim has an inner rim tapered surface;

FIG. 25 is a diagram showing a stator blade according to the fourth embodiment B in which the inner rim has an inner rim tapered surface and inner rim vertical surfaces;

FIG. 26 is a partially enlarged view of a turbomolecular pump according to a fifth embodiment;

FIG. 27 is a diagram showing the appearance of a stator blade spacer according to the fifth embodiment A;

FIG. 28 is a diagram showing the appearance of a stator blade spacer according to the fifth embodiment B;

FIGS. 29A and 29B are diagrams for illustrating taper angles;

FIG. 30 is a diagram showing a conventional stator blade;

FIG. 31 is a partially enlarged view of the stator blade shown in FIG. 30;

FIG. 32 is a diagram showing a conventional stator blade without an outer rim;

FIG. 33 is a partially enlarged view of the stator blade shown in FIG. 32;

FIG. 34 is a schematic view showing an example of the configuration of a conventional turbomolecular pump; and

FIG. 35 is a partially enlarged view of the turbomolecular pump shown in FIG. 34.

(i) Outline of Embodiments

[0027] In present embodiments, in a vacuum pump in which the rotor blade in at least one stage of the rotor blades in multiple stages has an outer diameter that is smaller at a side corresponding to the outlet port, or the rotor blade in at least one stage of the rotor blades in multiple stages has an inner diameter that is larger at a side corresponding to the outlet port, at least one of an inner circumference portion or an inner circumference portion of the stator blade that is located immediately above the rotor blade having a smaller outer diameter or immediately above the rotor blade having a larger inner diameter has a tapered surface (inclined surface) sloping down toward the outlet port.

[0028] By providing the tapered surface, entering molecules are reflected at a right angle, sent toward the inner circumference side, and hit by the rotor blade in the upper stage. The molecules are thus sent to the next exhaustion stage.

[0029] In this manner, the outer circumference portion or the inner circumference portion of a stator blade, which do not function to exhaust gas in conventional techniques, also contribute to the exhaustion, thereby enhancing the exhaustion efficiency of the vacuum pump.

(ii) Details of Embodiments

[0030] Referring to FIGS. 1 to 29A and 29B, preferred embodiments of the present invention are now described in detail.

Structure of Vacuum Pump

[0031] FIG. 1 is a schematic view showing an example of the configuration of a turbomolecular pump 100 according to an embodiment of the present invention. The turbomolecular pump 100 has a circular outer cylinder 127 having an inlet port 101 at its upper end. A rotating body 103 in the outer cylinder 127 includes a plurality of rotor blades 102 (102a, 102b, 102c, ...), which are turbine blades for gas suction and exhaustion, in its outer circumference section. The rotor blades 102 extend radially in multiple stages. The rotating body 103 has a rotor shaft 113 in its center. The rotor shaft 113 is suspended in the air and position-controlled by a magnetic bearing of 5-axis control, for example.

[0032] Upper radial electromagnets 104 include four electromagnets arranged in pairs on an X-axis and a Y-axis. Four upper radial sensors 107 are provided in close proximity to the upper radial electromagnets 104 and associated with the respective upper radial electromagnets 104. Each upper radial sensor 107 may be an inductance sensor or an eddy current sensor having a conduction winding, for example, and detects the position of the rotor shaft 113 based on a change in the inductance of the conduction winding, which changes according to the position of the rotor shaft 113. The upper radial sensors 107 are configured to detect a radial displacement of the rotor shaft 113, that is, the rotating body 103 fixed to the rotor shaft 113, and send it to the controller 200.

[0033] In the controller 200, for example, a compensation circuit having a PID adjustment function generates an excitation control command signal for the upper radial electromagnets 104 based on a position signal detected by the upper radial sensors 107. Based on this excitation control command signal, an amplifier circuit 150 (described below) shown in FIG. 2 controls and excites the upper radial electromagnets 104 to adjust a radial position of an upper part of the rotor shaft 113.

[0034] The rotor shaft 113 may be made of a high magnetic permeability material (such as iron and stainless steel) and is configured to be attracted by magnetic forces of the upper radial electromagnets 104. The adjustment is performed independently in the X-axis direction and the Y-axis direction. Lower radial electromagnets 105 and lower radial sensors 108 are arranged in a similar manner as the upper radial electromagnets 104 and the upper radial sensors 107 to adjust the radial position of the lower part of the rotor shaft 113 in a similar manner as the radial position of the upper part.

[0035] Additionally, axial electromagnets 106A and 106B are arranged so as to vertically sandwich a metal disc 111, which has a shape of a circular disc and is provided in the lower part of the rotor shaft 113. The metal disc 111 is made of a high magnetic permeability material such as iron. An axial sensor 109 is provided to detect an axial displacement of the rotor shaft 113 and send an axial position signal to the controller 200.

[0036] In the controller 200, the compensation circuit having the PID adjustment function may generate an excitation control command signal for each of the axial electromagnets 106A and 106B based on the signal on the axial position detected by the axial sensor 109. Based on these excitation control command signals, the amplifier circuit 150 controls and excites the axial electromagnets 106A and 106B separately so that the axial electromagnet 106A magnetically attracts the metal disc 111 upward and the axial electromagnet 106B attracts the metal disc 111 downward. The axial position of the rotor shaft 113 is thus adjusted.

[0037] As described above, the controller 200 appropriately adjusts the magnetic forces exerted by the axial electromagnets 106A and 106B on the metal disc 111, magnetically levitates the rotor shaft 113 in the axial direction, and suspends the rotor shaft 113 in the air in a non-contact manner. The amplifier circuit 150, which controls and excites the upper radial electromagnets 104, the lower radial electromagnets 105, and the axial electromagnets 106A and 106B, is described below.

[0038] The motor 121 includes a plurality of magnetic poles circumferentially arranged to surround the rotor shaft 113. Each magnetic pole is controlled by the controller 200 so as to drive and rotate the rotor shaft 113 via an electromagnetic force acting between the magnetic pole and the rotor shaft 113. The motor 121 also includes a rotational speed sensor (not shown), such as a Hall element, a resolver, or an encoder, and the rotational speed of the rotor shaft 113 is detected based on a detection signal of the rotational speed sensor.

[0039] Furthermore, a phase sensor (not shown) is attached adjacent to the lower radial sensors 108 to detect the phase of rotation of the rotor shaft 113. The controller 200 detects the position of the magnetic poles using both detection signals of the phase sensor and the rotational speed sensor.

[0040] A plurality of stator blades 123 (123a, 123b, 123c, ...) are arranged slightly spaced apart from the rotor blades 102 (102a, 102b, 102c, ...). Each rotor blade 102 (102a, 102b, 102c, ...) is inclined by a predetermined angle from a plane perpendicular to the axis of the rotor shaft 113 in order to transfer exhaust gas molecules downward through collision.

[0041] The stator blades 123 are also inclined by a predetermined angle from a plane perpendicular to the axis of the rotor shaft 113. The stator blades 123 extend inward of the outer cylinder 127 and alternate with the stages of the rotor blades 102. The outer circumference ends of the stator blades 123 are inserted between and thus supported by a plurality of layered stator blade spacers 125 (125a, 125b, 125c, ...).

[0042] The stator blade spacers 125 are ring-shaped members made of a metal, such as aluminum, iron, stainless steel, or copper, or an alloy containing these metals as components, for example. The outer cylinder 127 is fixed to the outer circumferences of the stator blade spacers 125 with a slight gap. A base portion 129 is located at the base of the outer cylinder 127. The base portion 129 has an outlet port 133 providing communication to the outside. The exhaust gas transferred to the base portion 129 through the inlet port 101 from the chamber is then sent to the outlet port 133.

[0043] According to the application of the turbomolecular pump 100, a threaded spacer 131 may be provided between the lower part of the stator blade spacer 125 and the base portion 129. The threaded spacer 131 is a cylindrical member made of a metal such as aluminum, copper, stainless steel, or iron, or an alloy containing these metals as components. The threaded spacer 131 has a plurality of helical thread grooves 131a in its inner circumference surface. When exhaust gas molecules move in the rotation direction of the rotating body 103, these molecules are transferred toward the outlet port 133 in the direction of the helix of the thread grooves 131a. In the lowermost section of the rotating body 103 below the rotor blades 102 (102a, 102b, 102c, ...), a cylindrical portion 102d extends downward. The outer circumference surface of the cylindrical portion 102d is cylindrical and projects toward the inner circumference surface of the threaded spacer 131. The outer circumference surface is adjacent to but separated from the inner circumference surface of the threaded spacer 131 by a predetermined gap. The exhaust gas transferred to the thread grooves 131a by the rotor blades 102 and the stator blades 123 is guided by the thread grooves 131a to the base portion 129.

[0044] The base portion 129 is a disc-shaped member forming the base section of the turbomolecular pump 100, and is generally made of a metal such as iron, aluminum, or stainless steel. The base portion 129 physically holds the turbomolecular pump 100 and also serves as a heat conduction path. As such, the base portion 129 is preferably made of rigid metal with high thermal conductivity, such as iron, aluminum, or copper.

[0045] In this configuration, when the motor 121 drives and rotates the rotor blades 102 together with the rotor shaft 113, the interaction between the rotor blades 102 and the stator blades 123 causes the suction of exhaust gas from the chamber through the inlet port 101. The exhaust gas taken through the inlet port 101 moves between the rotor blades 102 and the stator blades 123 and is transferred to the base portion 129. At this time, factors such as the friction heat generated when the exhaust gas comes into contact with the rotor blades 102 and the conduction of heat generated by the motor 121 increase the temperature of the rotor blades 102. This heat is conducted to the stator blades 123 through radiation or conduction via gas molecules of the exhaust gas, for example.

[0046] The stator blade spacers 125 are joined to each other at the outer circumference portion and conduct the heat received by the stator blades 123 from the rotor blades 102, the friction heat generated when the exhaust gas comes into contact with the stator blades 123, and the like to the outside.

[0047] In the above description, the threaded spacer 131 is provided at the outer circumference of the cylindrical portion 102d of the rotating body 103, and the thread grooves 131a are engraved in the inner circumference surface of the threaded spacer 131. However, this may be inversed in some cases, and a thread groove may be engraved in the outer circumference surface of the cylindrical portion 102d, while a spacer having a cylindrical inner circumference surface may be arranged around the outer circumference surface.

[0048] According to the application of the turbomolecular pump 100, to prevent the gas drawn through the inlet port 101 from entering an electrical portion, which includes the upper radial electromagnets 104, the upper radial sensors 107, the motor 121, the lower radial electromagnets 105, the lower radial sensors 108, the axial electromagnets 106A, 106B, and the axial sensor 109, the electrical portion may be surrounded by a stator column 122. The inside of the stator column 122 may be maintained at a predetermined pressure by purge gas.

[0049] In this case, the base portion 129 has a pipe (not shown) through which the purge gas is introduced. The introduced purge gas is sent to the outlet port 133 through gaps between a protective bearing 120 and the rotor shaft 113, between the rotor and the stator of the motor 121, and between the stator column 122 and the inner circumference cylindrical portion of the rotor blade 102.

[0050] The turbomolecular pump 100 requires the identification of the model and control based on individually adjusted unique parameters (for example, various characteristics associated with the model). To store these control parameters, the turbomolecular pump 100 includes an electronic circuit portion 141 in its main body. The electronic circuit portion 141 may include a semiconductor memory, such as an EEPROM, electronic components such as semiconductor elements for accessing the semiconductor memory, and a substrate 143 for mounting these components. The electronic circuit portion 141 is housed under a rotational speed sensor (not shown) near the center, for example, of the base portion 129, which forms the lower part of the turbomolecular pump 100A, and is closed by an airtight bottom lid 145.

[0051] Some process gas introduced into the chamber in the manufacturing process of semiconductors has the property of becoming solid when its pressure becomes higher than a predetermined value or its temperature becomes lower than a predetermined value. In the turbomolecular pump 100A, the pressure of the exhaust gas is lowest at the inlet port 101 and highest at the outlet port 133. When the pressure of the process gas increases beyond a predetermined value or its temperature decreases below a predetermined value while the process gas is being transferred from the inlet port 101 to the outlet port 133, the process gas is solidified and adheres and accumulates on the inner side of the turbomolecular pump 100.

[0052] For example, when $SiCl_4$ is used as the process gas in an Al etching apparatus, according to the vapor pressure curve, a solid product (for example, $AlCl_3$) is deposited at a low vacuum (760 [torr] to 10^{-2} [torr]) and a low temperature (about 20 [°C]) and adheres and accumulates on the inner side of the turbomolecular pump 100A. When the deposit of the process gas accumulates in the turbomolecular pump 100, the accumulation may narrow the pump flow passage and degrade the performance of the turbomolecular pump 100. The above-mentioned product tends to solidify and adhere in areas with higher pressures, such as the vicinity of the outlet port and the vicinity of the threaded spacer 131.

[0053] To solve this problem, conventionally, a heater or annular water-cooled tube 149 (not shown) is wound around the outer circumference of the base portion 129, and a temperature sensor (e.g., a thermistor, not shown) is embedded in the base portion 129, for example. The signal of this temperature sensor is used to perform control to maintain the temperature of the base portion 129 at a constant high temperature (preset temperature) by heating with the heater or cooling with the water-cooled tube 149 (hereinafter referred to as TMS (temperature management system)).

[0054] The amplifier circuit 150 is now described that controls and excites the upper radial electromagnets 104, the lower radial electromagnets 105, and the axial electromagnets 106A and 106B of the turbomolecular pump 100 configured as described above. FIG. 2 is a circuit diagram of the amplifier circuit 150.

[0055] In FIG. 2, one end of an electromagnet winding 151 forming an upper radial electromagnet 104 or the like is connected to a positive electrode 171a of a power supply 171 via a transistor 161, and the other end is connected to a negative electrode 171b of the power supply 171 via a current detection circuit 181 and a transistor 162. Each transistor 161, 162 is a power MOSFET and has a structure in which a diode is connected between the source and the drain thereof.

[0056] In the transistor 161, a cathode terminal 161a of its diode is connected to the positive electrode 171a, and an anode terminal 161b is connected to one end of the electromagnet winding 151. In the transistor 162, a cathode terminal 162a of its diode is connected to a current detection circuit 181, and an anode terminal 162b is connected to the negative electrode 171b.

[0057] A diode 165 for current regeneration has a cathode terminal 165a connected to one end of the electromagnet winding 151 and an anode terminal 165b connected to the negative electrode 171b. Similarly, a diode 166 for current regeneration has a cathode terminal 166a connected to the positive electrode 171a and an anode terminal 166b connected to the other end of the electromagnet winding 151 via the current detection circuit 181. The current detection circuit 181 may include a Hall current sensor or an electric resistance element, for example.

[0058] The amplifier circuit 150 configured as described above corresponds to one electromagnet. Accordingly, when the magnetic bearing uses 5-axis control and has ten electromagnets 104, 105, 106A, and 106B in total, an identical amplifier circuit 150 is configured for each of the electromagnets. These ten amplifier circuits 150 are connected to the power supply 171 in parallel.

[0059] An amplifier control circuit 191 may be formed by a digital signal processor portion (not shown, hereinafter referred to as a DSP portion) of the controller 200. The amplifier control circuit 191 switches the transistors 161 and 162 between on and off.

[0060] The amplifier control circuit 191 is configured to compare a current value detected by the current detection circuit 181 (a signal reflecting this current value is referred to as a current detection signal 191c) with a predetermined current command value. The result of this comparison is used to determine the magnitude of the pulse width (pulse width time Tp1, Tp2) generated in a control cycle Ts, which is one cycle in PWM control. As a result, gate drive signals 191a and 191b having this pulse width are output from the amplifier control circuit 191 to gate terminals of the transistors 161 and 162.

[0061] Under certain circumstances such as when the rotational speed of the rotating body 103 reaches a resonance point during acceleration, or when a disturbance occurs during a constant speed operation, the rotating body 103 may require positional control at high speed and with a strong force. For this purpose, a high voltage of about 50 V, for example, is used for the power supply 171 to enable a rapid increase (or decrease) in the current flowing through the electromagnet winding 151. Additionally, a capacitor is generally connected between the positive electrode 171a and the negative electrode 171b of the power supply 171 to stabilize the power supply 171 (not shown).

[0062] In this configuration, when both transistors 161 and 162 are turned on, the current flowing through the electromagnet winding 151 (hereinafter referred to as an electromagnet current iL) increases, and when both are turned off, the electromagnet current iL decreases.

[0063] Also, when one of the transistors 161 and 162 is turned on and the other is turned off, a freewheeling current is maintained. Passing the freewheeling current through the amplifier circuit 150 in this manner reduces the hysteresis loss in the amplifier circuit 150, thereby limiting the power consumption of the entire circuit to a low level. Moreover, by controlling the transistors 161 and 162 as described above, high frequency noise, such as harmonics, generated in the turbomolecular pump 100 can be reduced. Furthermore, by measuring this freewheeling current with the current detection circuit 181, the electromagnet current iL flowing through the electromagnet winding 151 can be detected.

[0064] That is, when the detected current value is smaller than the current command value, as shown in FIG. 3, the transistors 161 and 162 are simultaneously on only once in the control cycle Ts (for example, 100 μs) for the time corresponding to the pulse width time Tp1. During this time, the electromagnet current iL increases accordingly toward the current value iLmax (not shown) that can be passed from the positive electrode 171a to the negative electrode 171b via the transistors 161 and 162.

[0065] When the detected current value is larger than the current command value, as shown in FIG. 4, the transistors 161 and 162 are simultaneously off only once in the control cycle Ts for the time corresponding to the pulse width time Tp2. During this time, the electromagnet current iL decreases accordingly toward the current value iLmin (not shown) that can be regenerated from the negative electrode 171b to the positive electrode 171a via the diodes 165 and 166.

[0066] In either case, after the pulse width time Tp1, Tp2 has elapsed, one of the transistors 161 and 162 is on. During this period, the freewheeling current is thus maintained in the amplifier circuit 150.

First Embodiment

[0067] Referring to FIGS. 5 to 16, a first embodiment is now described.

[0068] FIG. 5 is a schematic view showing an example of the configuration of the turbomolecular pump according to the first embodiment. FIG. 6 is a partially enlarged view of the turbomolecular pump according to the first embodiment shown in FIG. 5.

[0069] In the first embodiment, one or both of an inner rim 600 or an outer rim 700 of a stator blade 123 have tapered surfaces (inner rim tapered surface 610, outer rim tapered surface 710) that slope down toward the outlet port.

[0070] The tapered surface is provided in a section in which the rotor blade in one stage of the rotor blades in multiple stages has an outer diameter that is smaller at the side corresponding to the outlet port, or a section in which the rotor blade in one stage of the rotor blades in multiple stages has an inner diameter that is larger at the side corresponding to the outlet port. A stator blade 123 having a tapered surface is arranged between these rotor blades.

[0071] FIG. 7 is a diagram showing a stator blade 123 according to the first embodiment A in which the inner rim has a tapered surface.

[0072] As shown in this figure, the inner rim 600 has an inner rim tapered surface 610 sloping down toward the outlet port. When molecules are transferred to and collide with the inner rim tapered surface 610, the molecules are reflected at a right angle, hit by the rotor blade in the upper stage, and sent to the next stage. In this respect, the inner rim 600 having the inner rim tapered surface 610 contributes to the exhaustion action. As is clear from the figure, the inner rim 600 and the outer rim 700 hold and fix the blades 550 of the stator blade 123.

[0073] FIG. 8 is a diagram showing a stator blade 123 according to the first embodiment B in which the inner rim has a tapered surface. The stator blade 123 according to the first embodiment B has inner rim vertical surfaces 620 and inner rim circumference surfaces 630.

[0074] For example, the stator blade 123 is made of aluminum and manufactured as a casting using a mold or by cutting.

[0075] When the stator blade 123 is manufactured as a casting using a mold, the product needs to be removed from the mold. The inner rim vertical surfaces 620 are provided for this reason. The section under each blade 550 in which an inner rim vertical surface 620 is formed has an inner rim circumference surface 630, which is parallel to the outer rim 700.

[0076] FIG. 9 is a diagram showing a stator blade 123 according to the first embodiment C in which the inner rim and the outer rim have tapered surfaces. As shown in this figure, not only the inner rim 600 but also the outer rim 700 has an outer rim tapered surface 710 sloping down toward the outlet port.

[0077] In this first embodiment C, in addition to the inner rim 600, the outer rim 700 also contributes to the exhaustion action.

[0078] In the first embodiment C, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0079] FIG. 10 is a diagram showing a stator blade 123 according to the first embodiment D in which the inner rim and the outer rim have tapered surfaces, vertical surfaces, and circumference surfaces.

[0080] As in the first embodiment B, outer rim vertical surfaces 720 are provided because the product needs to be removed from a mold when it is manufactured as a casting using the mold. The section under each blade 550 in which an outer rim vertical surface 720 is formed has an outer rim circumference surface 730, which is parallel to the inner rim 600.

[0081] FIGS. 11A and 11B are diagrams showing a stator blade 123 according to the first embodiment E in which the inner rim and the outer rim have tapered surfaces and the outer rim has a tapered surface above (below) the blades.

[0082] With the first embodiment E, the inner rim 600 has the same shape as the first embodiment A and the first embodiment C, but the configuration of the outer rim 700 differs from that of the first embodiment C. That is, in the embodiment shown in FIG. 11A, the outer rim tapered surface 710 extends above the surfaces of the blades 550, forming an extra portion 740.

[0083] In the embodiment shown in FIG. 11B, the outer rim tapered surface 710 extends to the lower side beyond the back surfaces of the blades 550, forming an extra portion 740.

[0084] This extra portion 740 facilitates the setting of the axial dimension of the stator blade 123. That is, the adjustment in the height direction can be made within a range that does not affect the blades 550.

[0085] In this first embodiment E, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0086] The first embodiment E does not have a vertical surface and is therefore manufactured by cutting.

[0087] FIG. 12 is a diagram showing a stator blade 123 according to the first embodiment F in which the inner rim and the outer rim have tapered surfaces and an inner circumference surface is provided above (below) the blades.

[0088] With this first embodiment F, the inner rim 600 has the same shape as the first embodiment A and the first embodiment C, but the configuration of the outer rim 700 differs from that of the first embodiment C. That is, an outer rim inner circumference surface 760 is formed above (below) the surfaces of the blades 550. Unlike the outer rim tapered surface 710, the outer rim inner circumference surface 760 is parallel to the axis of the turbomolecular pump 100.

[0089] By providing the outer rim inner circumference surfaces 760 and adjusting the dimension in the axial direction, the positioning in the axial direction is achieved when installing the stator blade 123 in the turbomolecular pump 100.

[0090] In this first embodiment F, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the tapered surface 710.

[0091] The first embodiment F does not have a vertical surface and is therefore manufactured by cutting.

[0092] FIG. 13 is a diagram showing a stator blade 123 according to the first embodiment G in which the inner rim and the outer rim have tapered surfaces and vertical surfaces and an inner circumference surface is provided above (below) the blades of the outer rim. The difference between this embodiment G and the first embodiment F is that inner rim vertical surfaces 620 and outer rim vertical surfaces 720 are provided.

[0093] By providing the outer rim inner circumference surfaces 760 and adjusting the dimension in the axial direction, the positioning in the axial direction is achieved when installing the stator blade 123 in the turbomolecular pump 100.

[0094] In this first embodiment G, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0095] FIGS. 14A and 14B are diagrams showing a stator blade 123 according to the first embodiment H in which the inner rim and the outer rim have tapered surfaces and vertical surfaces and the outer rim has a tapered surface above (below) the blades. FIG. 14A is an external view as seen from above, and FIG. 14B is an external view as seen from below.

[0096] The difference between this embodiment and the first embodiment E is that inner rim vertical surfaces 620 and outer rim vertical surfaces 720 are provided.

[0097] The presence of the extra portion 740 facilitates the setting of the axial dimension of the stator blade 123.

[0098] In this first embodiment H, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the tapered surface 710.

[0099] FIG. 15 is a diagram showing a stator blade 123 according to the first embodiment I in which the inner rim and the outer rim have tapered surfaces and a flange is provided.

[0100] This embodiment I has a flange 750 projecting outward (toward the outer cylinder 127 when installed) from the outer rim 700.

[0101] This flange 750 allows the stator blade 123 to be positioned and held in the axial direction. That is, by adjusting the thickness (height in the axial direction) of the flange 750, the positioning in the axial direction of the stator blade 123 is achieved. Also, this flange 750 is held so the stator blade 123 is fixed to the outer cylinder 127.

[0102] In this first embodiment I, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0103] The first embodiment I does not have a vertical surface and is therefore manufactured by cutting.

[0104] FIG. 16 is a diagram showing a stator blade 123 according to the first embodiment J in which the inner rim and the outer rim have tapered surfaces and inner rim vertical surfaces, outer rim vertical surfaces and a flange is provided.

[0105] As in the embodiment I, this embodiment J has a flange 750 projecting outward (toward the outer cylinder 127 when installed) from the outer rim 700.

[0106] This flange 750 allows the stator blade 123 to be positioned and held in the axial direction. That is, by adjusting the thickness (height in the axial direction) of the flange 750, the positioning in the axial direction of the stator blade 123 is achieved. Also, this flange 750 is held so the stator blade 123 is fixed to the outer cylinder 127.

[0107] The difference between this embodiment J and the first embodiment I is that inner rim vertical surfaces 620 and outer rim vertical surfaces 720 are provided.

[0108] In this first embodiment J, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

Second Embodiment

[0109] A second embodiment is now described with reference to FIGS. 17 to 21.

[0110] FIG. 17 is a partially enlarged view of a turbomolecular pump according to the second embodiment.

[0111] In this second embodiment, the outer rim 700 of a stator blade 123 has an outer rim tapered surface 710, which slopes down toward the outlet port, and an outer rim inner circumference surface 760. That is, the outer rim 700 has both the outer rim tapered surface 710 and the outer rim inner circumference surface 760. The inner rim 600 is the same as that in the first embodiment.

[0112] FIG. 18 is a diagram showing a stator blade 123 according to the second embodiment A in which the outer rim has a tapered surface and an inner circumference surface.

[0113] The outer rim tapered surface 710 is located at a position corresponding to the blades 550. The outer rim inner circumference surface 760 is provided below the outer rim tapered surface 710. This outer rim inner circumference surface 760 is not inclined and is parallel to the axis of the turbomolecular pump 100.

[0114] The positioning of the stator blade 123 is achieved by adjusting the outer rim inner circumference surface 760 in the height direction. The absence of a blade 550 in the position corresponding to the outer rim inner circumference surface 760 facilitates the adjustment.

[0115] In this second embodiment A, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0116] The second embodiment A does not have a vertical surface and is therefore manufactured by cutting.

[0117] FIG. 19 is a diagram showing a stator blade 123 according to the second embodiment B in which the outer rim has a tapered surface, an inner circumference surface, and a flange.

[0118] The outer rim tapered surface 710 is located at a position corresponding to the blades 550. The outer rim inner circumference surface 760 is provided below the outer rim tapered surface 710.

[0119] The difference between the second embodiment B and the second embodiment A is that the outer rim 700 has a flange 750 projecting outward (toward the outer cylinder 127 when installed).

[0120] This flange 750 allows the stator blade 123 to be positioned and held in the axial direction. That is, by adjusting the thickness (height in the axial direction) of the flange 750, the positioning in the axial direction of the stator blade 123 is achieved. Also, this flange 750 is held so the stator blade 123 is fixed to the outer cylinder 127.

[0121] In this second embodiment B, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0122] The second embodiment B does not have a vertical surface and is therefore manufactured by cutting.

[0123] FIG. 20 is a diagram showing a stator blade 123 according to the second embodiment C in which the outer rim has a tapered surface and an inner circumference surface and inner rim vertical surfaces and outer rim vertical surface are provided.

[0124] The outer rim tapered surface 710 is located at a position corresponding to the blades 550. The outer rim inner circumference surface 760 is provided below the outer rim tapered surface 710.

[0125] The difference between this second embodiment C and the second embodiment A is that the inner rim vertical surface 630 and the outer rim vertical surface 720 are provided because the product needs to be removed from a mold when it is manufactured as a casting using the mold.

[0126] In this second embodiment C, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

[0127] FIG. 21 is a diagram showing a stator blade 123 according to the second embodiment D in which the outer rim has a tapered surface, an inner circumference surface, and a flange.

[0128] The outer rim tapered surface 710 is located at a position corresponding to the blades 550. The outer rim inner circumference surface 760 is provided below the outer rim tapered surface 710.

[0129] The difference between the second embodiment D and the second embodiment C is that the outer rim 700 has a flange 750 projecting outward (toward the outer cylinder 127 when installed).

[0130] This flange 750 allows the stator blade 123 to be positioned and held in the axial direction. That is, by adjusting the thickness (height in the axial direction) of the flange 750, the positioning in the axial direction of the stator blade 123 is achieved. Also, this flange 750 is held so the stator blade 123 is fixed to the outer cylinder 127.

[0131] In this second embodiment D, the inner rim 600 and the outer rim 700 each have a tapered surface (610, 710), but only the outer rim 700 may have the outer rim tapered surface 710.

Third Embodiment

[0132] Referring to FIG. 22, a third embodiment is now described.

[0133] FIG. 22 is a partially enlarged view of a turbomolecular pump according to the third embodiment.

[0134] In this third embodiment, the stator blades 123 used in the first embodiment are arranged reversely or in the same orientation. At least the stator blade 123 in the last stage is reversely arranged.

[0135] By arranging the stator blades 123 in this manner, the products of the same size (the stator blades 123) may be used for different functions, reducing the manufacturing costs.

[0136] Additionally, since the outer rim tapered surfaces 710 are continuously connected, a gap is not formed with respect to the spacer.

Fourth Embodiment

[0137] A fourth embodiment is now described with reference to FIGS. 23 to 25.

[0138] FIG. 23 is a partially enlarged view of a turbomolecular pump according to the fourth embodiment.

[0139] In this fourth embodiment, the inner rim 600 of a stator blade 123 has an inner rim tapered surface 610 sloping down toward the outlet port. That is, the inner rim 600 that is located in a section in which the diameter at the bases of the blades 550 of the stator blade 123 on the upstream side is smaller than the diameter at the bases of the blades 550 of the stator blade 123 on the downstream side has an inner rim tapered surface 610.

[0140] FIG. 24 is a diagram showing a stator blade 123 according to the fourth embodiment A in which the inner rim 600 has an inner rim tapered surface 610. The inner rim 600 shown in FIG. 24 is manufactured by cutting because it does not have inner rim vertical surfaces 620.

[0141] FIG. 25 is a diagram showing a stator blade 123 according to the fourth embodiment B in which the inner rim 600 has an inner rim tapered surface 610 and inner rim vertical surfaces. The inner rim 600 shown in FIG. 25 is manufactured by casting using a mold because it has the inner rim vertical surfaces 620.

[0142] FIGS. 24 and 25 both show a type of stator blade 123 without an outer rim 700, but the fourth embodiment can also be applied to a type of stator blade 123 with an outer rim 700.

Fifth Embodiment

[0143] A fifth embodiment is now described with reference to FIGS. 26 to 28.

[0144] FIG. 26 is a partially enlarged view of a turbomolecular pump according to the fifth embodiment.

[0145] This fifth embodiment relates to a stator blade spacer 800 having a stator blade spacer portion 870 that holds the side of a stator blade 123 corresponding to the outer frame 127 and enables the positioning of the stator blades 123 in the height direction.

[0146] FIG. 27 (the fifth embodiment A) and FIG. 28 (the fifth embodiment B) are diagrams each showing the appearance of a stator blade spacer 800. As shown in these figures, the stator blade spacer 800 has protrusions 860 extending in the height direction from the spacer portion 870 within the range of the stator blade 123 in the height direction. At least a part of the inner circumference surface 830 of the stator blade spacer portion 870 and the protrusions 860 has a stator blade spacer tapered surface 810 sloping down toward the outlet port. The inner circumference surface 830 of the stator blade spacer portion 870 and the range in which the protrusions 860 extend within the range of the stator blade 123 in the height direction are also defined as the "outer circumference portion of the stator blade".

[0147] Blade fitting grooves 820, to which the blades 550 of a stator blade 123 is fitted and held when installed, are provided between the protrusions 860.

[0148] The stator blade spacer 800 shown in FIG. 28 further has a stator blade spacer flange 850. The stator blade spacer flange 850 enables the positioning of the stator blade spacer 800 in the height direction. Moreover, the stator blade spacer 800 can be held and fixed by holding the stator blade spacer flange 850.

Angle of Tapered Surface

[0149] The angles of the tapered surfaces in the first to fifth embodiments are now described.

[0150] There is no limitation to the angle of a tapered surface as long as the tapered surface (inclined surface) slopes down toward the outlet port.

[0151] FIG. 29A is a cross-sectional view of a stator blade 123 corresponding to the first embodiment H. In the example shown in this figure, the tapered surface of the stator blade 123 is at the angle of the line (imaginary line) connecting the inner circumference lower end A of a stator blade spacer 125 to the inner circumference upper end B of a stator blade spacer 125.

[0152] FIG. 29B is a cross-sectional view of a stator blade 123 corresponding to the second embodiment D. In the example shown in this figure, the tapered surface of the stator blade 123 is at the angle of the line (imaginary line) connecting the point of intersection H of a perpendicular drawn from the distal end X of the upper rotor blade 102 to the lower stator blade 123 to the point at (1) the basal end of a blade 550 of the stator blade 123 or (2) the inner circumference lower side of the stator blade 123.

[0153] As described above, the tapered surface may have various angles, and the angle may be appropriately determined according to various conditions.

[0154] In each embodiment, other than a tapered surface, a gently curved surface may also be used.

[0155] The embodiments and modifications of the present invention may be combined as necessary.

[0156] The invention is amenable to various modifications without departing from the spirit of the invention. The invention is, of course, intended to cover all modifications.

[0157]

100 Turbomolecular pump
101 Inlet port
102 Rotor blade
103 Rotating body
113 Rotor shaft
123 Stator blade
125 Stator blade spacer
127 Outer cylinder
129 Base portion
133 Outlet port
200 Controller
550 Blade
600 Inner rim
610 Inner rim tapered surface
620 Inner rim vertical surface
630 Inner rim circumference surface
700 Outer rim
710 Outer rim tapered surface
720 Outer rim vertical surface
730 Outer rim circumference surface
740 Extra portion
750 Flange
760 Outer rim inner circumference surface
800 Stator blade spacer
810 Stator blade spacer tapered surface
820 Blade fitting groove
830 Stator blade spacer inner circumference surface
850 Stator blade spacer flange
860 Protrusion
870 Stator blade spacer portion

Claims

1. A vacuum pump comprising:

a casing that has an inlet port and an outlet port;
a rotating shaft that is rotationally supported inside the casing;
rotor blades in multiple stages that are fixed to the rotating shaft and rotatable together with the rotating shaft; and
stator blades in multiple stages that are fixed to the casing and located between the rotor blades,
the rotor blade in at least one stage of the rotor blades in multiple stages being configured to have an outer diameter that is smaller at an outlet port side than at an inlet port side, or the rotor blade in at least one stage of the rotor blades in multiple stages being configured to have an inner diameter that is larger at the outlet port side than at the inlet port side, wherein
an outer circumference portion or an inner circumference portion of the stator blade that is located immediately above the rotor blade having a smaller outer diameter or immediately above the rotor blade having a larger inner diameter has a tapered surface sloping down to the outlet port side.

2. The vacuum pump according to claim 1, wherein,

the stator blade includes a plurality of radially arranged blades and an inner rim or an outer

rim that holds the plurality of blades, and
an outer circumference surface of the inner rim or an inner circumference surface of the outer rim has a tapered surface sloping down to the outlet port side.

3. The vacuum pump according to claim 1, wherein

the stator blade includes a plurality of radially arranged blades and a spacer portion that holds the plurality of blades and enables positioning of the stator blade in a height direction, and
an inner circumference surface of the spacer portion has a tapered surface sloping down to the outlet port side.

4. The vacuum pump according to claim 2 or 3, wherein the stator blade is undercut to surfaces of the plurality of blades facing the outlet port side.

5. The vacuum pump according to claim 2 or 3, wherein the stator blade has a vertical surface or a tapered surface on a rear side of the plurality of blades.

6. The vacuum pump according to claim 1, wherein

a protrusion is provided that extends within a range of the stator blade in a height direction from a spacer portion that holds a casing side of the stator blade and enables positioning of the stator blade in the height direction, and
at least a part of an inner circumference surface of the spacer portion and the protrusion has a tapered surface sloping down to the outlet port side.

7. A stator blade for a vacuum pump including a casing having an inlet port and an outlet port, the stator blade comprising:

a plurality of blades arranged radially; and
an inner rim or an outer rim holding the plurality of blades, wherein
an outer circumference surface of the inner rim or an inner circumference surface of the outer rim has a tapered surface sloping down toward an outlet port side.

8. A spacer for a vacuum pump including a casing having an inlet port and an outlet port, the spacer including:

a spacer portion that is configured to, when a stator blade having a plurality of radially arranged blades is placed, hold a casing side of the stator blade and enable positioning of the stator blade in a height direction; and
a protrusion that extends from the spacer portion within a range of the stator blade in the height direction, wherein
at least a part of an inner circumference surface of the spacer portion and the protrusion has a tapered surface sloping down to the outlet port side.

FIG. 1

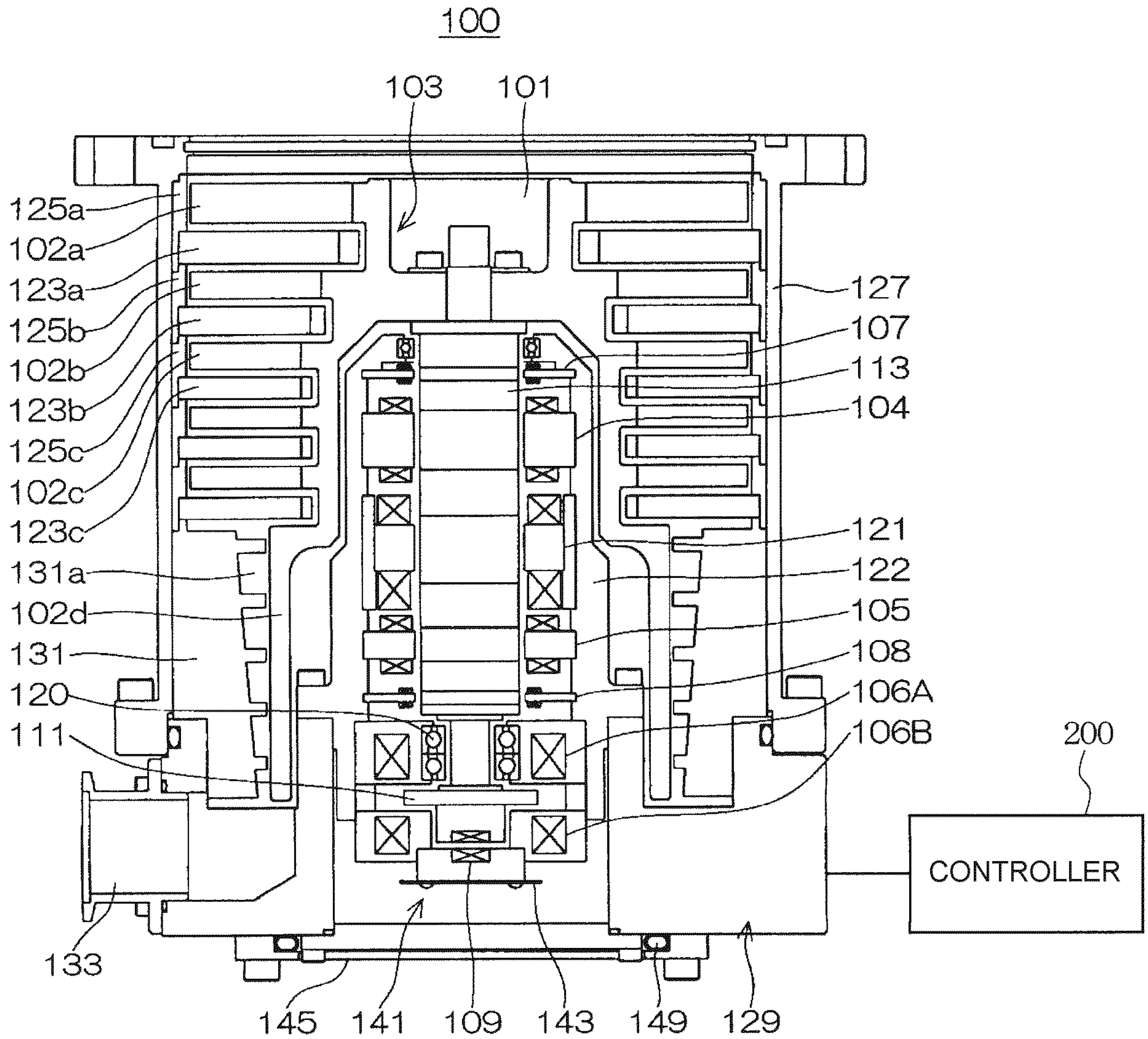

100
103
101
125a
102a
123a
125b
102b
123b
125c
102c
123c
131a
102d
131
120
111
133
127
107
113
104
121
122
105
108
106A
106B
200
CONTROLLER
145
141
109
143
149
129

FIG. 2

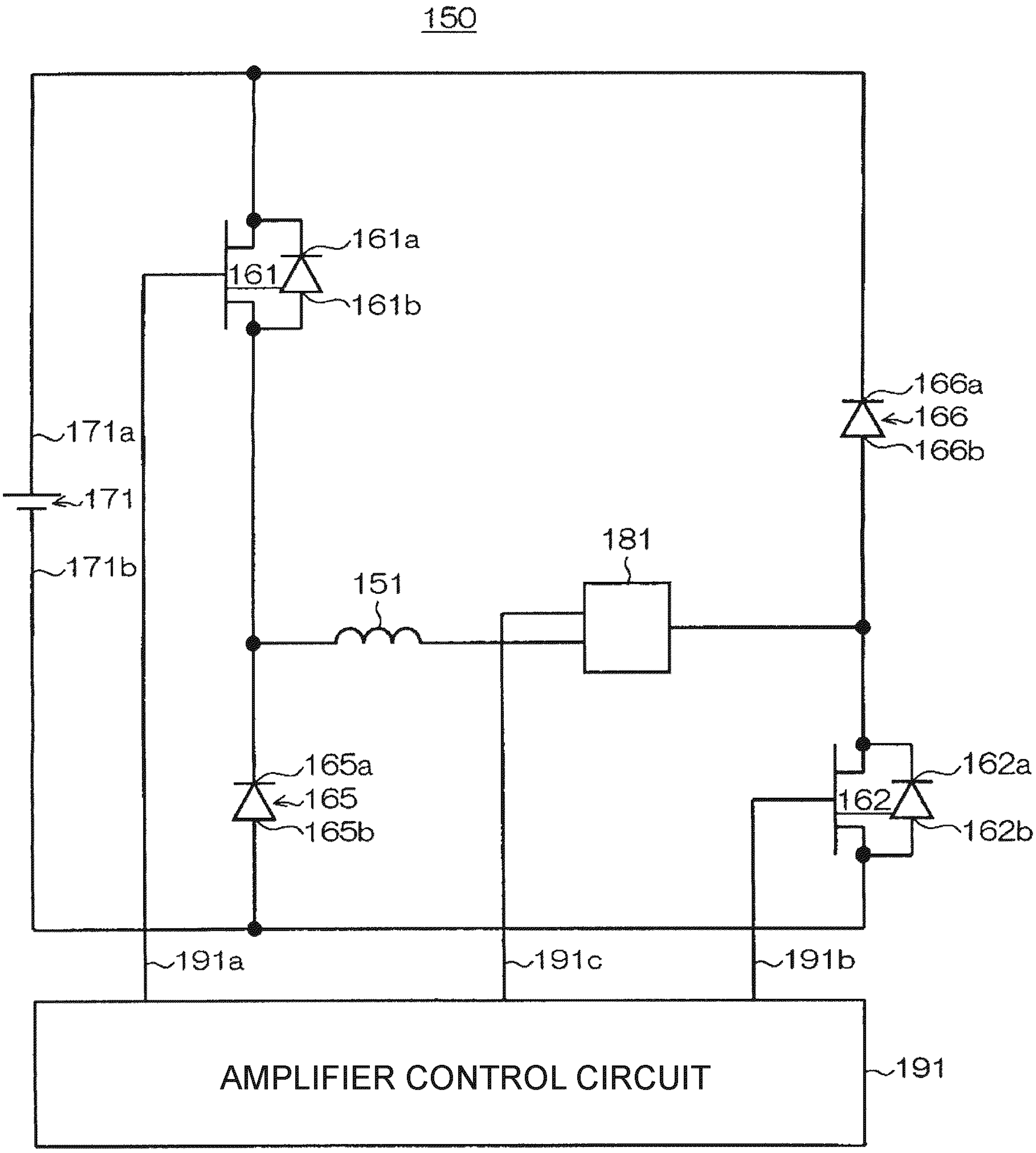

150
161a
161
161b
166a
166
166b
171a
171
171b
181
151
165a
165
165b
162a
162
162b
191a
191c
191b
AMPLIFIER CONTROL CIRCUIT
191

FIG. 3

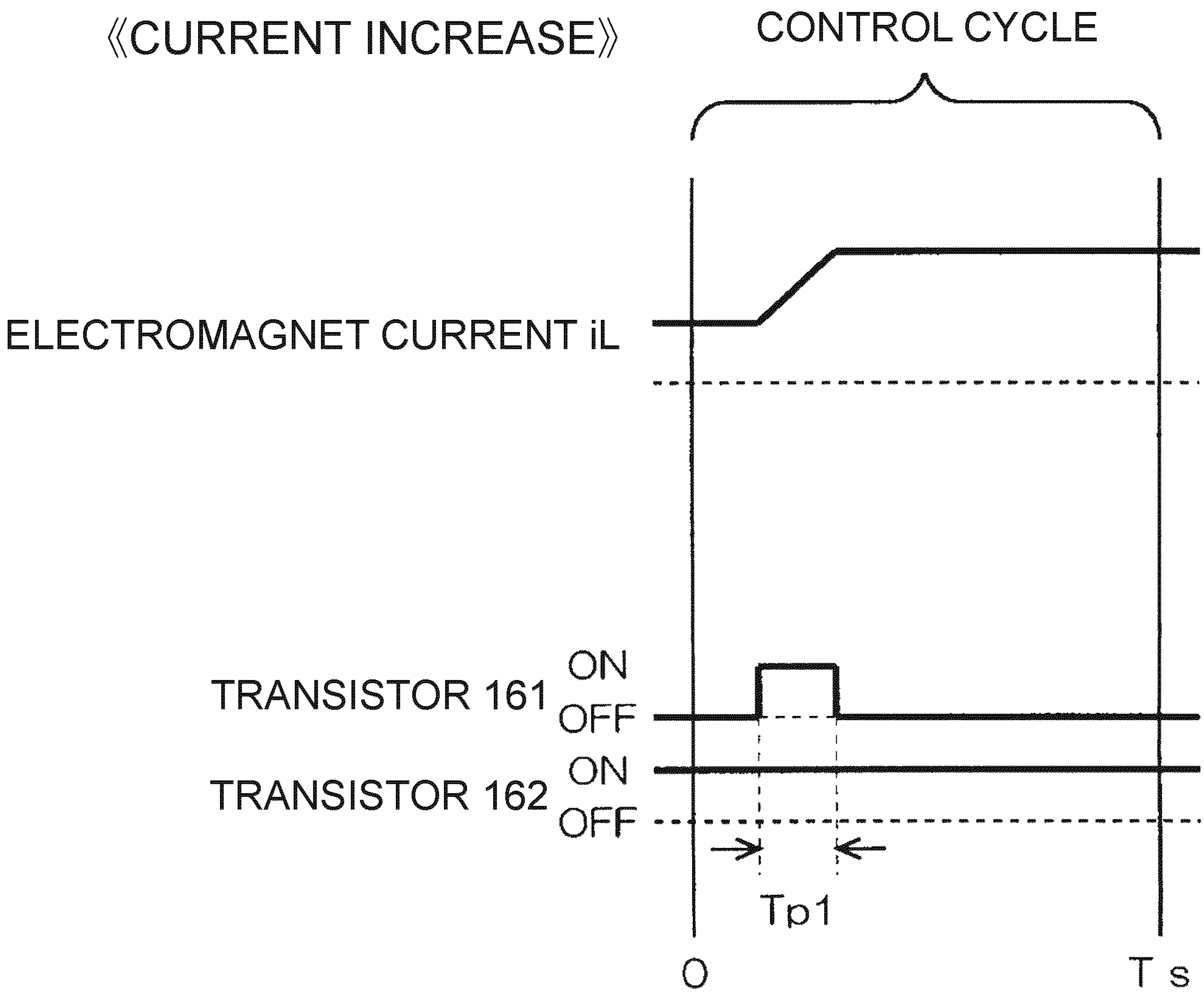

《CURRENT INCREASE》
CONTROL CYCLE
ELECTROMAGNET CURRENT iL
TRANSISTOR 161
ON
OFF
TRANSISTOR 162
ON
OFF
Tp1
0
T s

FIG. 4

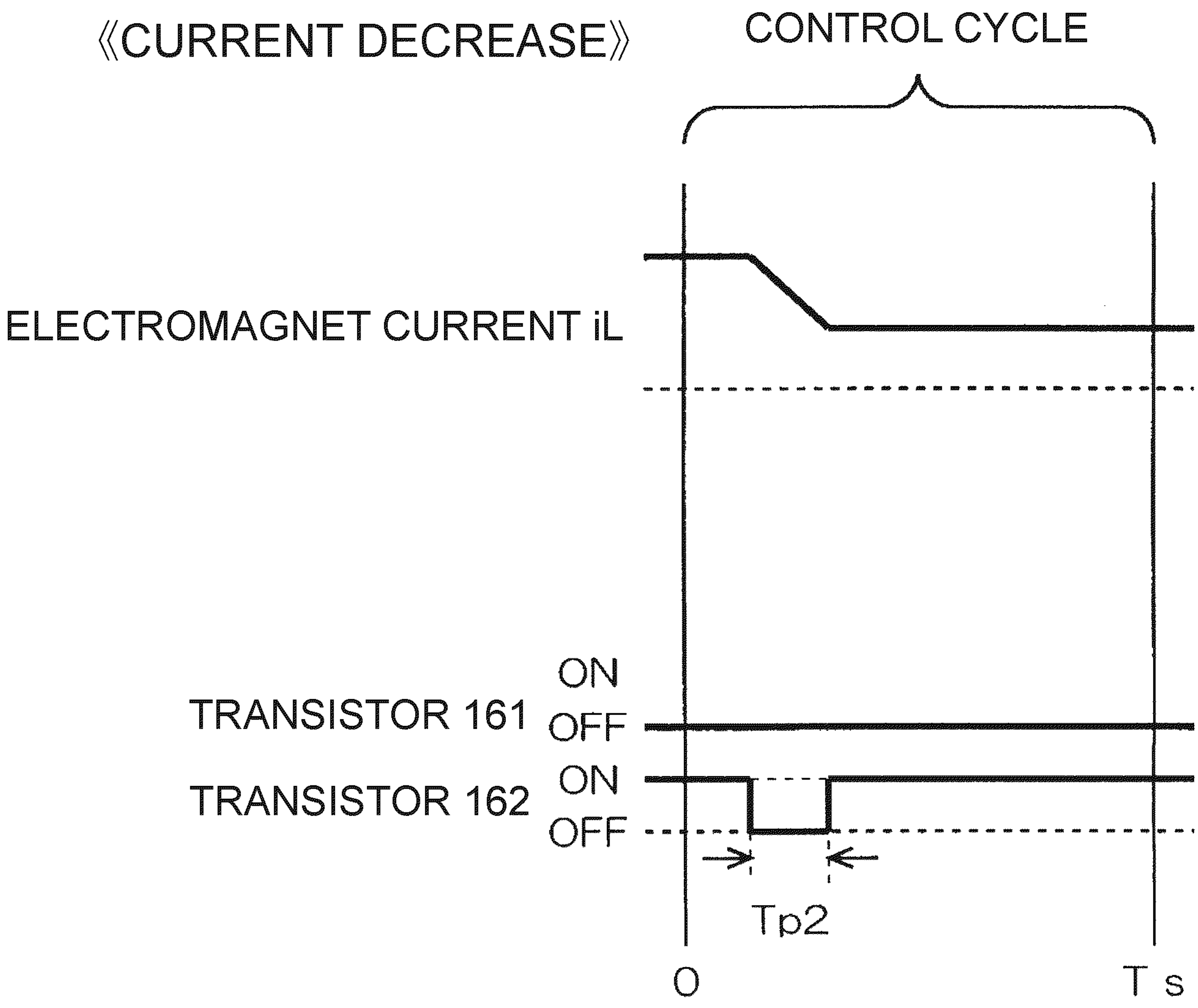

《CURRENT DECREASE》
CONTROL CYCLE
ELECTROMAGNET CURRENT iL
TRANSISTOR 161
ON
OFF
TRANSISTOR 162
ON
OFF
Tp2
0
T s

FIG. 5

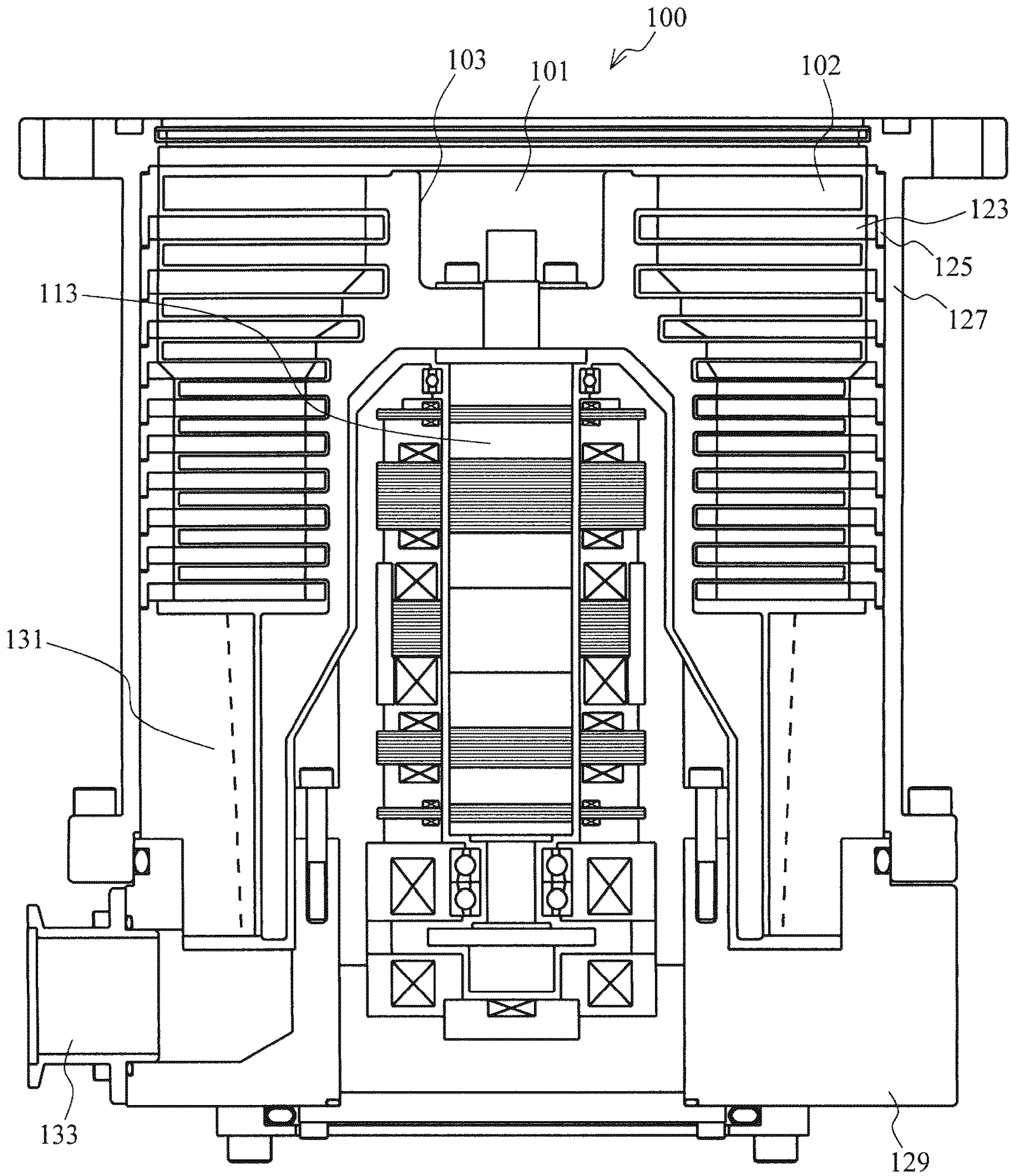


FIG. 6

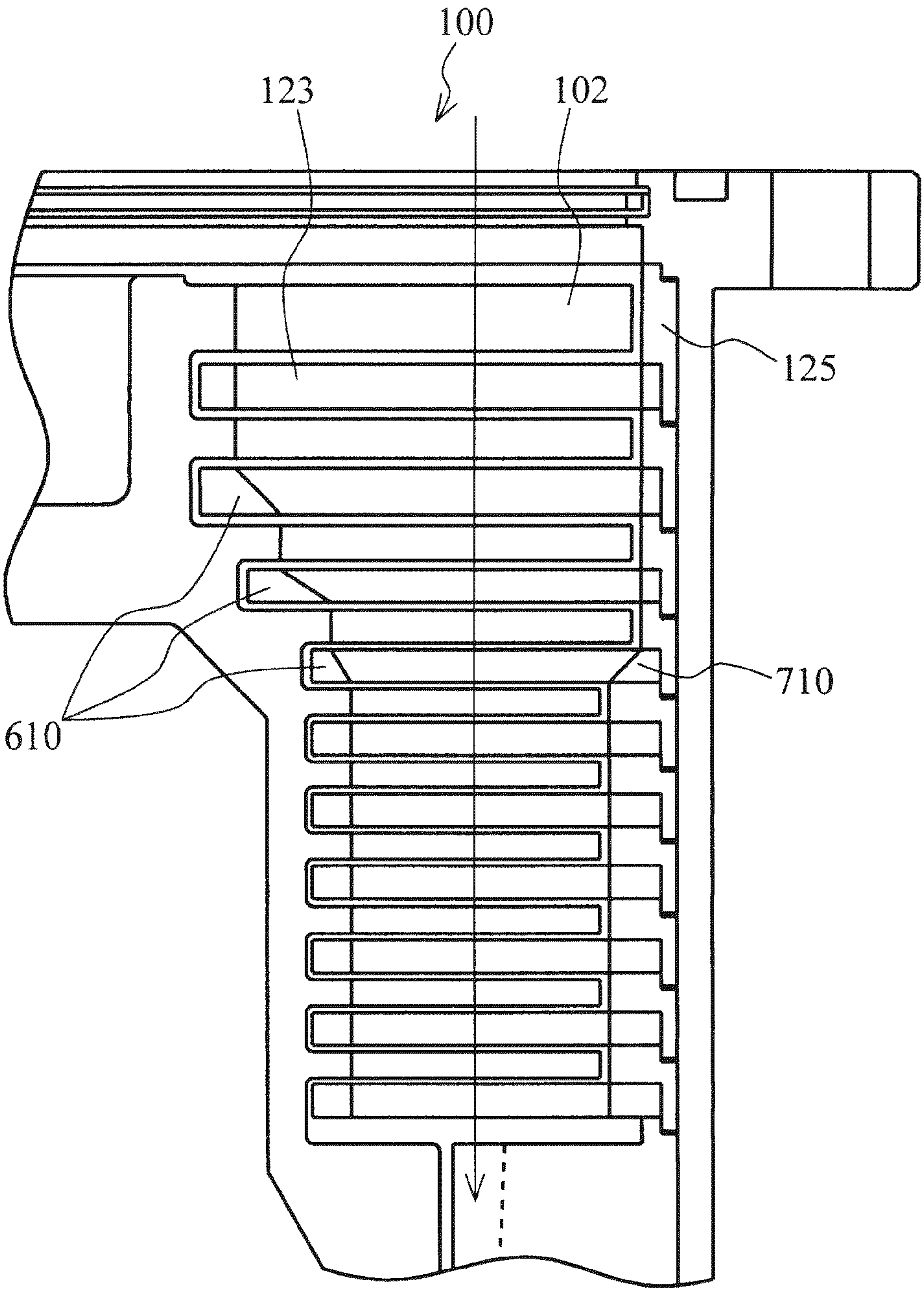


FIG. 7

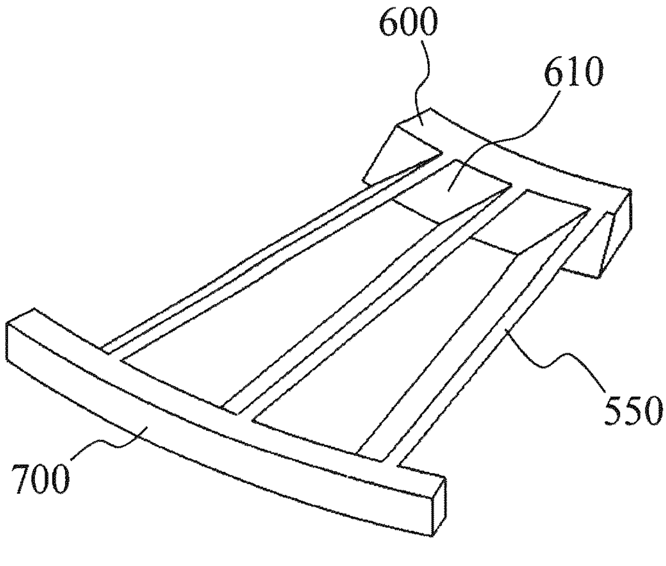


FIG. 8

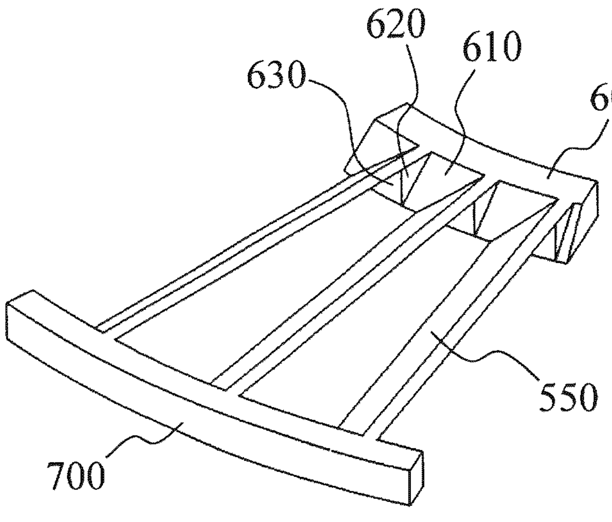


FIG. 9

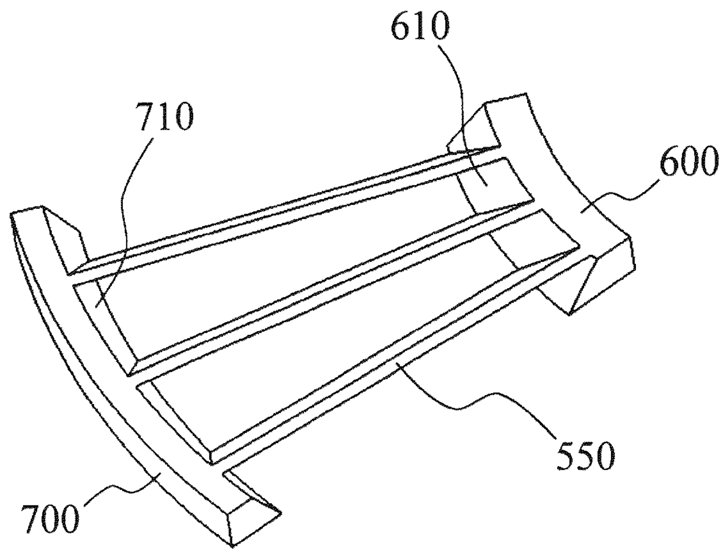


FIG. 10

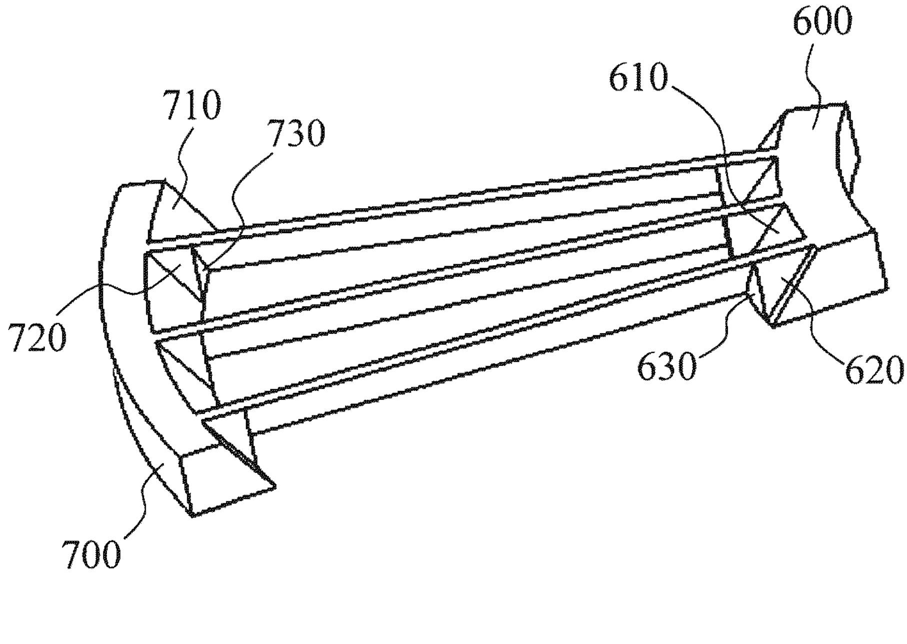
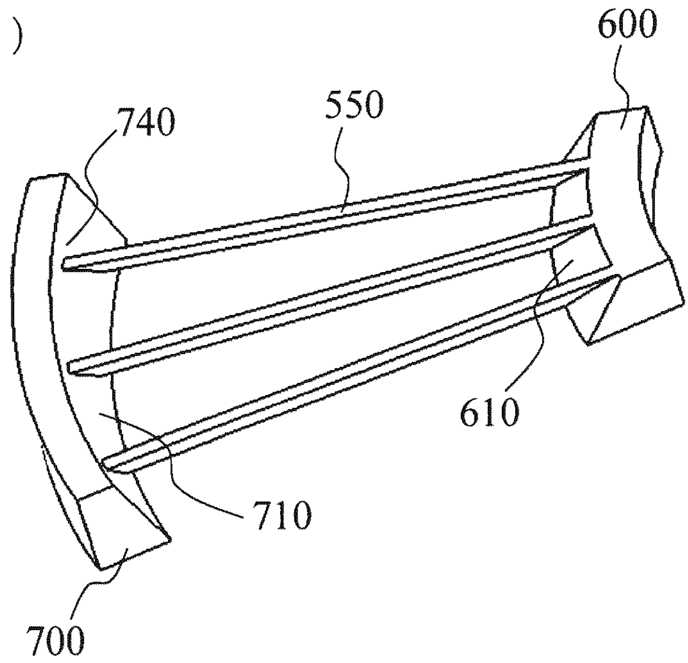


FIG. 11

(a)



(b)

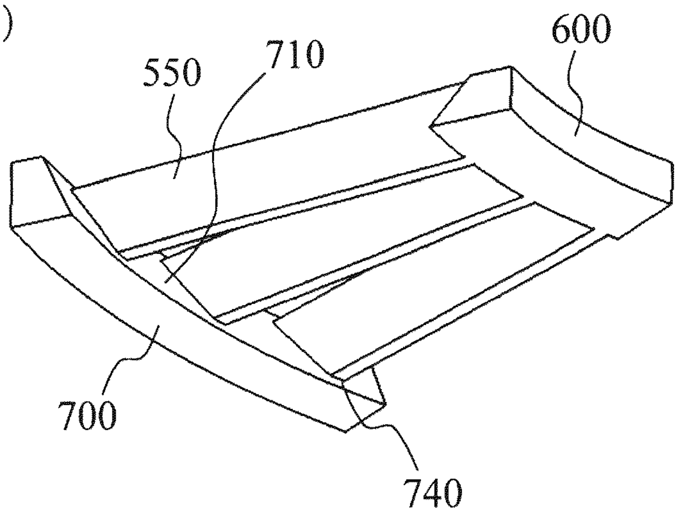


FIG. 12

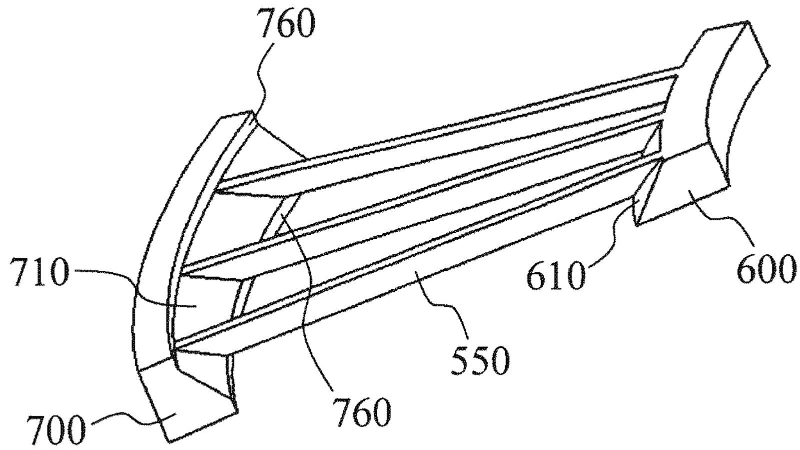


FIG. 13

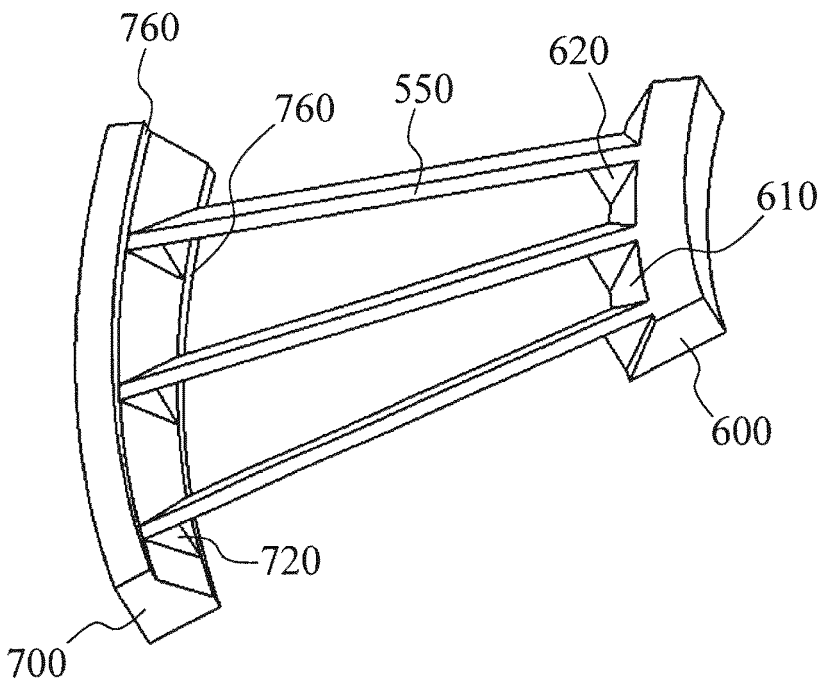


FIG. 14

(a)

(b)

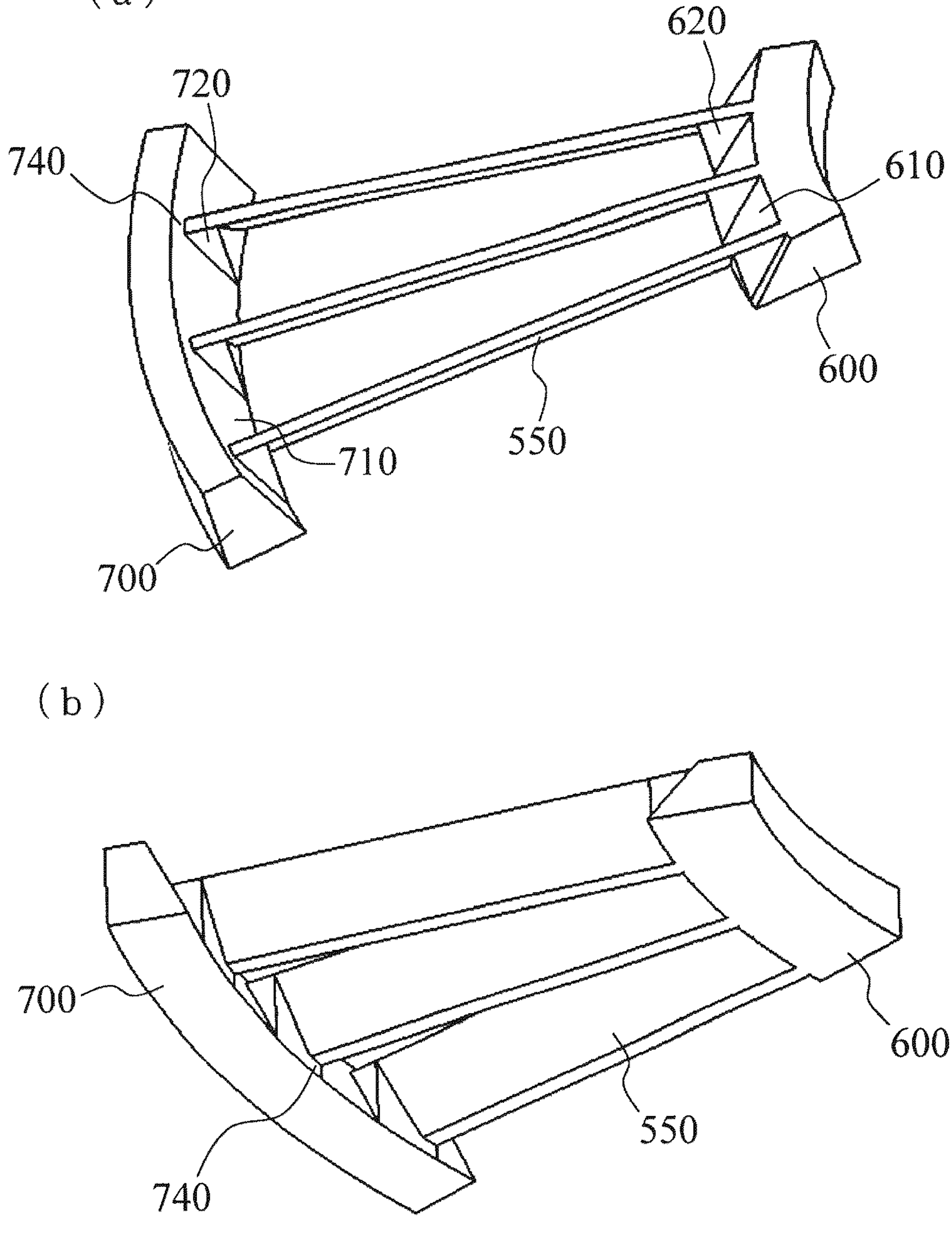


FIG. 15

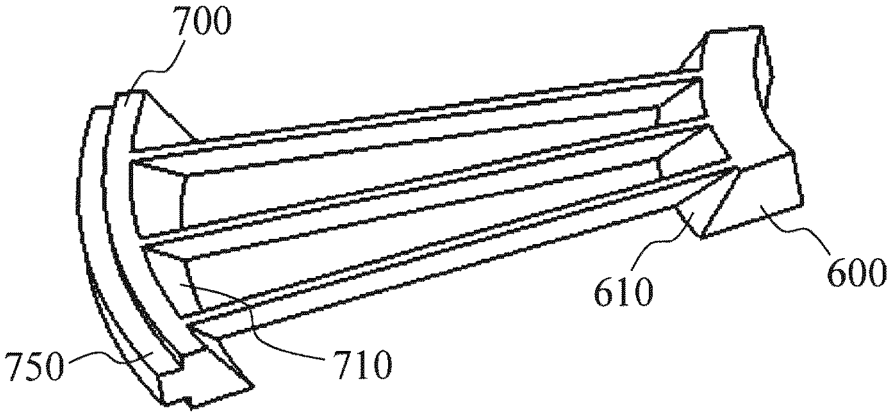


FIG. 16

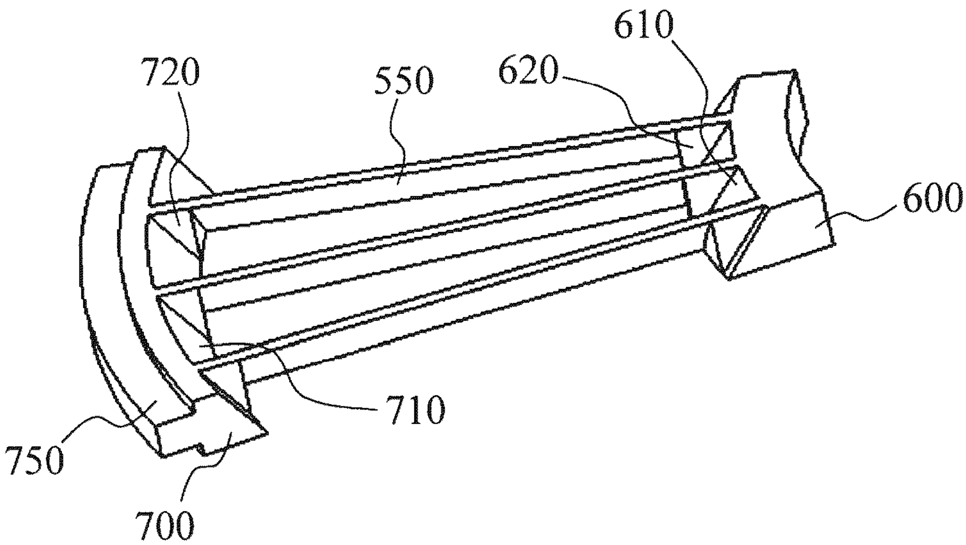


FIG. 17

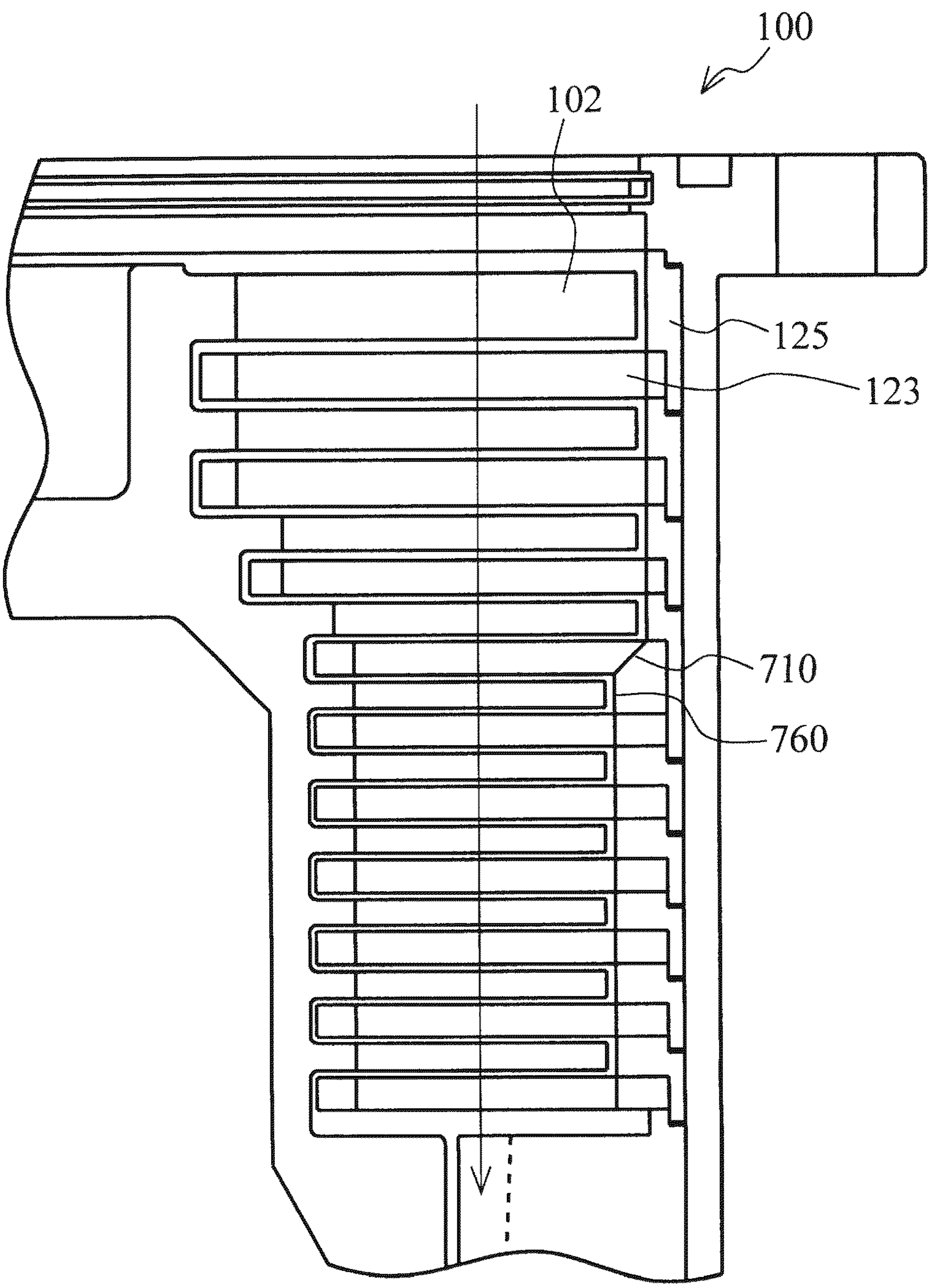


FIG. 18

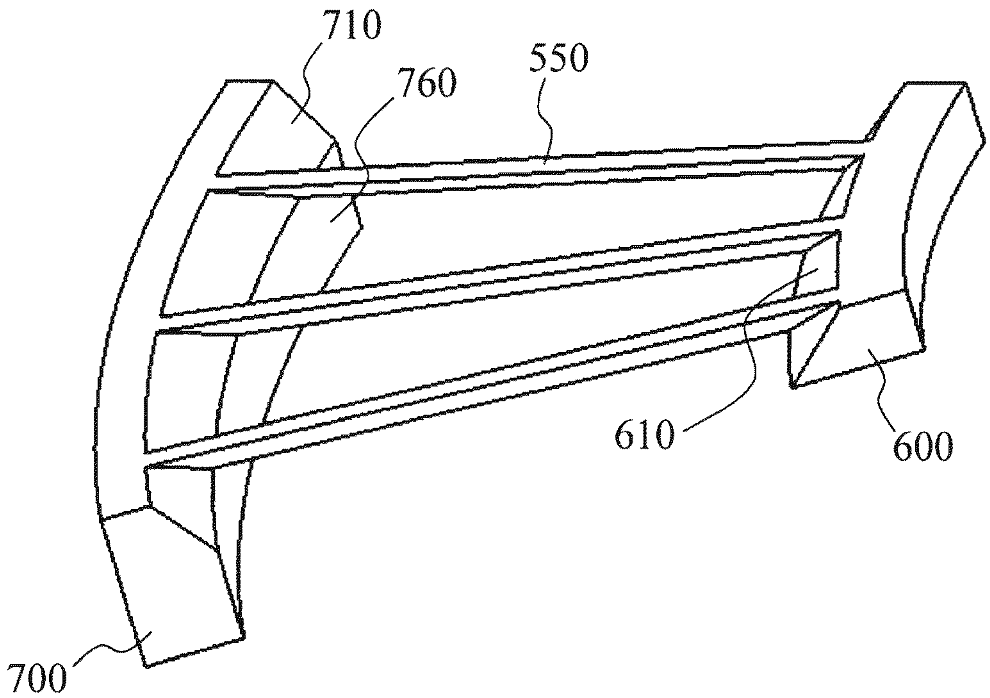


FIG. 19

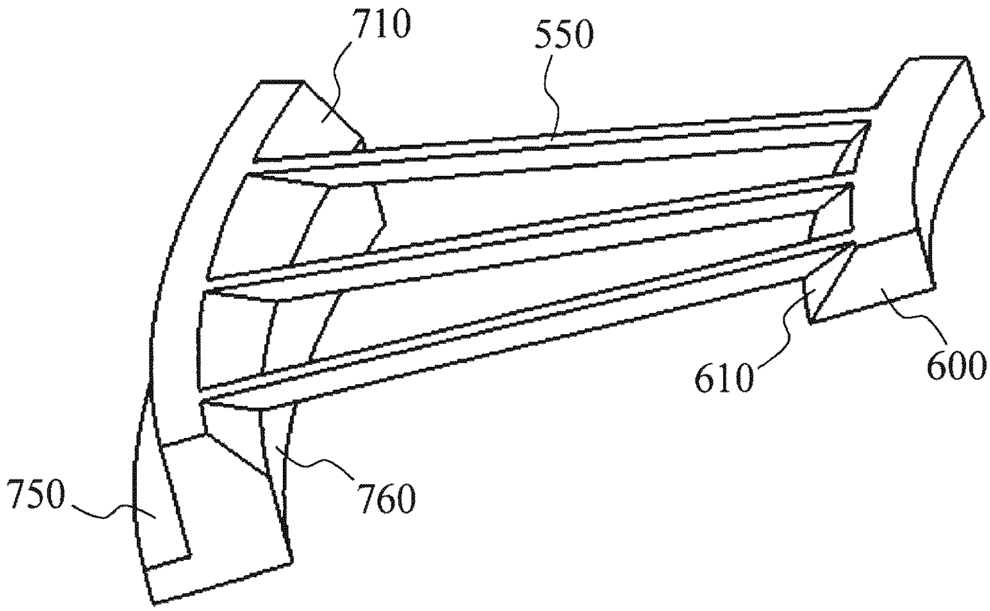


FIG. 20

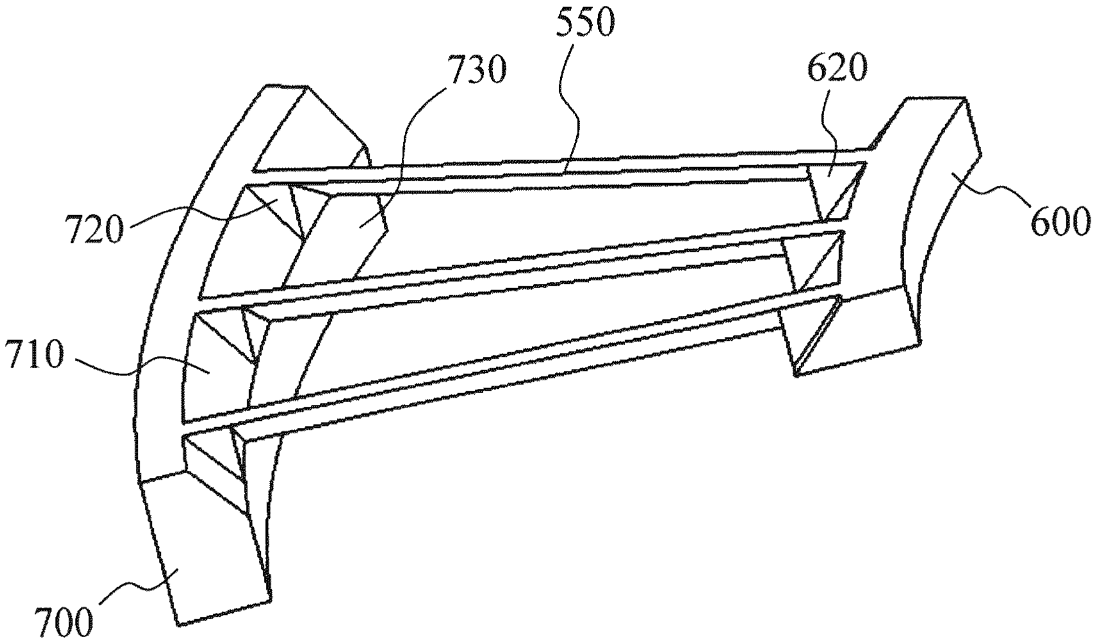


FIG. 21

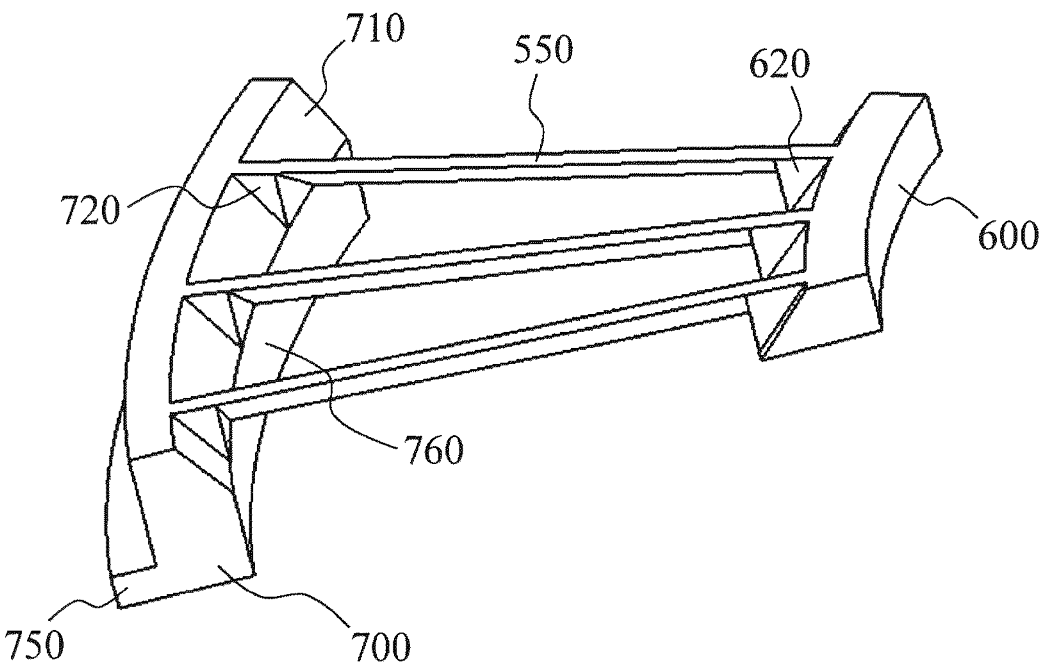


FIG. 22

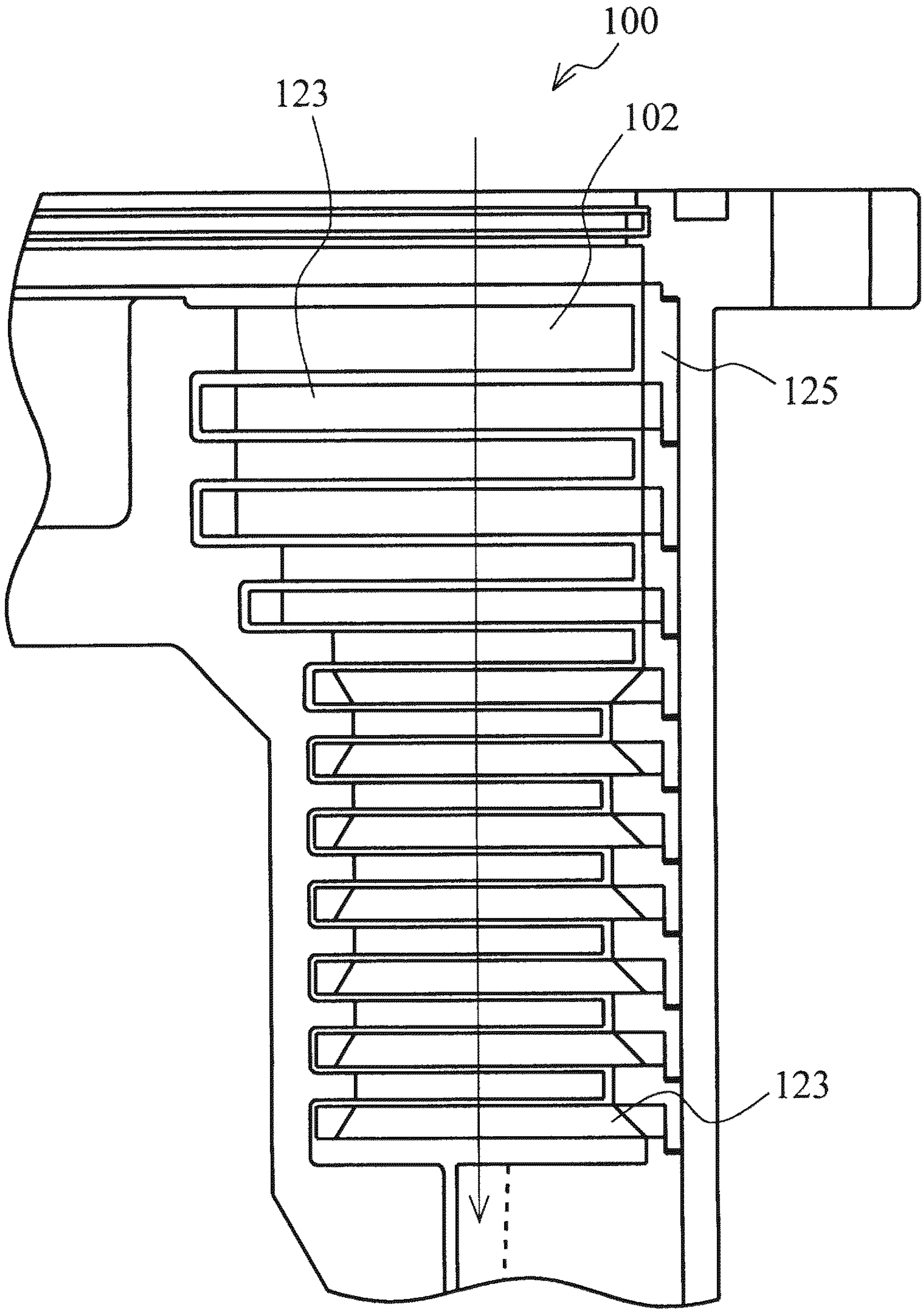


FIG. 23

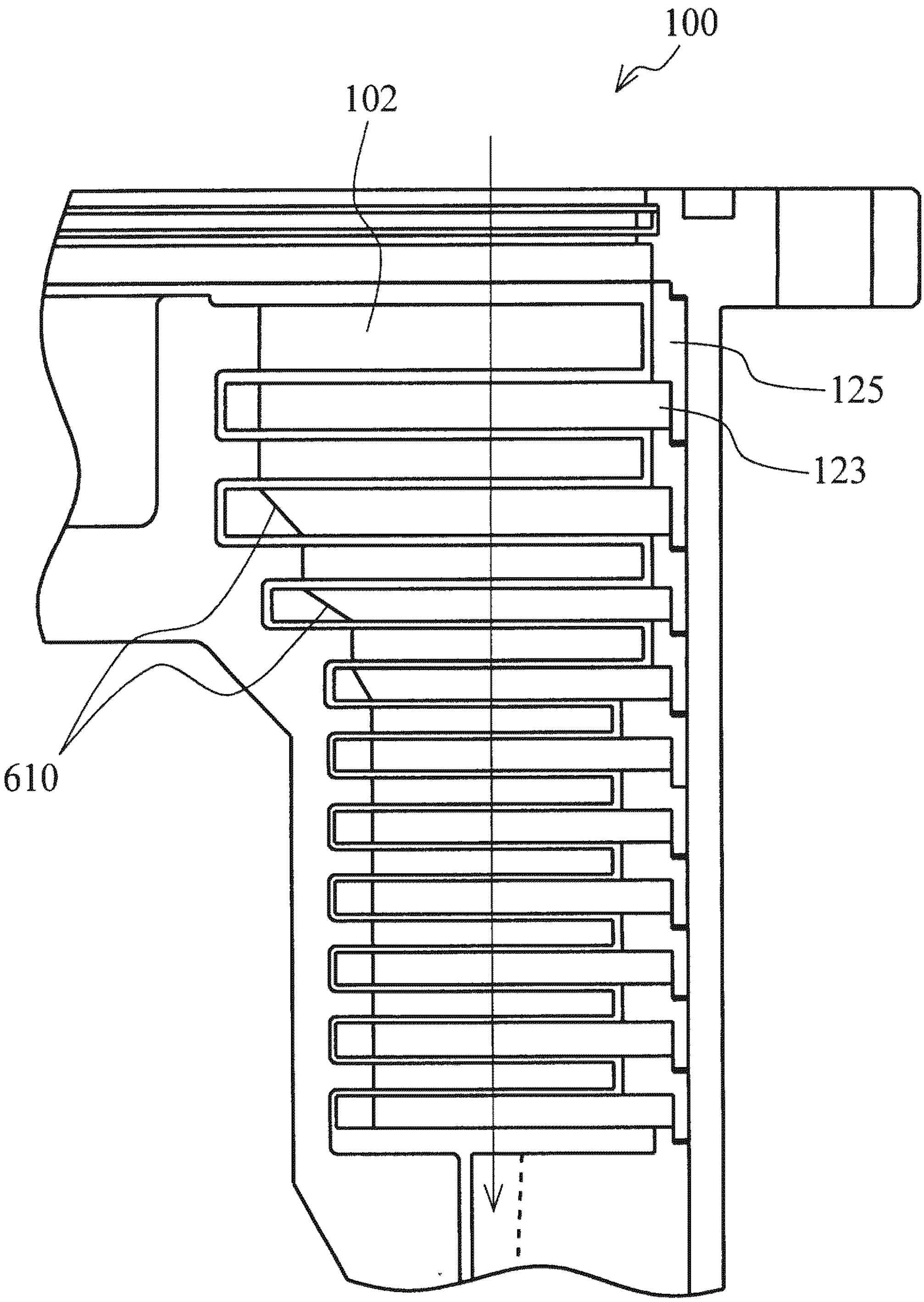


FIG. 24

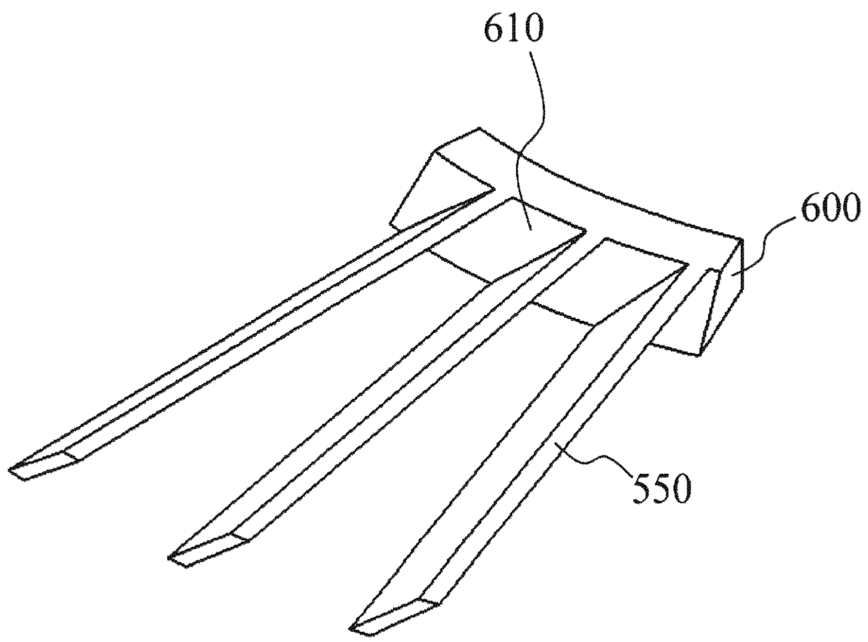


FIG. 25

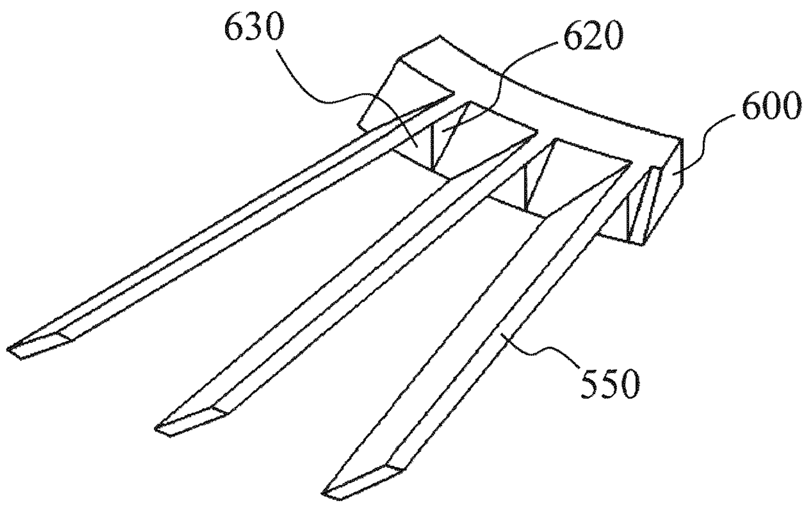


FIG. 26

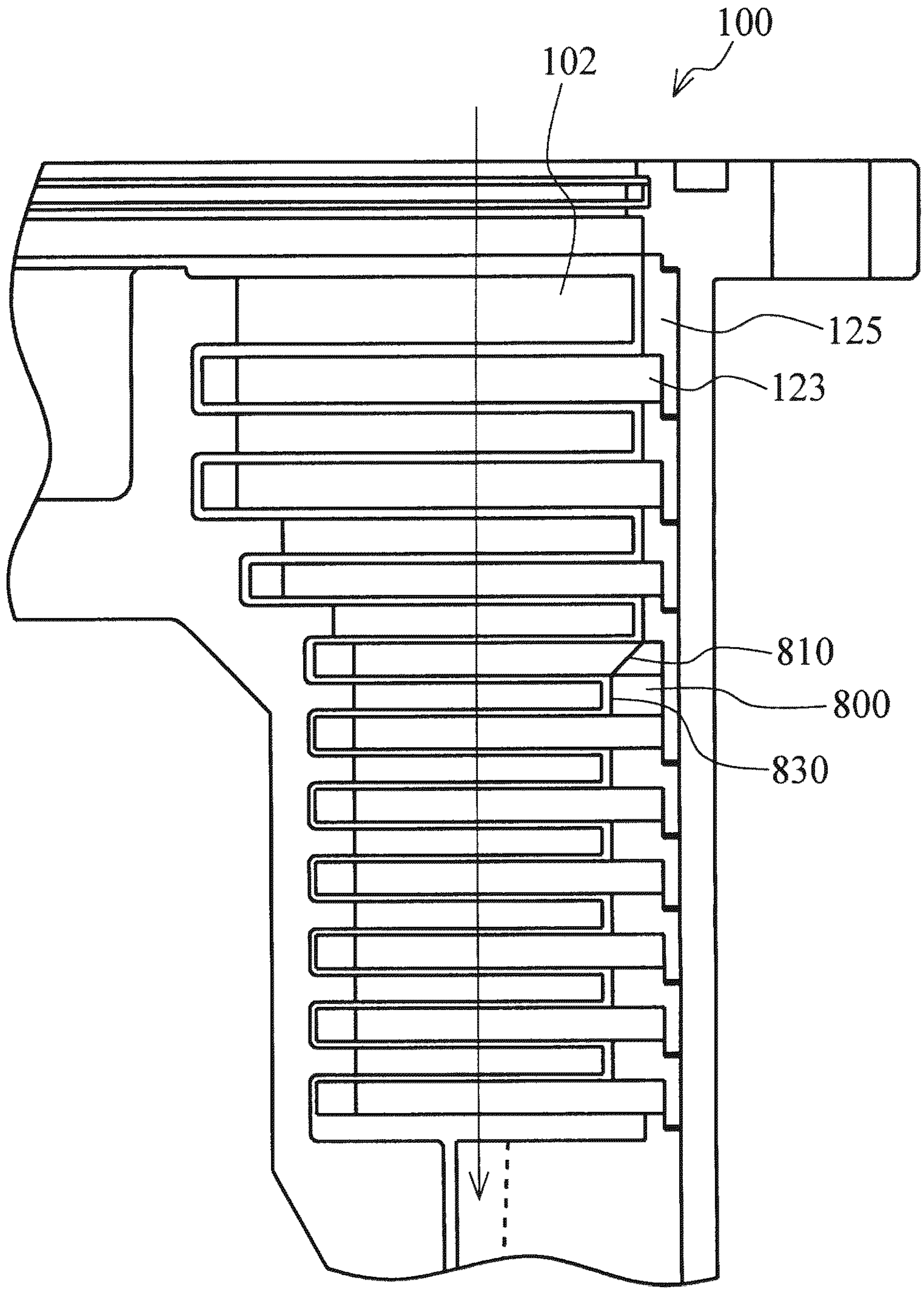


FIG. 27

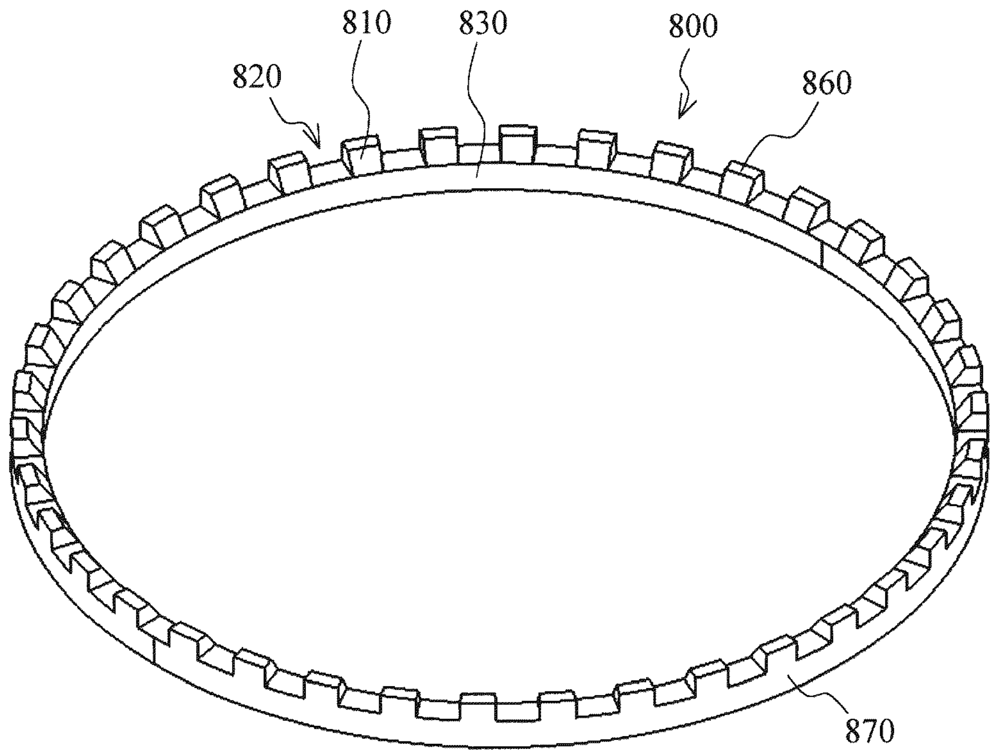


FIG. 28

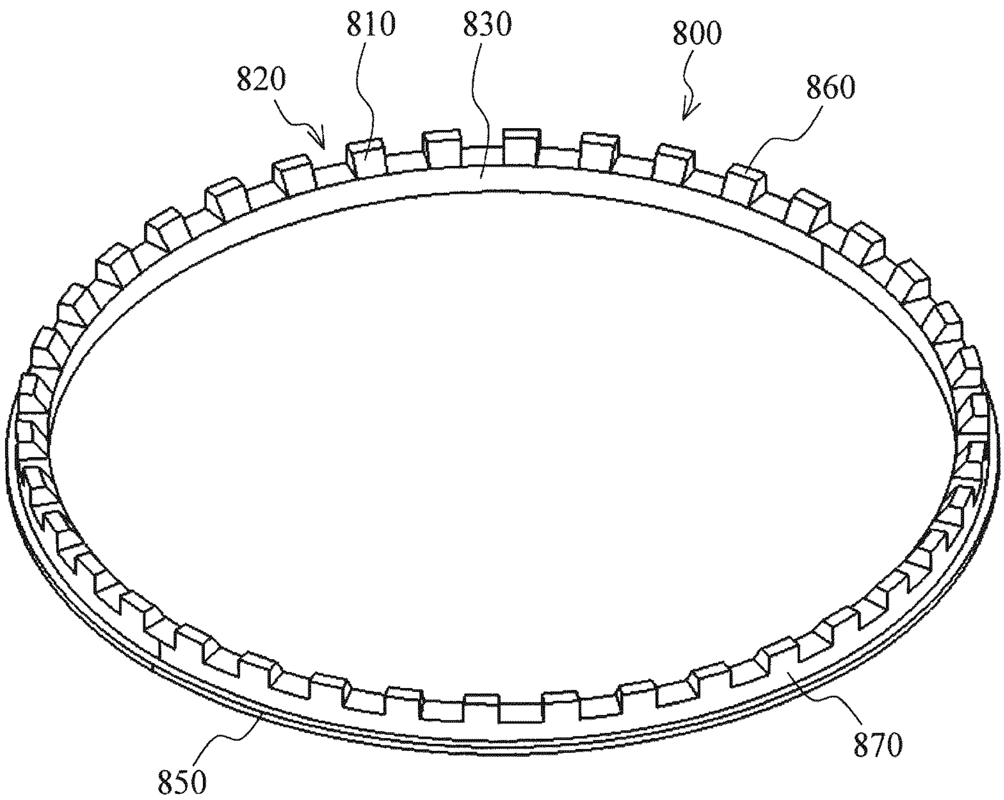


FIG. 29

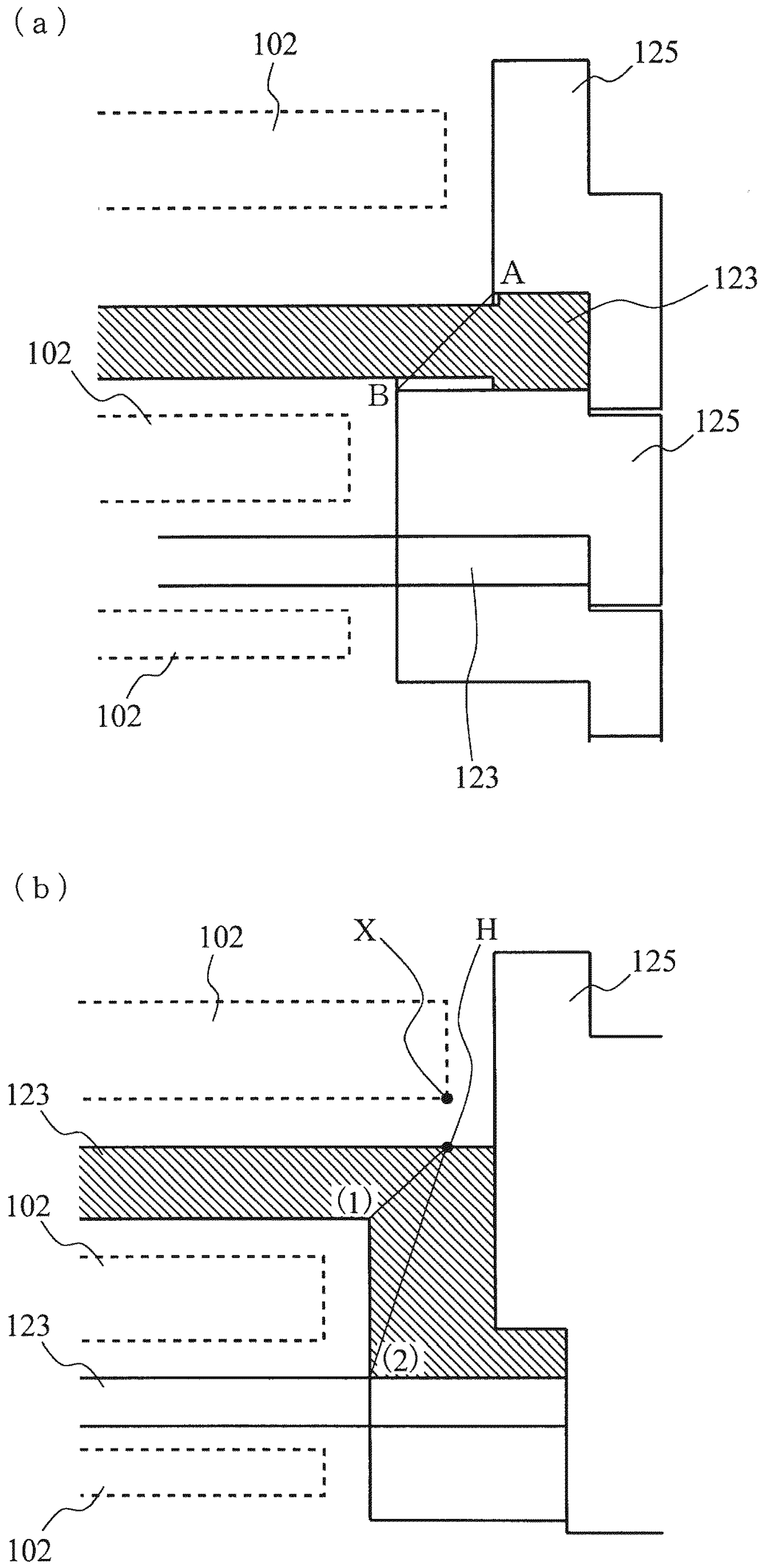


FIG. 30

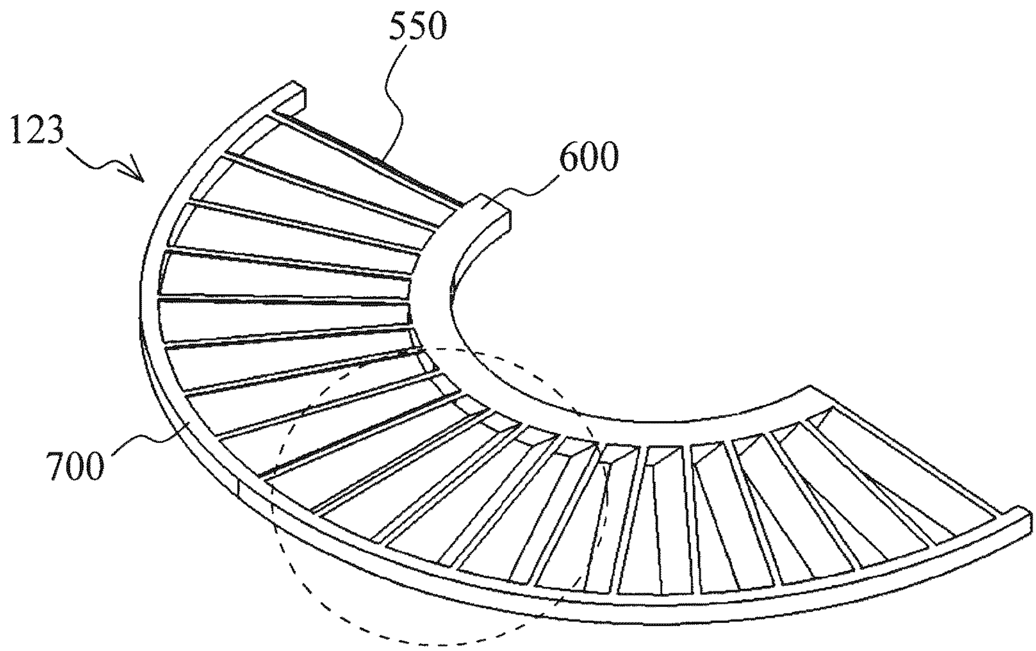


FIG. 31

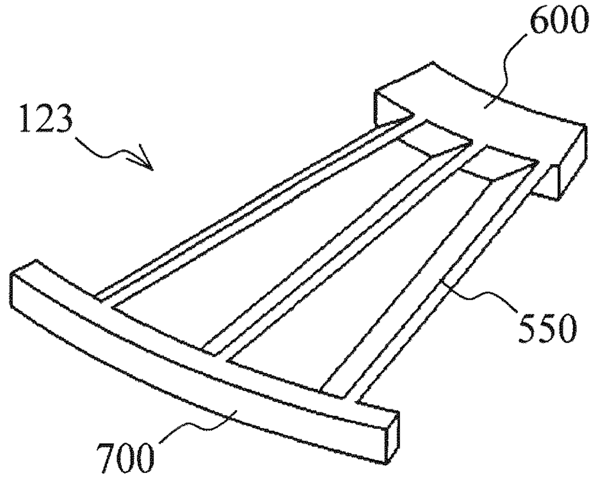


FIG. 32

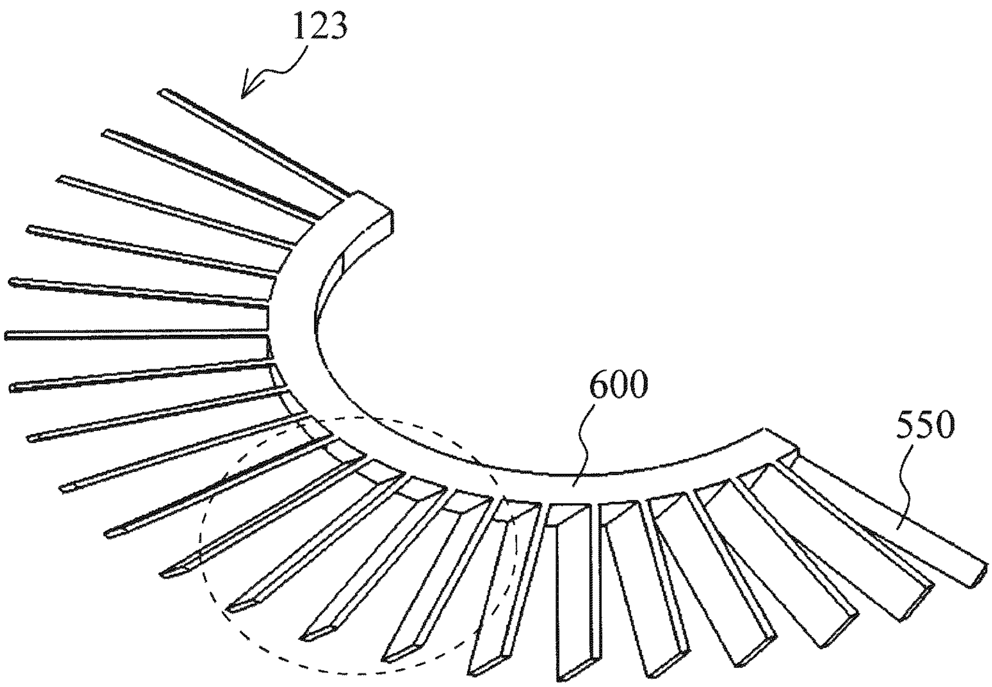


FIG. 33

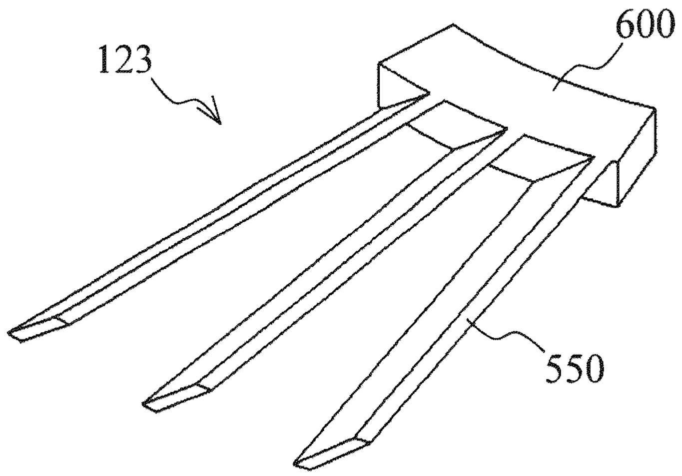


FIG. 34

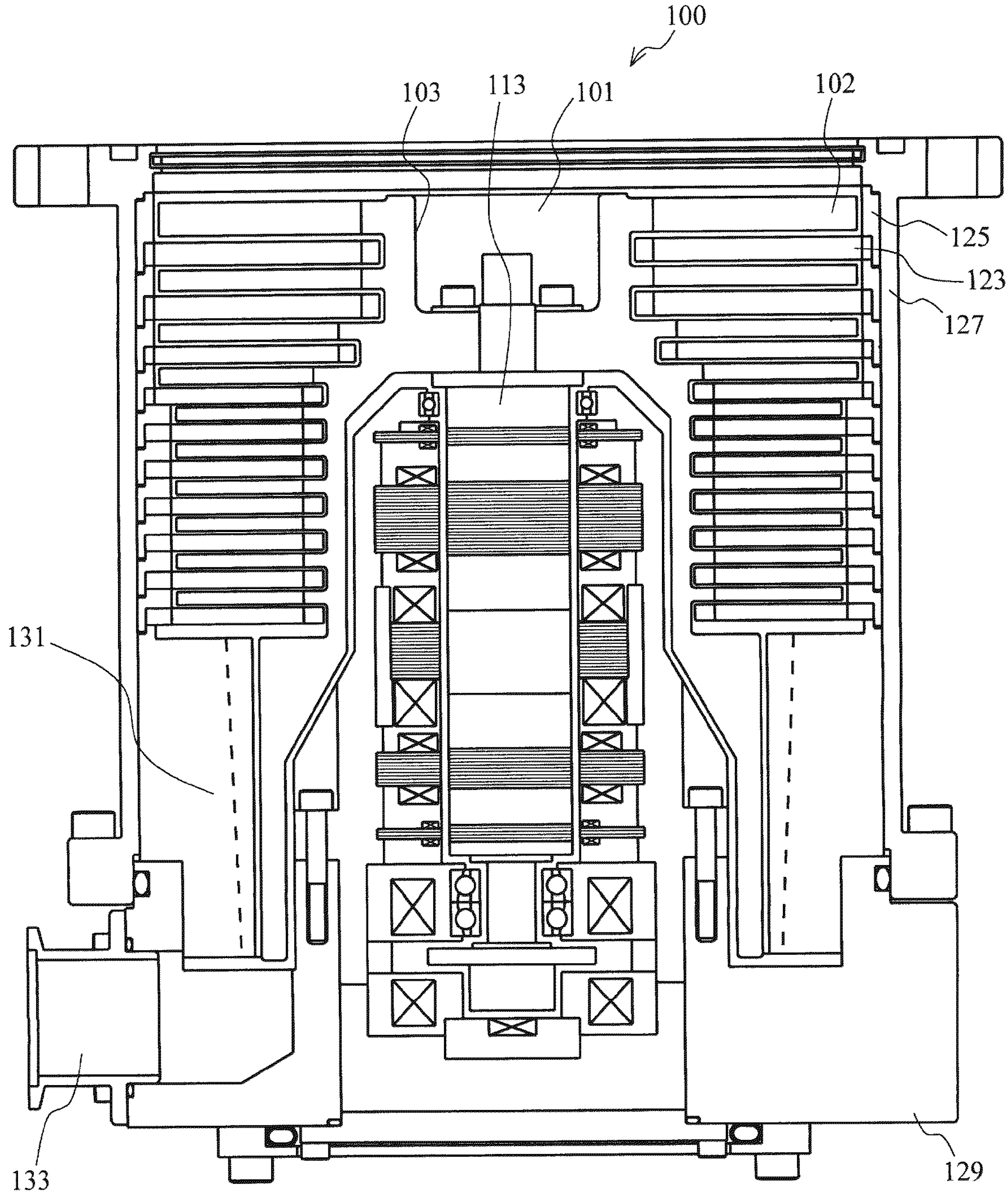
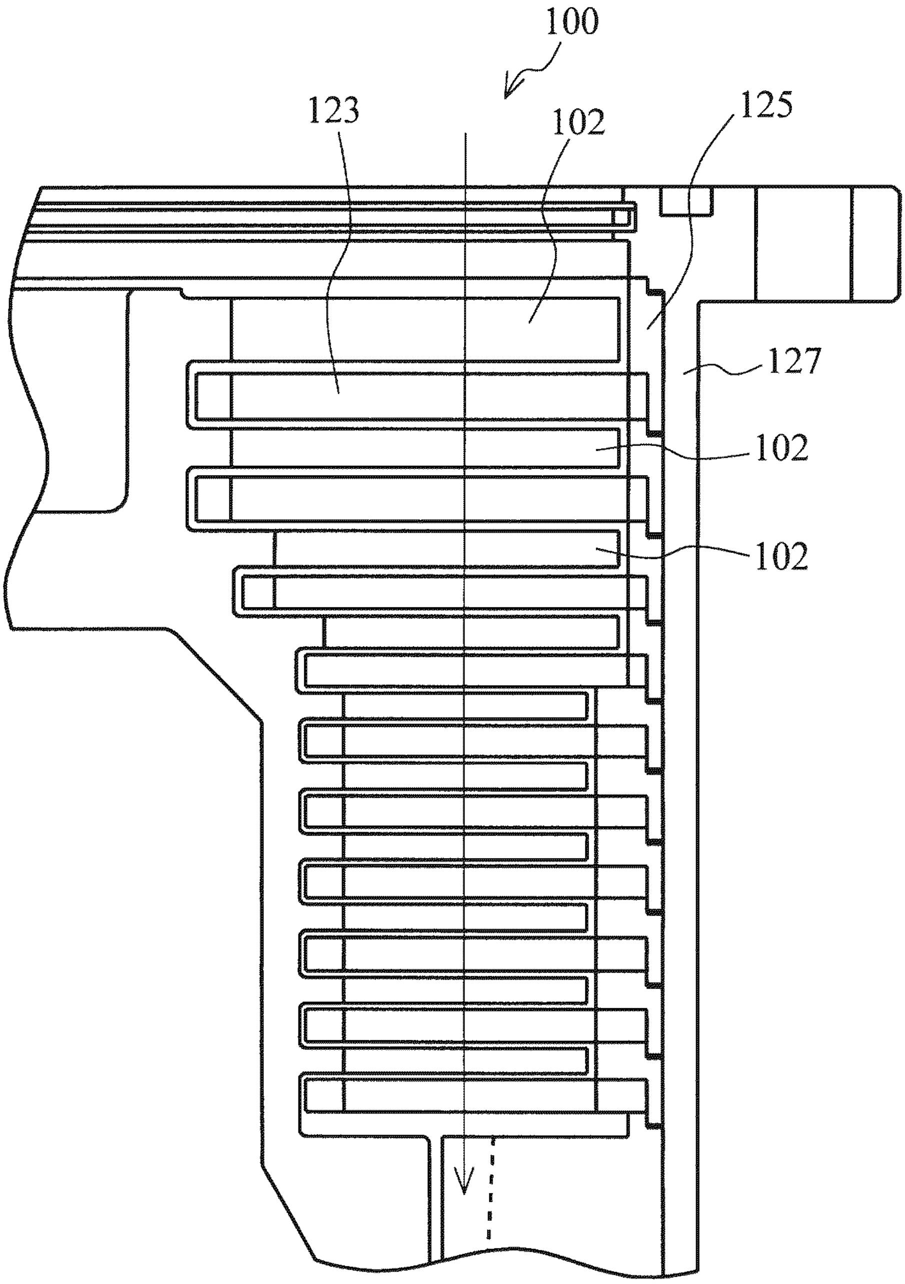


FIG. 35



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/028253

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. F04D19/04(2006.01)i
FI: F04D19/04D

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. F04D19/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2003-506630 A (LEYBOLD VAKUUM GMBH) 18 February 2003 (2003-02-18), paragraphs [0010]-[0024], fig. 1-10	1-2, 4-5, 7
X A	JP 2019-60241 A (SHIMADZU CORPORATION) 18 April 2019 (2019-04-18), paragraphs [0008]-[0022], [0036], [0037], fig. 1-6, 9	1, 3 6, 8
X	JP 2018-59459 A (EDWARDS KK) 12 April 2018 (2018-04-12), paragraphs [0011]-[0025], fig. 3, 4	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 August 2021	07 September 2021

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/028253

JP 2003-506630 A	18 February 2003	WO 2001/011240 A1 DE 19937392 A1
JP 2019-60241 A	18 April 2019	(Family: none)
JP 2018-59459 A	12 April 2018	US 2020/0025206 A1 paragraphs [0041]-[0081], fig. 3, 4 WO 2018/066471 A1 EP 3524822 A1 KR 10-2019-0057049 A CN 109844321 A

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2007002692 A **[0014]**
- JP 2018035718 A **[0014]**