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Nakamura et al.

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(54) **METHOD AND APPARATUS FOR GENERATING HAPTIC FEEDBACKS FOR ELECTRONIC APPARATUSES**

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G06F 3/041	(2006.01)
H02K 7/06	(2006.01)
H02K 33/00	(2006.01)

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(58) **Field of Classification Search**
None
See application file for complete search history.

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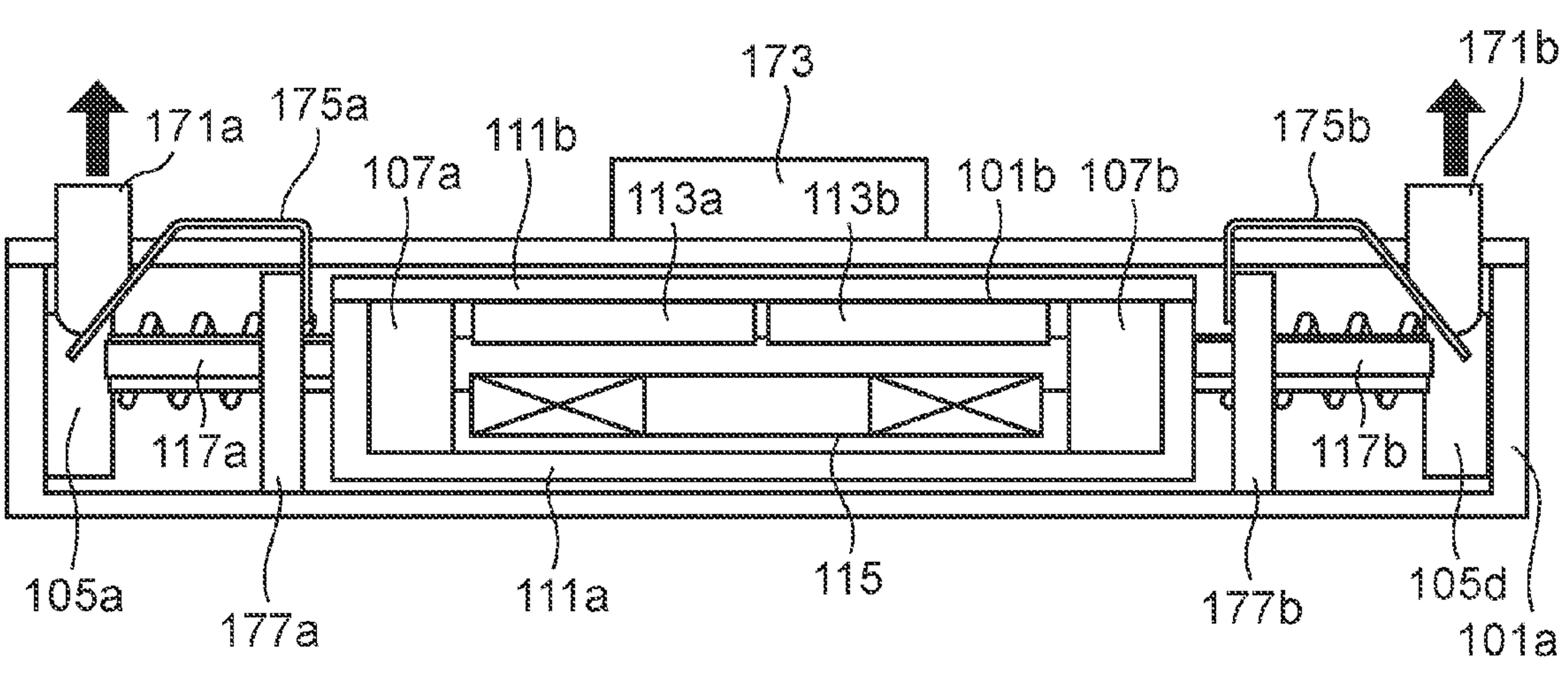
Primary Examiner — Brent Swarthout

(74) *Attorney, Agent, or Firm* — Antony P. Ng; Russell Ng PLLC

(57) **ABSTRACT**

A haptic actuator for generating haptic feedbacks to provide perceptions of different characteristics is provided. The haptic actuator includes a vibration mechanism and a striking mechanism. The vibration mechanism, in response to a receipt of a predetermined electric power, applies a steady vibration to a vibrating body. The striking mechanism, in response to the receipt of an electric power larger than the predetermined electric power, strikes the vibrating body in order to provide a haptic feedback to the vibrating body. The haptic actuator is able to apply a vibration according to the vibration mechanism and a vibration according to the striking mechanism to the vibrating body.

20 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

H02K 33/02	(2006.01)
G06F 3/0488	(2013.01)

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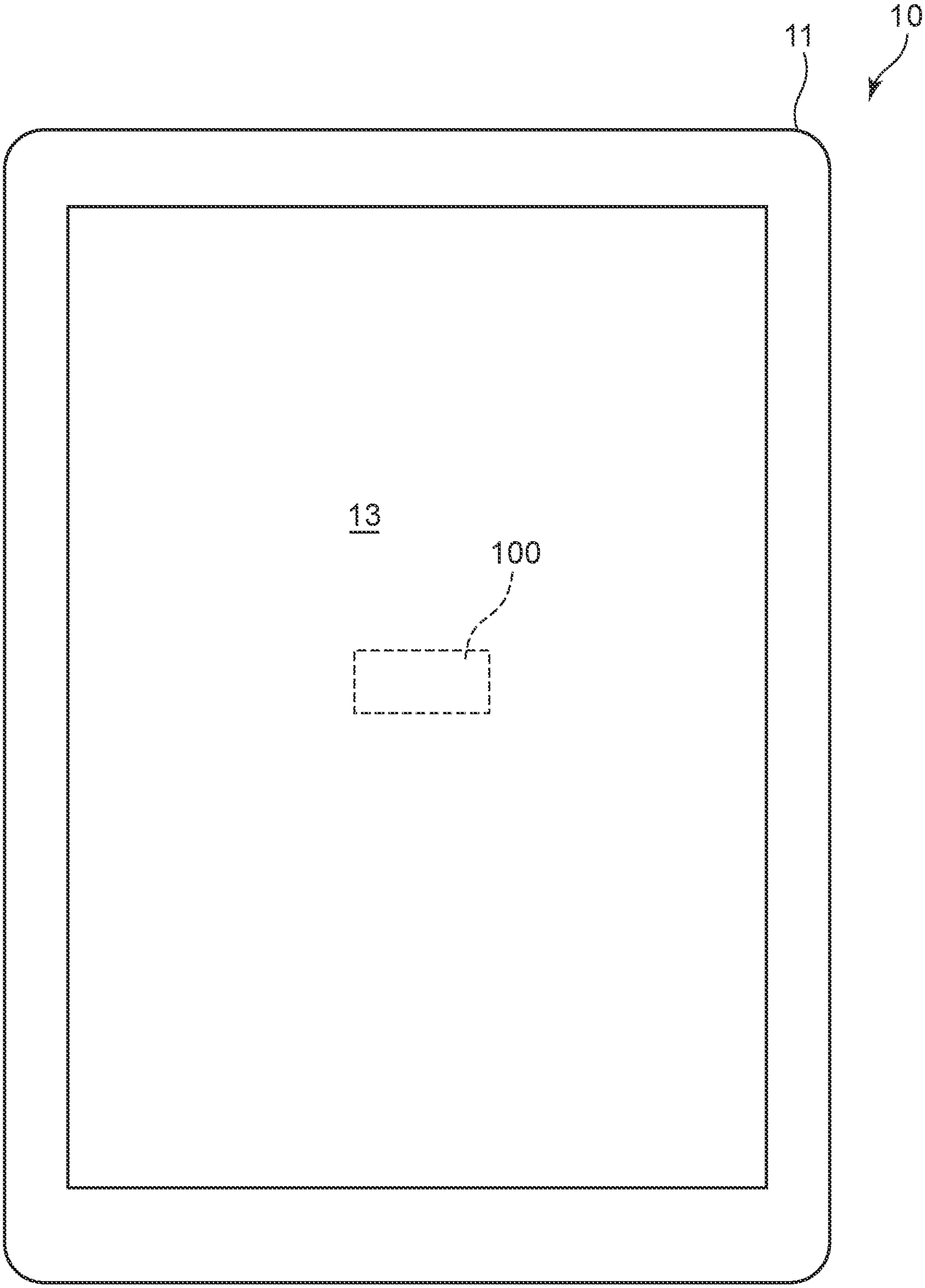

FIG. 1

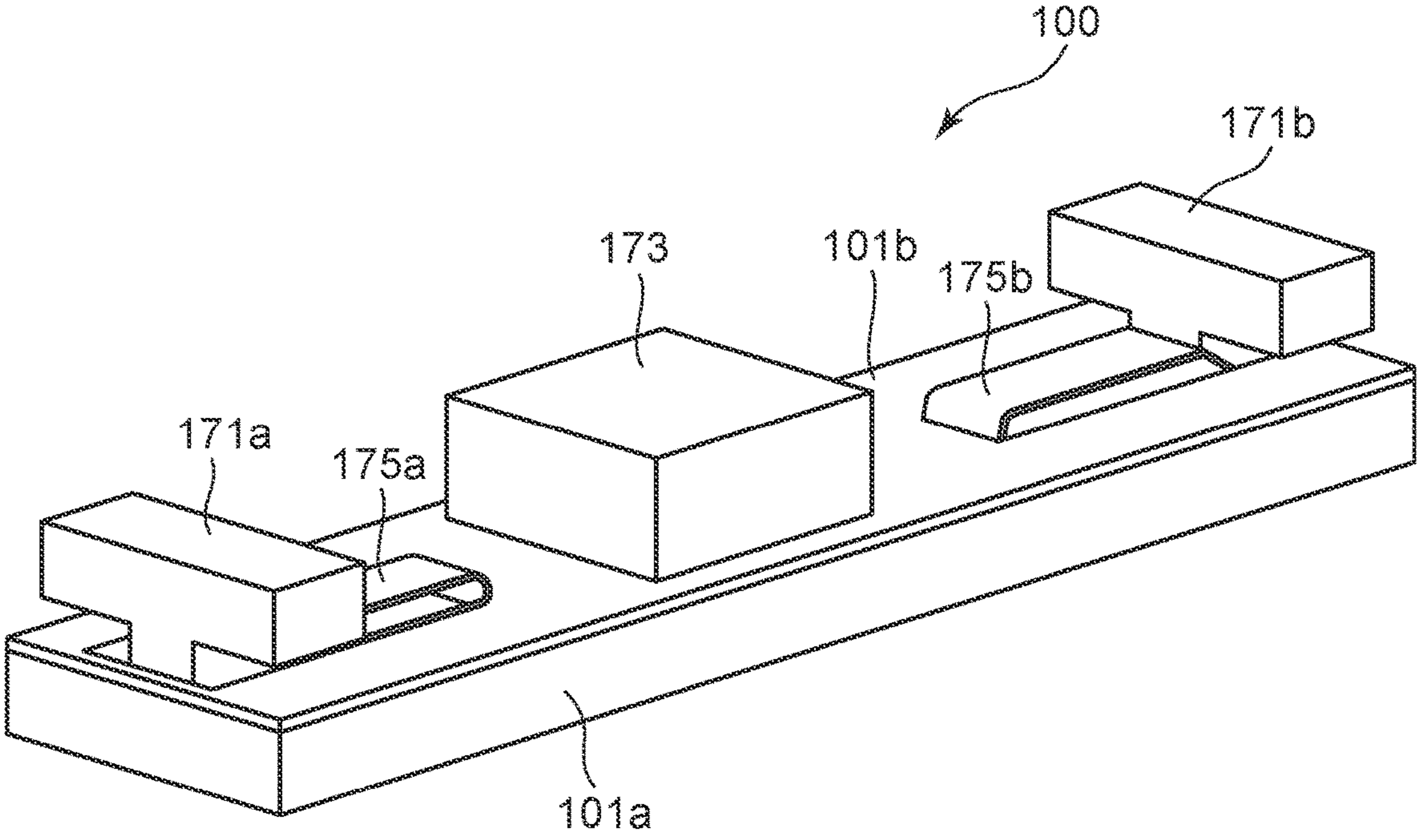

FIG. 2

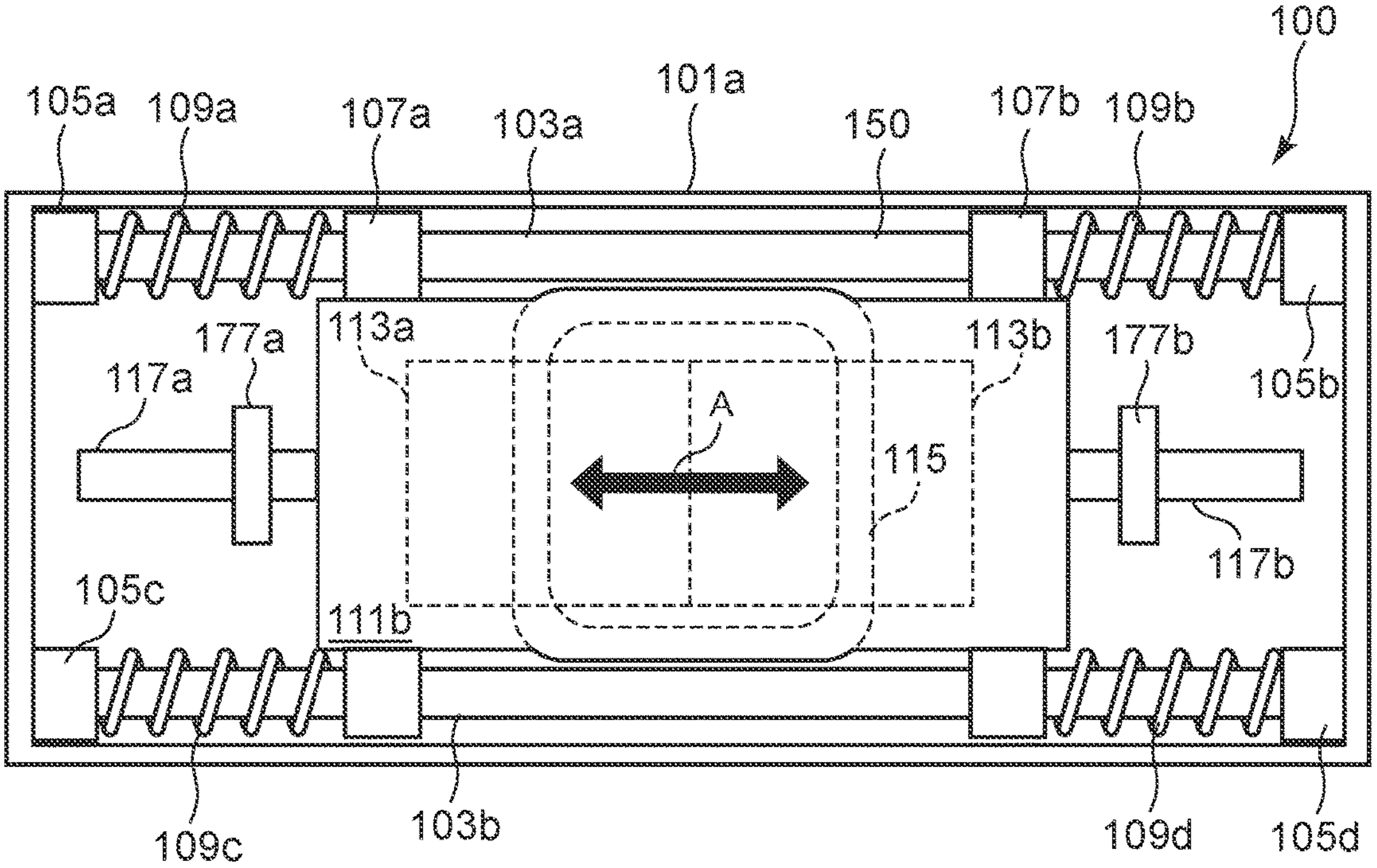
100
105a
109a
107a
103a
101a
150
107b
109b
113a
177a
117a
113b
177b
105b
A
115
117b
105c
111b
109c
103b
109d
105d

FIG. 3A

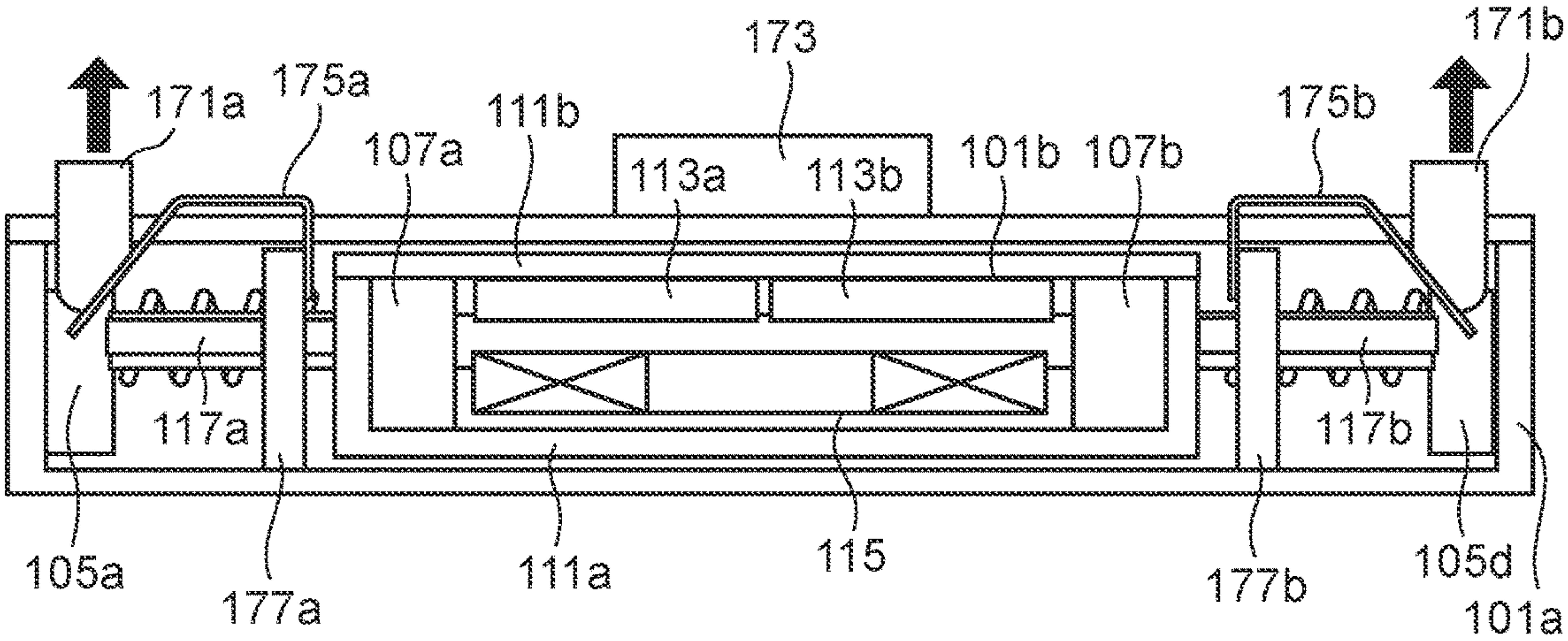
173
171b
171a
175a
111b
175b
107a
113a
113b
101b
107b
117a
117b
105a
177a
111a
115
177b
105d
101a

FIG. 3B

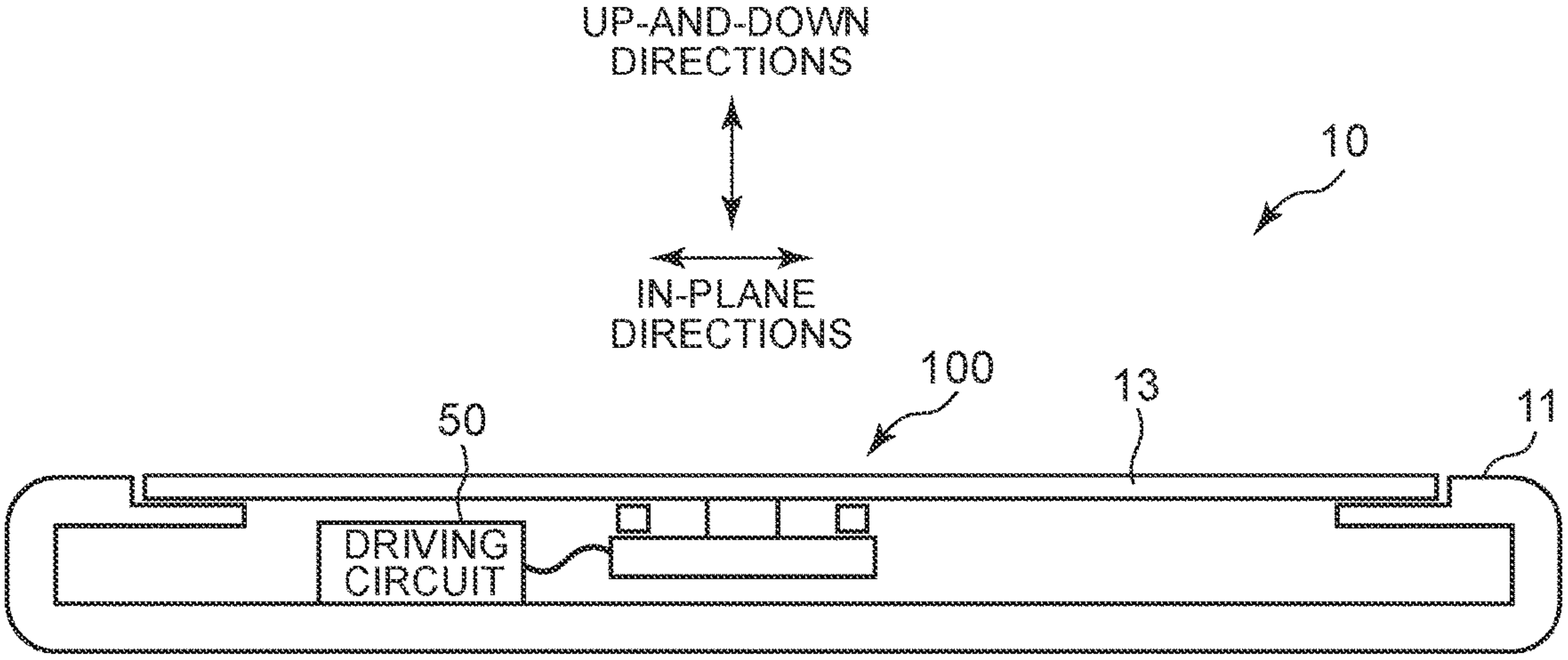

FIG. 4A

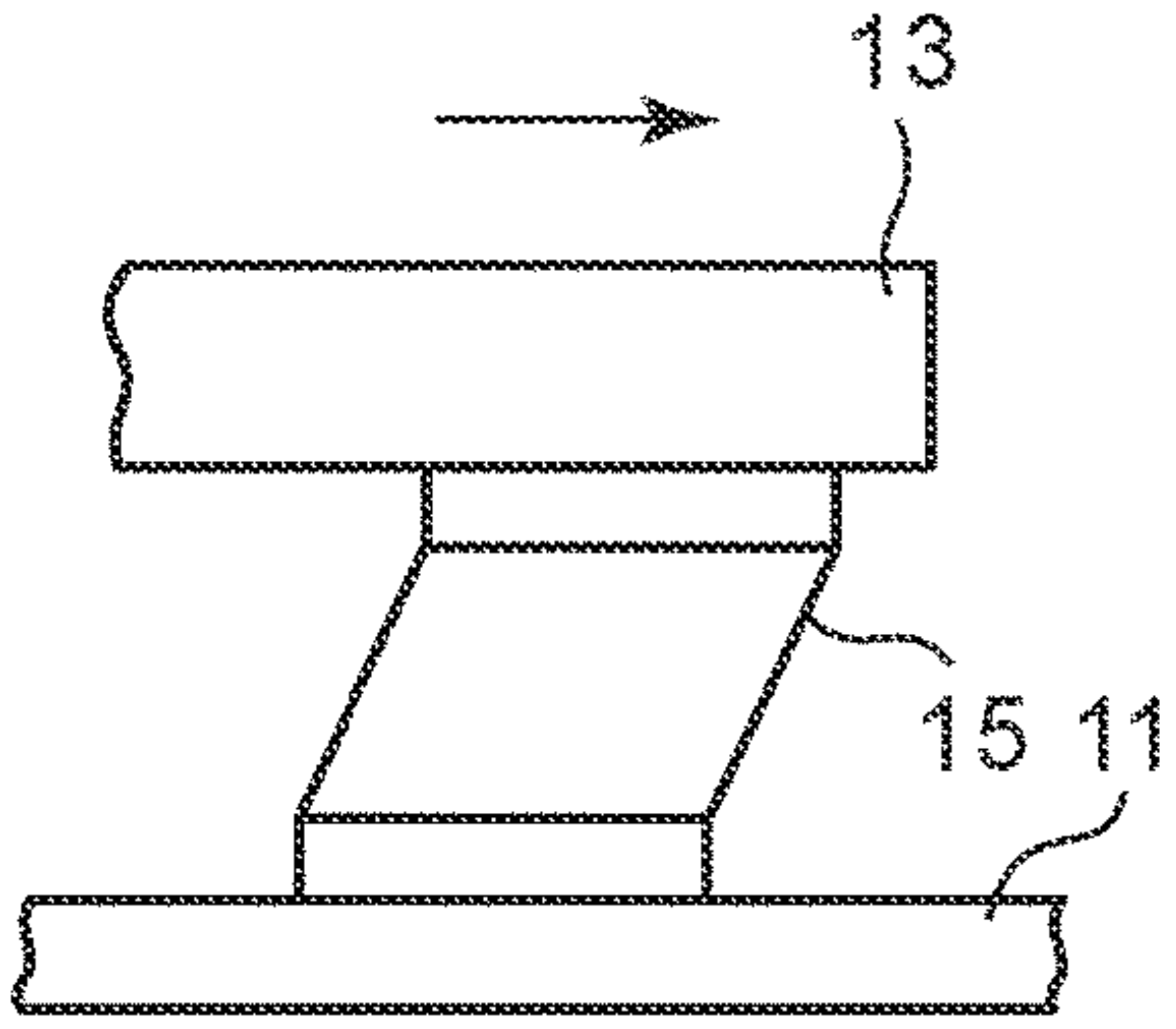

FIG. 4B

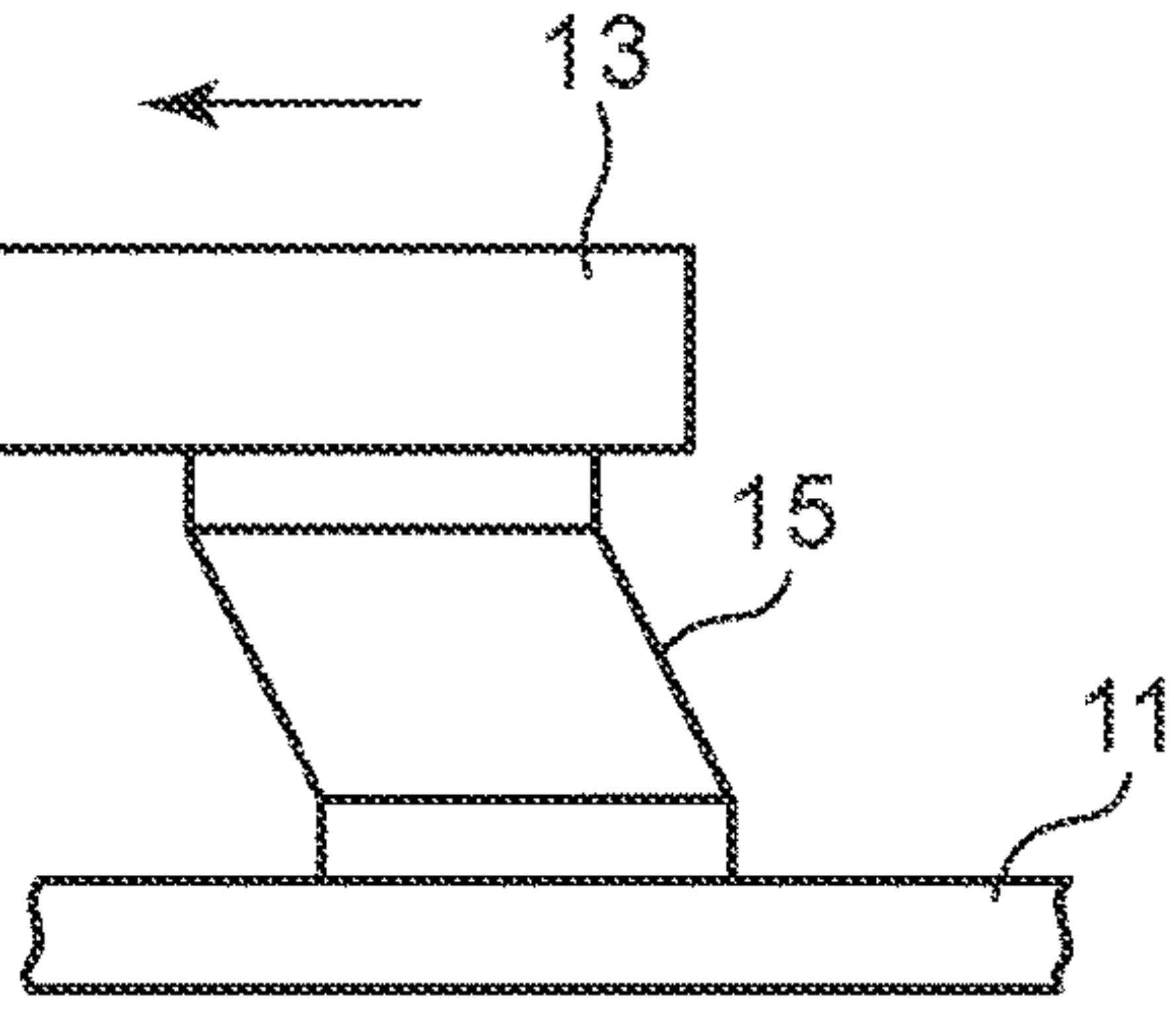

FIG. 4C

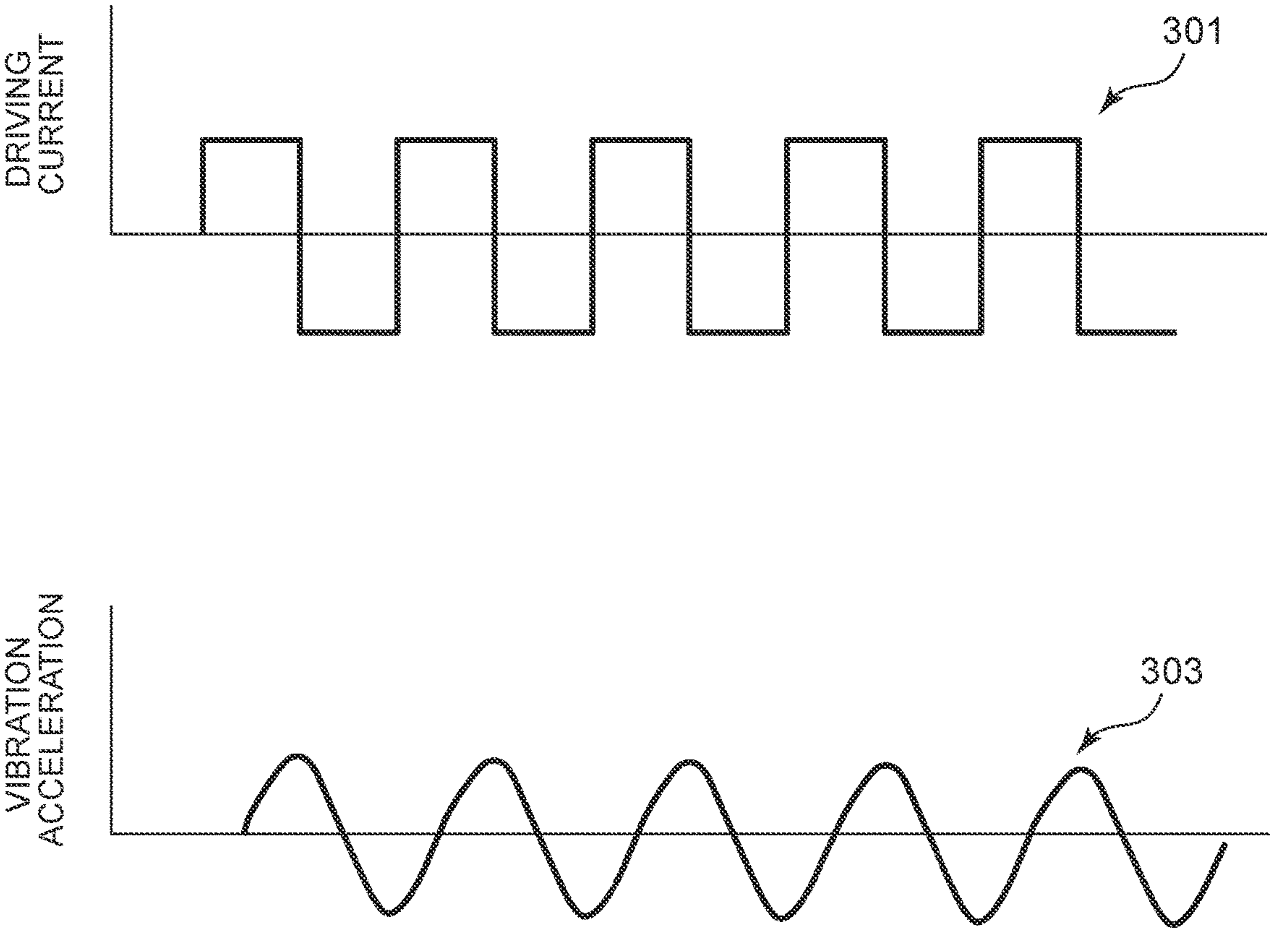

FIG. 5

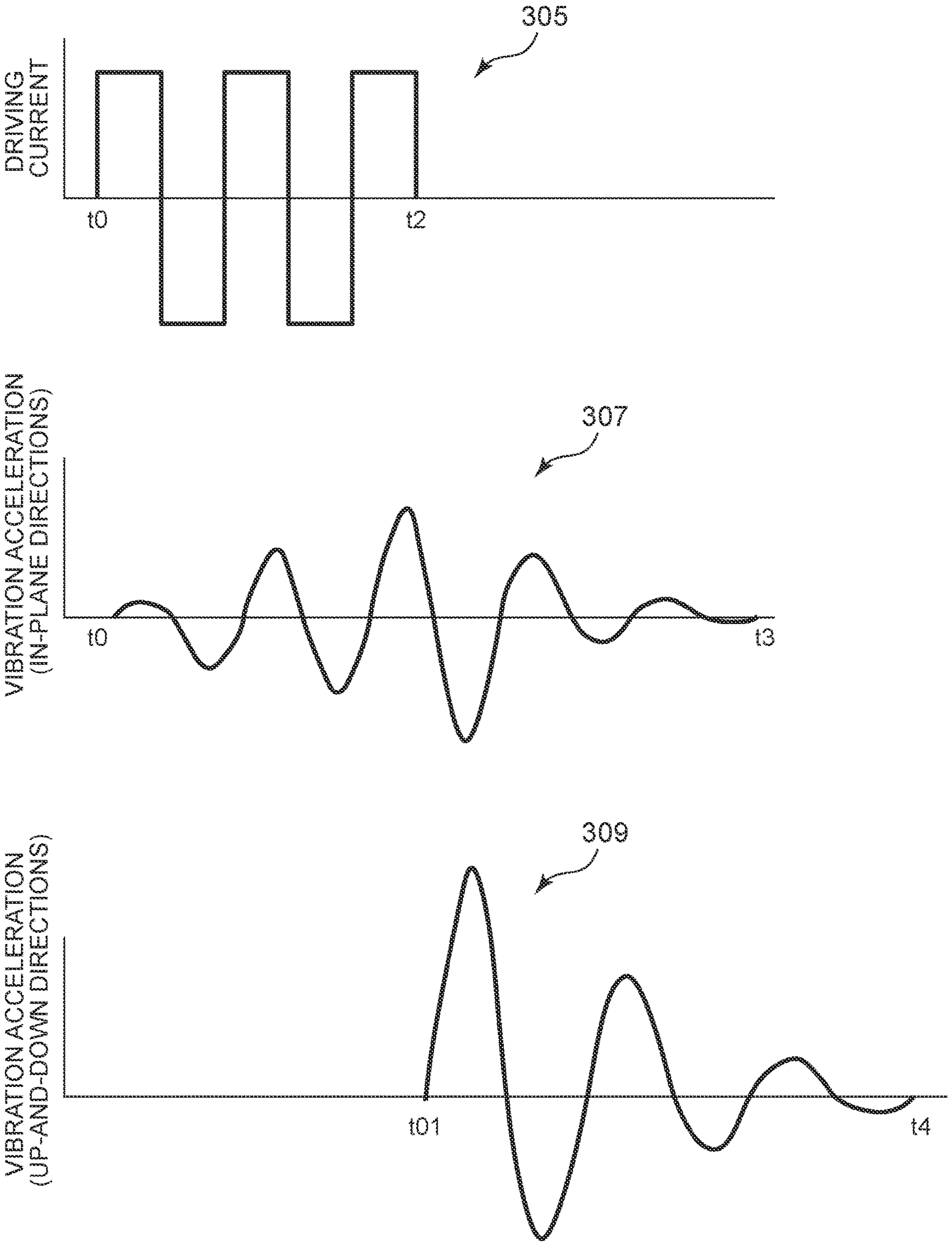
305
DRIVING CURRENT
t0
t2
307
VIBRATION ACCELERATION (IN-PLANE DIRECTIONS)
t0
t3
309
VIBRATION ACCELERATION (UP-AND-DOWN DIRECTIONS)
t01
t4

FIG. 6

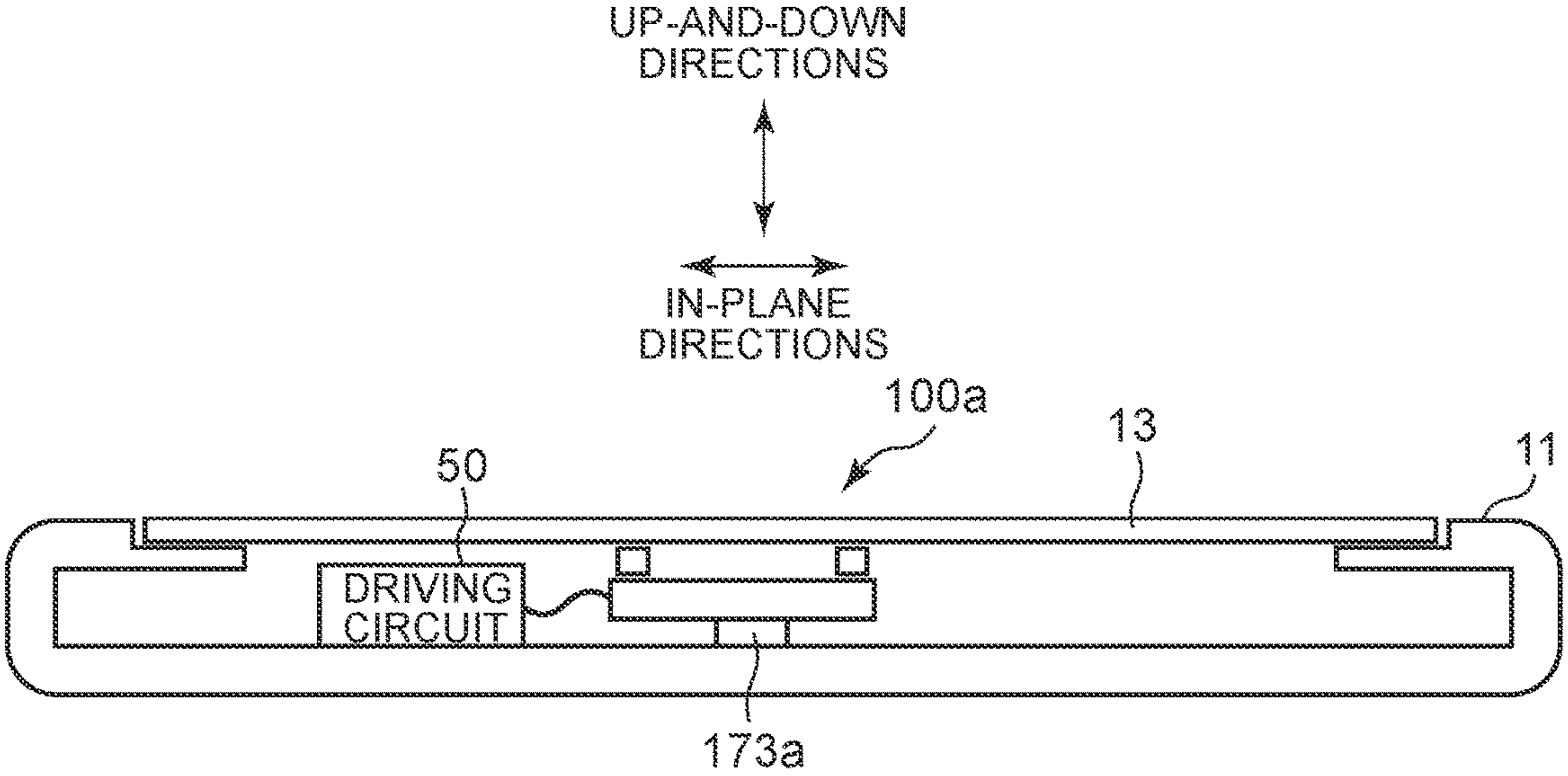
UP-AND-DOWN DIRECTIONS
IN-PLANE DIRECTIONS
100a
13
11
50
DRIVING CIRCUIT
173a

FIG. 7

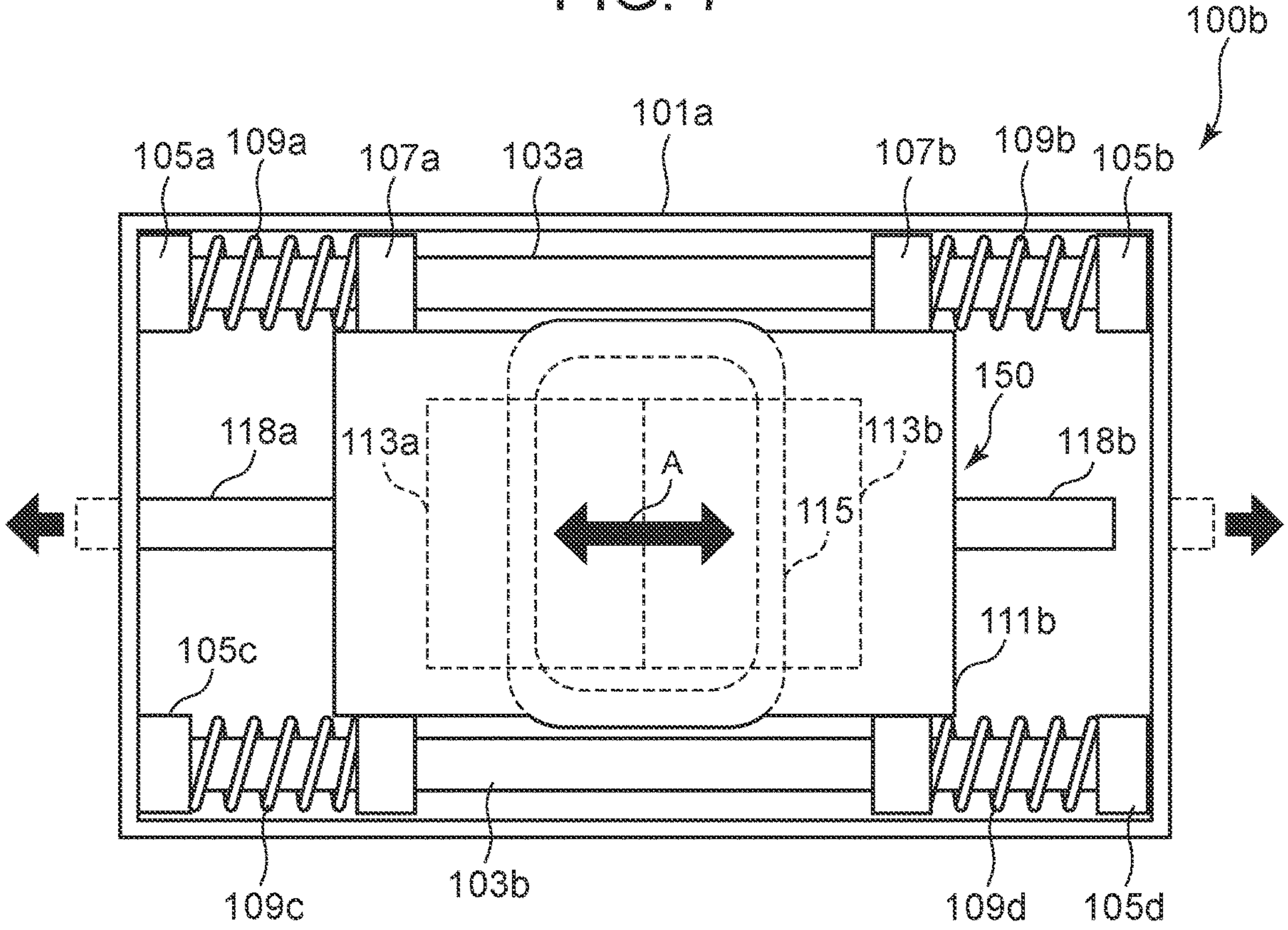
100b
101a
105a
109a
107a
103a
107b
109b
105b
150
118a
113a
A
113b
118b
115
105c
111b
109c
103b
109d
105d

FIG. 8

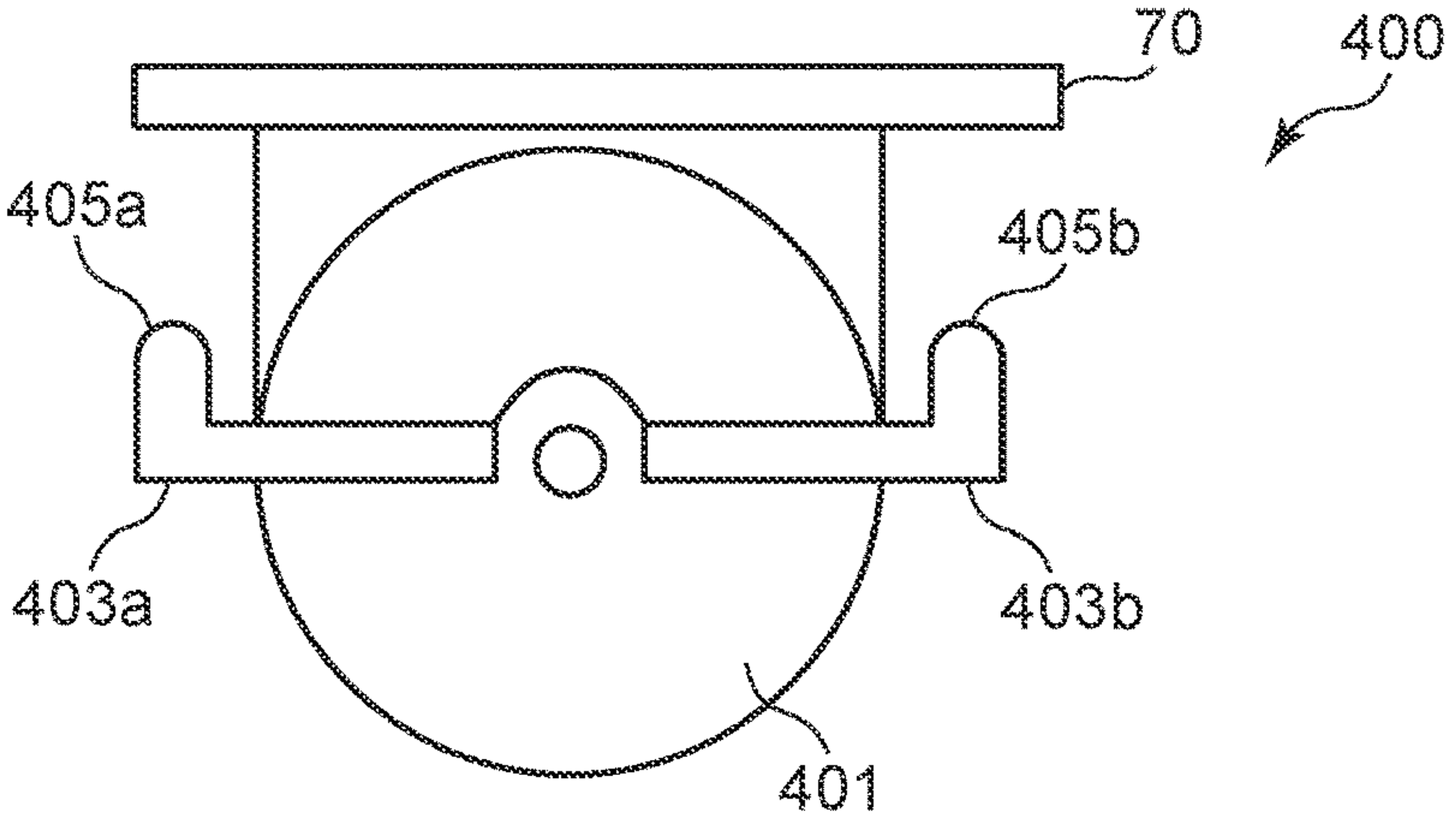

FIG. 9A

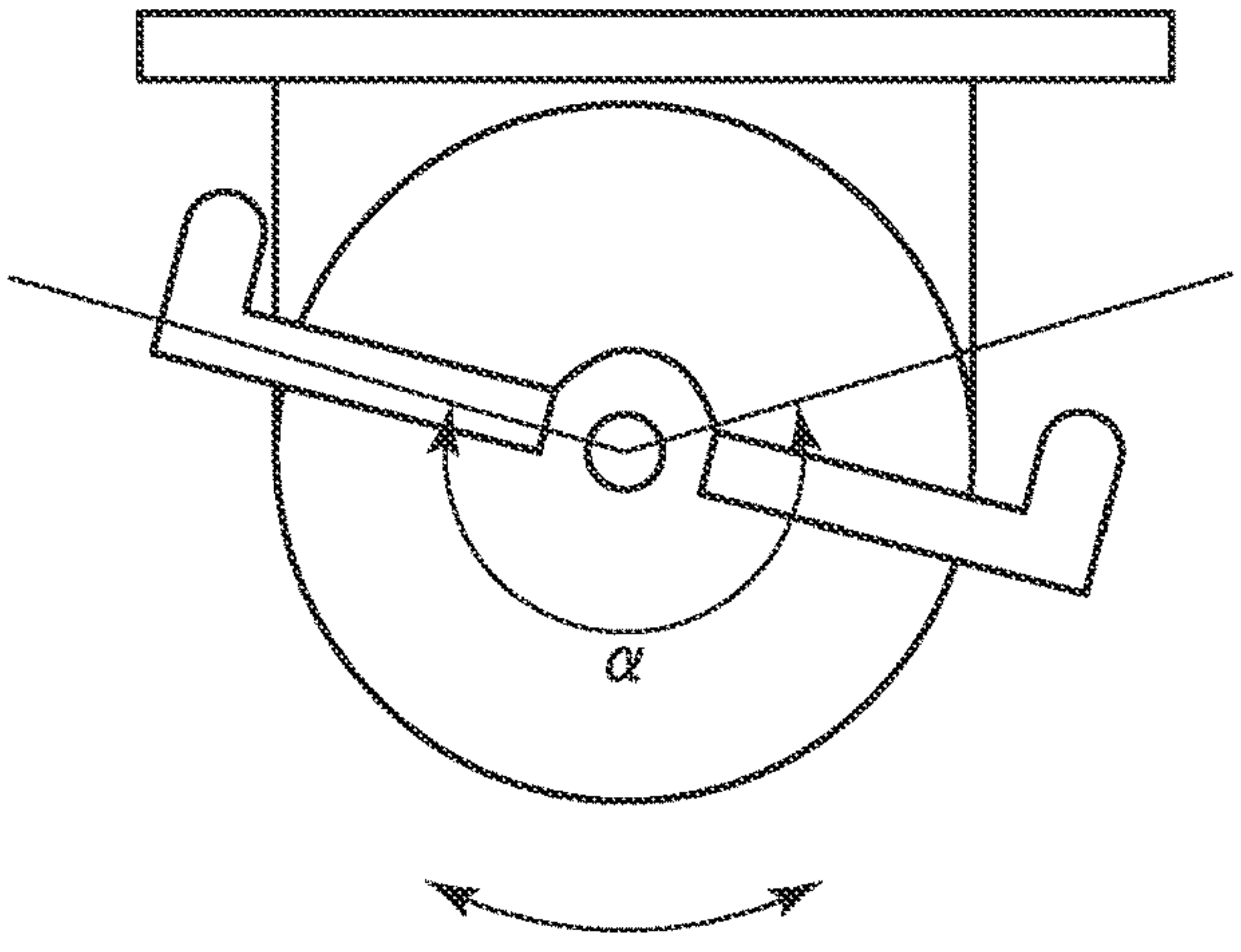

FIG. 9B

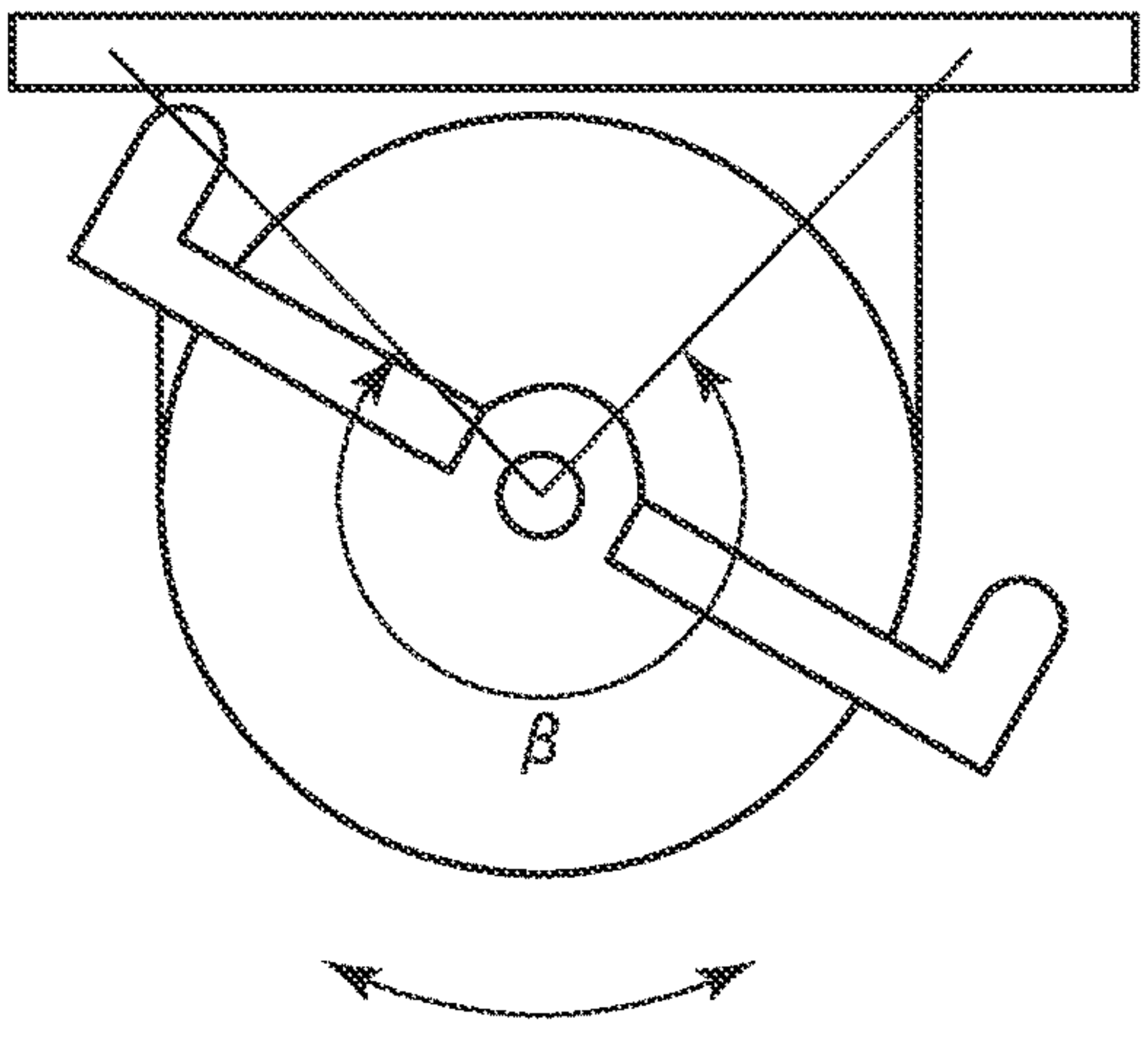

FIG. 9C

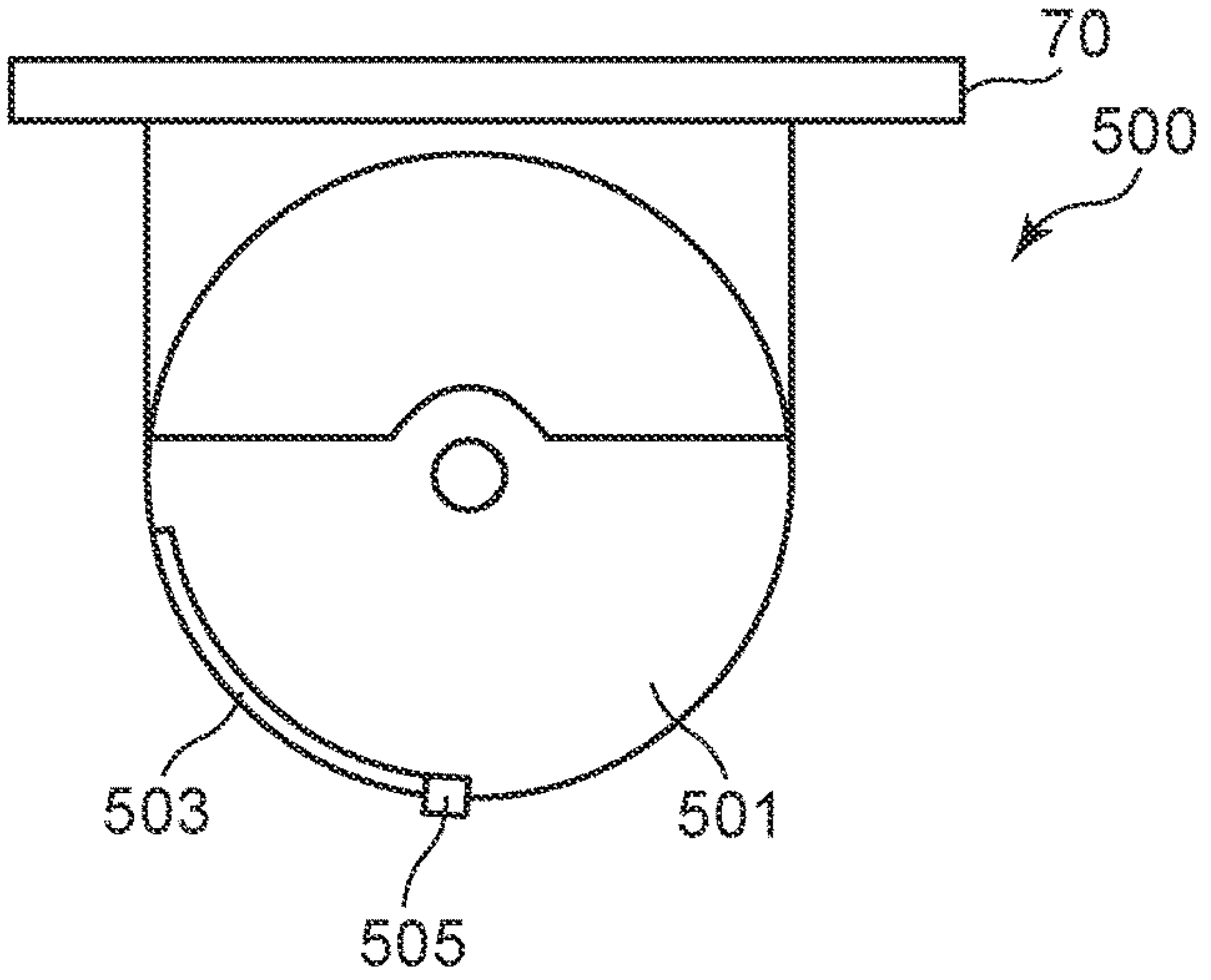

FIG. 10A

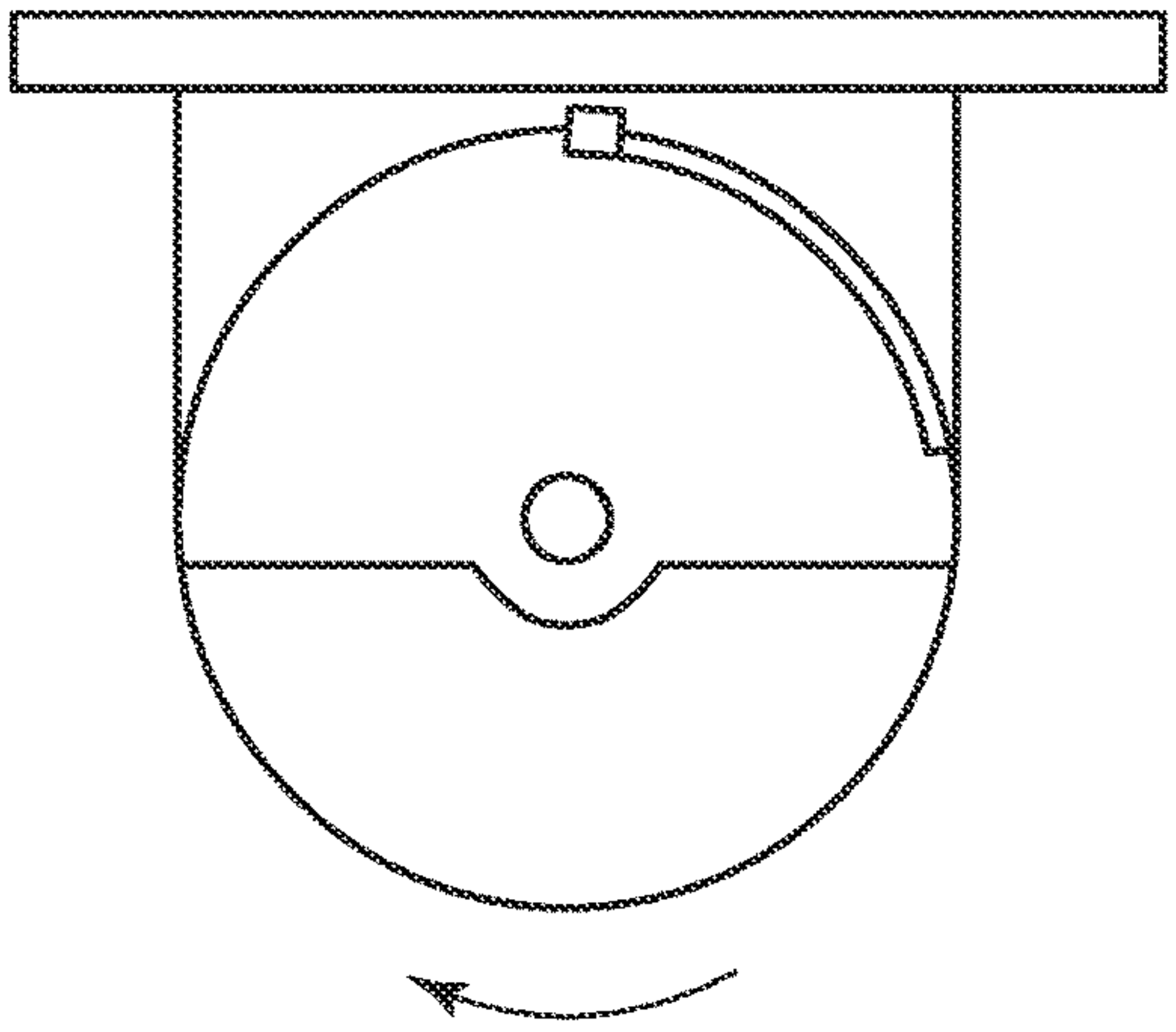

FIG. 10B

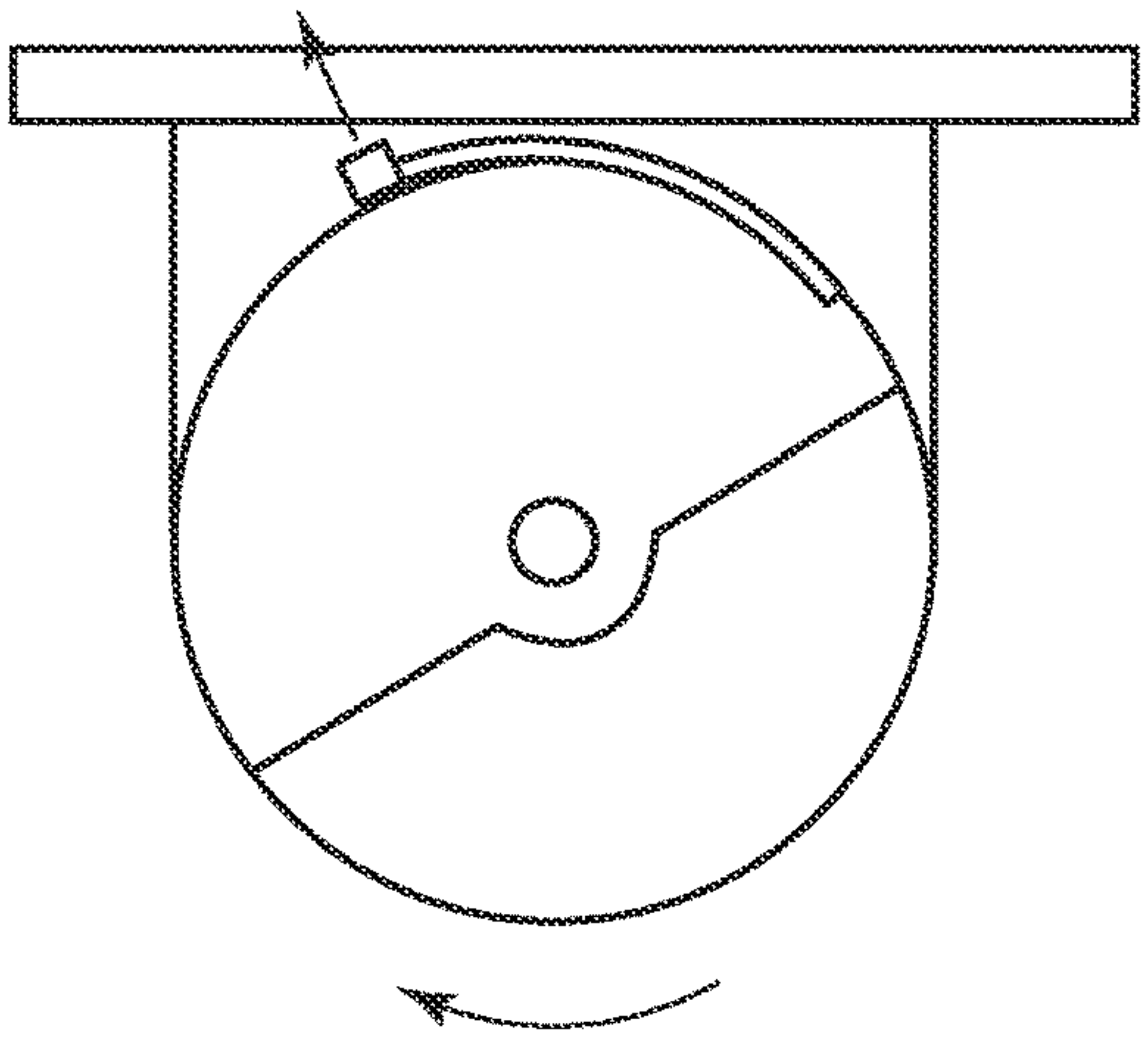

FIG. 10C

METHOD AND APPARATUS FOR GENERATING HAPTIC FEEDBACKS FOR ELECTRONIC APPARATUSES

PRIORITY CLAIM

The present application claims benefit of priority under 35 U.S.C. §§ 120, 365 to the previously filed Japanese Patent Application No. JP2016-167472 with a priority to date of Aug. 30, 2016, which is incorporated by reference herein.

TECHNICAL FIELD

The present invention relates to electronic apparatuses in general, and in particular to a technique of generating haptic feedbacks for electronic apparatuses.

BACKGROUND

Electronic apparatuses such as tablet terminals, smartphones, and mobile phones having a touch screen or a chassis may be provided with a haptic actuator that gives tactile feedbacks to the human body. A haptic actuator transmits a vibration to a vibrating body such as a touch screen or a chassis in response to an event generated by the system. A user perceives the vibration at the site with which the user has touched the vibrating body, or perceives the vibration as a sound. Haptic actuators, which use electric power as a driving source, can generally be characterized as an impact type or a vibration type, depending on the characteristics of the vibration.

Examples of the impact type haptic actuators include a shape memory metal impact actuator (SIA) that uses shape memory alloy. In the impact type haptic actuator, a vibration element strikes a vibrating body to provide a transient vibration. Examples of the vibration type haptic actuators include an eccentric rotating mass (ERM) actuator that uses an eccentric motor, a linear resonant actuator (LRA) that causes an alternating current to flow through a coil in a magnetic field to vibrate a movable element, and a piezoelectric actuator that uses a piezoelectric element. The vibration type haptic actuator gives a vibration of constant amplitude to a vibrating body for a predetermined time.

It will be convenient if haptic feedback can provide a set of perceptions having different characteristics according to the usage. For example, for a keystroke on a software keyboard, it is appropriate to give a strong, transient vibration that lasts a short time on the touch screen, so as to be able to address continuous keystrokes. For informing a user of an incoming mail or push notification from a website, it is appropriate to vibrate the chassis for a relatively long time enough for the user to notice it.

Currently, disposing both an impact type haptic actuator and a vibration type haptic actuator in a chassis of an electronic apparatus is disadvantageous from the space saving and cost saving standpoints.

Consequently, it would be preferable to provide an improved technique for generating haptic feedbacks for electronic apparatuses.

SUMMARY

In accordance with an embodiment of the present disclosure, a haptic actuator includes a vibration mechanism and a striking mechanism. The vibration mechanism, in response to a receipt of a predetermined electric power, applies a steady vibration to a vibrating body. The striking mechanism, in response to the receipt of an electric power larger than the predetermined electric power, strikes the vibrating body in order to provide a haptic feedback to the vibrating body. The haptic actuator is able to apply a vibration according to the vibration mechanism and a vibration according to the striking mechanism to the vibrating body. The striking mechanism is able to provide a strong vibration by striking the vibrating body.

The vibration mechanism includes a coil, a magnet that forms a magnetic field around the coil, and a movable element that performs a reciprocating operation in directions along an axis of vibration in response to an application of a first driving voltage to the coil. The striking mechanism strikes the vibrating body as the striking mechanism is displaced in conjunction with an operation of the movable element responsive to application of a second driving voltage larger than the first driving voltage to the coil.

All features and advantages of the present disclosure will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention itself, as well as a preferred mode of use, further objects, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is a plan view of a smartphone as an example of an electronic apparatus;

FIG. **2** is a perspective view showing an appearance of an actuator;

FIGS. **3A-3B** are a plan view and a cross-sectional view, respectively, illustrating a structure of the actuator from FIG. **2**;

FIGS. **4A-4C** are cross-sectional views of the smartphone from FIG. **1**;

FIG. **5** illustrates a driving current of the actuator from FIG. **2**, operating in a vibration mode and a vibration acceleration that occurs in a touch screen;

FIG. **6** illustrates a driving current of the actuator operating in a strike mode and vibration accelerations that occur in the touch screen;

FIG. **7** illustrates another way of attaching an actuator;

FIG. **8** is a plan view illustrating a structure of a different actuator;

FIGS. **9A-9C** illustrate a bidirectional rotary actuator; and

FIGS. **10A-10C** illustrate a (unidirectional) rotary actuator.

DETAILED DESCRIPTION

FIG. **1** is a plan view of a smartphone as an example of an electronic apparatus. As shown, a dual-mode haptic actuator **100** is mounted on a smartphone **10**, according to an embodiment of the present invention. The actuator **100** is disposed inside a chassis **11**, to apply haptic feedback from the back of a touch screen **13**. FIG. **2** is a perspective view showing an appearance of the actuator **100**. FIGS. **3A** and **3B** are a plan view and a cross-sectional view, respectively, illustrating the structure of the actuator **100**.

In FIG. **2**, the actuator **100** is of a flat, long and narrow shape that extends along an axis of vibration. The actuator **100** operates in a vibration mode, in which a movable element **150** (see FIGS. **3A-3B**) vibrates at constant amplitude, and in a strike mode, in which the movable element **150** strikes a vibrating body, in accordance with an event from the system. A haptic effect in the vibration mode is generated using a steady-state vibration of the movable element **150**, and a haptic effect in the strike mode is generated using a transient vibration of the movable element **150**.

The actuator **100** has a vibration mechanism including the movable element **150**, which is housed in a lower chassis **101***a* and an upper chassis **101***b*. Hammers **171***a* and **171***b* protrude upwardly from respective longitudinal ends of the upper chassis **101***b*, although only one of the hammers **171***a*, **171***b* may be provided. The hammers **171***a* and **171***b* are elastically supported by leaf springs **175***a* and **175***b*, respectively.

A striking mechanism includes the movable element **150**, at least one hammer **171***a*, **171***b*, and the corresponding leaf spring **175***a*, **175***b*. The leaf springs **175***a*, **175***b* cause the hammers **171***a*, **171***b* to remain in the home position when the actuator **100** is stopped. In the strike mode, the leaf springs **175***a*, **175***b* cause the hammers **171***a*, **171***b* to move in an upward direction in the figure to the striking position, while applying elastic force to the movable element **150** that is displaced to a large extent. At the center of the upper chassis **101***b*, a spacer **173** is provided through which the actuator **100** is affixed to the rear surface of the touch screen **13**.

FIG. **3**A is a plan view of the actuator **100**, with the upper chassis **101***b*, the hammers **171***a*, **171***b*, the leaf springs **175***a*, **175***b*, and the spacer **173** removed therefrom. FIG. **3**B is a cross-sectional view taken along the longitudinal centerline in FIG. **3**A. Shafts **103***a* and **103***b* have their respective ends fixed to the lower chassis **101***a* via securing portions **105***a* to **105***d*.

The shafts **103***a* and **103***b* penetrate through corresponding ends of weights **107***a* and **107***b* to allow the weights **107***a*, **107***b* to perform a reciprocating linear motion. Compression coil springs **109***a* to **109***d* are disposed between the securing portions **105***a* to **105***d* and the weights **107***a*, **107***b*. Magnets **113***a* and **113***b* of different magnetic pole directions are affixed to a lower surface of an upper yoke **111***b*. A coil **115** is disposed in a coil space formed by the upper yoke **111***b* and a lower yoke **111***a*.

The coil **115** is fixed to the lower chassis **101***a* via a securing member (not shown). The magnetic flux emitted from the magnets **113***a*, **113***b* flow through the magnetic path configured with the upper yoke **111***b*, the lower yoke **111***a*, and the coil space. The lower yoke **111***a* has end surfaces in the vibration directions to which shafts **117***a* and **117***b* are fixed. Spring securing portions **177***a* and **177***b* are fixed to the lower chassis **101***a*, and serve to secure the leaf springs **175***a* and **175***b*, respectively.

The shafts **117***a* and **117***b* penetrate through the spring securing portions **177***a* and **177***b*, respectively. The upper yoke **111***b*, the lower yoke **111***a*, the weights **107***a* and **107***b*, the magnets **113***a* and **113***b*, and the shafts **117***a* and **117***b* constitute the movable element **150**. It should be noted that the actuator **100** may be configured such that the movable element includes the coil and that the magnets and yokes are fixed to the lower chassis **101***a*.

FIGS. **4**A, **4**B and **4**C are cross-sectional views of the smartphone **10** from FIG. **1**. FIG. **4**A shows the state where the actuator **100** is attached to the touch screen **13**, and FIGS. **4**B and **4**C are enlarged views of a portion where the touch screen **13** is attached to the chassis **11**. In FIG. **4**A, the directions perpendicular to the surfaces of the touch screen **13** are defined as up-and-down directions, and the horizontal directions are defined as in-plane directions. As the space inside the chassis **11** is small in the up-and-down directions, the actuator **100** is disposed so that the axis of vibration extends in the in-plane directions, and the spacer **173** is affixed to the rear surface of the touch screen **13**.

The touch screen **13** is fixed to the chassis **11** via a double-sided tape **15**. The double-sided tape **15** has a body formed of a cushioning material such as polyurethane foam or polyethylene foam, with its both sides coated with adhesive. With only its periphery fixed, the touch screen **13** is apt to vibrate in the up-and-down directions. As shown in FIGS. **4**B and **4**C, the double-sided tape **15** can provide the touch screen **13** with a degree of freedom of displacement in the in-plane directions, allowing the touch screen **13** to vibrate in the in-plane directions in addition to the up-and-down directions.

An operation of the actuator **100** mounted on the smartphone **10** will now be described. In a state where no driving voltage is applied to the coil **115**, the movable element **150** is placed in a neutral position, with no contact between the shafts **117***a*, **117***b* and the leaf springs **175***a*, **175***b*. The hammers **171***a*, **171***b* are located in the home position, with no contact with the touch screen **13**. To cause the actuator **100** to operate in a vibration mode, a driving circuit **50** applies to the coil **115** a square wave driving voltage having a frequency equivalent to a resonant frequency of the movable element **150** for a predetermined time required for a haptic effect.

The movable element **150** performs a steady, reciprocating linear motion at constant frequency and amplitude in directions along the axis of vibration shown by the arrow A, due to the Lorentz force occurring in the coil **115** by the magnetic field formed by the magnets **113***a*, **113***b*, and the elastic force of the compression coil springs **109***a* to **109***d*. The steady vibration of the movable element **150** propagates to the lower chassis **101***a* and the upper chassis **101***b*, and further propagates through the spacer **173** to the touch screen **13**. As the upper chassis **101***b* vibrates in the in-plane directions, the touch screen **13** vibrates in the in-plane directions in the vibration mode.

The amplitude of the movable element **150** in the vibration mode is set so that the shafts **117***a*, **117***b* will not impact the leaf springs **175***a*, **175***b*. Thus, in the vibration mode, the hammers **171***a*, **171***b* are not displaced. FIG. **5** shows a driving current **301** that flows through the coil **115** at this time, and a vibration acceleration **303** in the in-plane directions that occurs in the touch screen **13**. Next, to cause the actuator **100** to operate in the strike mode, the driving circuit **50** applies a driving voltage larger than in the vibration mode to the coil **115**, for a time shorter than the time for which the driving voltage is applied in the vibration mode.

FIG. **6** shows a driving current **305** that flows through the coil **115** at this time, a vibration acceleration **307** in the in-plane directions that occurs on the touch screen **13**, and a vibration acceleration **309** in the up-and-down directions that occurs on the touch screen **13**. In a transient state from when a square wave driving voltage was applied to the coil **115** at time t**0** until when the vibration becomes stable, the driving current **305** flows through the coil **115**, and the vibration acceleration **307** in the in-plane directions increases gradually. The driving circuit **50** stops the driving voltage at time t**2** when a certain time has passed or at time t**2** after counting a certain number of pulses. The driving voltage in the strike mode is larger than the driving voltage in the vibration mode, so the vibration acceleration **307** has reached a maximum value, exceeding the maximum value of the vibration acceleration **303**, before reaching the time t**2**.

The amplitude of the movable element **150** attains the maximum value before reaching the time t**2**, and one of the shafts **117***a*, **117***b* impacts the corresponding leaf spring **175***a* or **175***b* at time t**01**. With this, the corresponding hammer **171***a* or **171***b* is displaced upwardly, and strikes the rear surface of the touch screen **13**. The hammer that gave the stroke returns to the home position with the elastic force of the corresponding leaf spring **171***a* or **171***b* when the movable element **150** moves in the opposite direction with the elastic force of the compression coil springs **109***a* to **109***d*. The touch screen **13** that was struck starts vibrating at time t**01**, with the vibration acceleration **309** in the up-and-down directions. The peak value of the vibration acceleration **309** caused by the striking of a hammer **171***a*, **171***b* can be made larger than the peak value of the vibration acceleration **307** in the in-plane directions.

After the time t**2**, with the absence of exciting force, the vibration of the movable element **150** attenuates with free vibration, and at time t**3**, the vibration acceleration **307** reaches the level where the vibration is unfelt by a human. Further, after the time t**2**, the amplitude of the movable element **150** decreases, so the vibration in the up-and-down directions also attenuates with free vibration, with no repeated striking of the touch screen **13** by the hammers **171***a*, **171***b*. In another example, the time for which the driving voltage is applied in the strike mode may be elongated so that the hammers **171***a* and **171***b* give a plurality of strokes alternately.

The period of time or the number of applied pulses until the driving voltage is stopped can be determined in advance through experiments. Although the movable element **150** has only one degree of freedom of vibration, the actuator **100** is able to provide the touch screen **13** with a steady vibration in the in-plane directions, which lasts a relatively long time, and a strong, transient vibration in the up-and-down directions. Thus, when the actuator is operated in the strike mode in response to keystrokes on the software keyboard and in the vibration mode in response to dragging or other gesture operations on the touch screen **13**, the user can perceive, at the fingertips, haptic feedback of different characteristics in accordance with a user's manipulations.

The actuator **100**, capable of applying a steady vibration and a vibration by striking to the touch screen **13**, can be attached to the smartphone **10** in various manners so as to implement haptic feedback of different characteristics. FIG. **7** illustrates how an actuator **100***a* is attached. The actuator **100***a* differs from the actuator **100** shown in FIGS. **3**A, **3**B, **4**A, **4**B, and **4**C only in that the actuator **100***a* is attached to the chassis **11** via a spacer **173***a* which is attached to the lower chassis **101***a*.

The spacer **173***a* allows the bottom surface of the chassis **11** to vibrate in in-plane directions in the vibration mode, and allows the touch screen **13** to vibrate in up-and-down directions in the strike mode. When a user holds the smartphone **10** with the left hand and performs manipulations on the touch screen **13** with the right hand, the user can perceive, at the fingertip, the vibration of the touch screen **13** in the strike mode in response to a software keyboard manipulation, and can perceive, with the left hand, the vibration of the chassis **11** in the vibration mode in response to a gesture manipulation. It should be noted that an actuator **100** or **100***a* may be attached to the chassis **11** by directly affixing the lower chassis **101***a* to the inner surface of the chassis **11**, in which case the spacer **173** or **173***a* can be omitted.

In the actuators **100** and **100***a*, the magnitude and time of application of the driving voltage are adjusted to cause the lower chassis **101***a* and the upper chassis **101***b* to vibrate in directions along the axis of vibration and cause the hammers **171***a*, **171***b* to be displaced at a right angle with respect to the axis of vibration, but the directions of the axis of vibration and striking are not limited to these directions. FIG. **8** is a plan view illustrating an actuator **100***b* that causes a lower chassis **101***a* and an upper chassis **101***b* as well as hammers to vibrate in directions along the axis of vibration. The actuator **100***b* includes shafts **118***a* and **118***b* serving also as the hammers, in place of the shafts **117***a* and **117***b* of the actuator **100**.

The shafts **118***a* and **118***b* are configured such that one of the shafts protrudes through a sidewall of the lower chassis **101***a* in the strike mode with large amplitude, and that neither of the shafts protrudes in the vibration mode with small amplitude. When mounting the actuator **100***b*, a side surface of the lower chassis **101***a* through which the shaft **118***a* or **118***b* protrudes can be affixed to a side surface of the chassis **11** of the smartphone **10**, so that a vibration and a stroke can both be applied to the chassis **11** in the directions along the axis of vibration. In this case, at the same time, the upper chassis **101***b* may be affixed to the rear surface of the touch screen **13**, or the lower chassis **101***a* may be affixed to the bottom surface of the chassis **11**.

While the actuators **100**, **100***a*, and **100***b* have the movable element **150** that performs a reciprocating linear motion, the direction of the motion of the movable element is not limited thereto. The present invention is applicable to a rotary actuator in which a movable element including an eccentric weight, such as an ERM, performs a rotational motion. FIGS. **9**A, **9**B, and **9**C are plan views, as seen in an axial direction, of an actuator **400** which generates a vibration by causing an eccentric weight **401** to rotate in two directions like a pendulum. The actuator **400** has its main body fixed to a vibrating body **70**.

The eccentric weight **401** has, on respective sides, arms **403***a* and **403***b* equipped with hammers **405***a* and **405***b*, respectively. A motor performs a bidirectional rotational operation through cooperation of a coil through which an electric current flows and a magnet. FIG. **9**A illustrates the state where the eccentric weight **401** is stationary, with no driving voltage applied to the coil of the motor.

FIG. **9**B illustrates the state where the eccentric weight **401** rotates bidirectionally through a predetermined rotation angle α as a driving voltage preset for the vibration mode is applied. In the vibration mode, although the vibration of the main body propagates to the vibrating body **70**, the hammers **405***a* and **405***b* do not impact the vibrating body **70**, as the rotation angle α is small.

FIG. **9**C illustrates the state where the eccentric weight **401** rotates bidirectionally when a driving voltage for the strike mode larger than the driving voltage for the vibration mode is applied. In the strike mode, an angular acceleration occurring in the eccentric weight **401** becomes larger than in the vibration mode, leading to an increased rotation angle β, so one of the hammers **405***a* and **405***b* strikes the vibrating body **70**.

FIGS. **10**A, **10**B, and **10**C are plan views, as seen in an axial direction, of an actuator **500** that generates a vibration by causing an eccentric weight **501** to rotate in one direction. The actuator **500** has its main body fixed to a vibrating body **70**. On the periphery of the eccentric weight **501**, a hammer **505** is fixed via a leaf spring **503**. A motor performs a rotational operation through cooperation of a coil through which an electric current flows and a magnet. FIG. **10**A shows the state where no driving voltage is applied to the coil of the motor. The leaf spring **503** urges the hammer **505** so as to let it remain in a home position closest to the axis.

FIG. **10**B shows the state where the eccentric weight **501** rotates at a predetermined rotational speed when a driving voltage preset for the vibration mode is applied. In the vibration mode, a vibration of the main body that has occurred from rotation of the eccentric weight **501** propagates to the vibrating body **70**. The hammer **505** is displaced only a small distance from the home position by centrifugal force, but the displacement is not enough for the hammer to impact the vibrating body **70**.

FIG. **10**C shows the state where the eccentric weight **501** rotates when a driving voltage larger than the driving voltage for the vibration mode is applied in the strike mode. In the strike mode, the rotational speed becomes higher than in the vibration mode, so the hammer **505** is displaced a larger distance by the centrifugal force, allowing it to strike the vibrating body **70**. With the application of the driving voltage stopped, the rotational speed decreases, so the hammer **505** returns to its home position with the elastic force of the leaf spring **503**.

As has been described, the present invention provides an improved technique for generating haptic feedbacks for electronic apparatuses.

While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A haptic actuator, comprising:

a vibration mechanism having a movable element,
  in response to a receipt of a first driving current, vibrates said movable element at a first vibration acceleration having a first amplitude along a plane of a surface of a device to which said haptic actuator is attached;
  in response to a receipt of a second driving current larger than said first driving current, vibrates said movable element at a second vibration acceleration having a maximum amplitude higher than said first amplitude along said plane of said surface of said device; and
a striking mechanism, in response to a receipt of said maximum amplitude of said second vibration acceleration higher than said first amplitude of said first vibration acceleration, strikes said surface of said device.

2. The haptic actuator of claim **1**, wherein said vibration mechanism further includes a coil an a magnet for providing a magnetic field around said coil to vibrate said movable element.

3. The haptic actuator of claim **1**, wherein said first driving current is a square wave.

4. The haptic actuator of claim **3**, wherein said second driving current is a square wave.

5. The haptic actuator of claim **3**, wherein said striking mechanism is a hammer.

6. The haptic actuator of claim **1**, wherein said vibration mechanism vibrates said movable element steadily in response the receipt of said first driving current.

7. The haptic actuator of claim **6**, wherein said vibration mechanism vibrates said movable element by ramping up to a maximum amplitude in response to the receipt of said second driving current, and then ramping down from said maximum amplitude after the supply of said second driving current has stopped.

8. The haptic actuator of claim **2**, wherein said vibration mechanism includes an eccentric weight that rotates at a prescribed rotational speed in response to the receipt of said first driving current to said coil.

9. The haptic actuator of claim **8**, wherein said striking mechanism strikes said surface of said device as said striking mechanism is displaced in conjunction with a rotation of said eccentric weight responsive to an application of said second driving current larger than said first driving current to said coil.

10. The haptic actuator of claim **2**, wherein said vibration mechanism includes an eccentric weight that rotates bidirectionally through a prescribed rotation angle in response to the receipt of said first driving current to said coil.

11. The haptic actuator of claim **10**, wherein said striking mechanism strikes said surface of said device as said striking mechanism is displaced in conjunction with a displacement of said eccentric weight responsive to an application of said second driving current larger than said first driving current to said coil.

12. An electronic apparatus, comprising:

a chassis;
a display surface associate with said chassis; and
a haptic actuator having
  a vibration mechanism having a movable element,
    in response to a receipt of a first driving current, vibrates said movable element at a first vibration acceleration having a first amplitude along a plane of a surface of a device to which said haptic actuator is attached;
    in response to a receipt of a second driving current larger than said first driving current, vibrates said movable element at a second vibration acceleration having a maximum amplitude higher than said first amplitude along said plane of said surface of said device; and
  a striking mechanism, in response to a receipt of said maximum amplitude of said second vibration acceleration higher than said first amplitude of said first vibration acceleration, strikes said surface of said device.

13. The electronic apparatus of claim **12**, wherein said vibration mechanism further includes a coil and a magnet for providing a magnetic field around said coil to vibrate said movable element.

14. The electronic apparatus of claim **12**, wherein said vibration mechanism vibrates said movable element steadily in response the receipt of said first driving current.

15. The electronic apparatus of claim **14**, wherein said vibration mechanism vibrates said movable element by ramping up to a maximum amplitude in response to the receipt of said second driving current, and then ramping down from said maximum amplitude after the supply of said second driving current has stopped.

16. A method comprising:

attaching an haptic actuator to a surface of a device;
during a vibration mode, supplying a first driving current to said haptic actuator to cause a movable element within said haptic actuator to vibrate along a plane of said surface of said device at a first vibration acceleration having a first amplitude; and
during a strike mode, supplying a second driving current larger than said first driving current to said haptic actuator to cause said movable element to vibrate along said plane of said surface of said device at a second vibration acceleration having a maximum amplitude higher than said first amplitude of said first vibration acceleration, and to cause a hammer to strike said surface of said device.

17. The method of claim **16**, wherein said second amplitude of said vibration of said movable element occurs before said supply of said second driving current has stopped.

18. The method of claim **16**, wherein said second amplitude of said vibration of said movable element causes said hammer to strike said surface of said device.

19. The electronic apparatus of claim **12**, wherein said first driving current and said second driving current are square waves.

20. The electronic apparatus of claim **12**, wherein said striking mechanism is a hammer.

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