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Electromagnetic braking device

Abstract

An electromagnetic braking device includes a brake disk, a fixed disk, an armature, a biasing member for biasing the armature, and a stator for attracting the armature. In a stator magnetic circuit member, a first yoke, a permanent magnet, and a second yoke are arranged in this order from one end to the other end of a U shape. In a rotatable state or a rotation braking state, even when the coil energization is OFF, the rotatable state or the rotation braking state is maintained. When a current of a predetermined magnitude flows through the coil in a first direction in the rotatable state, the state shifts to the rotation braking state, and when a current of a predetermined magnitude flows through the coil in a second direction in the rotation braking state, the state shifts to the rotatable state.

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Background/Summary

RELATED APPLICATIONS
(1) The present application is a National Phase of International Application No. PCT/JP2021/029262 filed Aug. 6, 2021, which claims priority to Japanese Application No. 2020-136512, filed Aug. 12, 2020.
TECHNICAL FIELD
(2) The present invention relates to a self-maintaining electromagnetic braking device.
BACKGROUND ART
(3) An electromagnetic braking device is known as a device that brakes movement of a rotation shaft (for example, a motor shaft, a wheel shaft, and the like) of a braking target (for example, a motor, a vehicle, and the like).
(4) A conventional electromagnetic braking device (non-excitation actuation type), for example, as described in Patent Documents 1 to 3, includes a brake disk rotatable integrally with a rotation shaft and slidable along a central axis of the rotation shaft, a fixed disk disposed facing one side of, and coaxially with, the brake disk, an armature disposed opposite to the other side of, and coaxially with, the brake disk and slidable along the central axis, a coil spring pressing the armature in a direction in which the brake disk is disposed, and an electromagnet that is disposed at a side of the armature opposite from the side at which the brake disk is disposed, that can generate a magnetic force for attracting the armature in a direction away from the brake disk, and that includes a coil and a yoke.
(5) In the conventional electromagnetic braking devices (non-excitation actuation types), when the electromagnet is not excited, the armature is biased by a biasing force of the coil spring, and by this the brake disk is sandwiched between and in contact with the armature and the fixed disk, thereby braking the rotation of the rotation shaft. On the other hand, when the electromagnet is excited, the magnetic force is generated from the electromagnet that attracts the armature, the armature moves toward a stator against the above-described biasing force of the coil spring, the brake disk is released from contact between the armature and the fixed disk, and the rotation shaft becomes rotatable.
(6) However, according to the conventional electromagnetic braking device (non-excitation actuation type), while in the rotatable state, it is necessary to always continuously supply a current to the coil of the electromagnet. Therefore, it cannot be said that power saving is achieved.
(7) As a solution to such a problem, there has been proposed a so-called “self-maintaining type” electromagnetic braking device that does not use a coil spring and that consumes electric power only when the state transitions between an activated state and a non-activated state (rotatable state) of the brake (see, for example, Patent Document 4).
PRIOR ART LITERATURE
Patent Documents
(8) Patent Document 1: JP-A-57-122836. Patent Document 2: JP-A-2010-144852 Patent Document 3: JP-A-2019-199957 Patent Document 4: JP-A-9-229105

SUMMARY OF INVENTION

Problems to be Solved by Invention

(9) FIG. **6** is a diagram illustrating a configuration of an electromagnetic braking device **900** described in Patent Document 4. Although detailed description is omitted, the electromagnetic braking device described in Patent Document 4 has the following problems because the armature is a bobbin type.

(10) (a) A second flange portion **932**, which is in the vicinity of one end **961** and another end **962** of a stator magnetic circuit member **960**, which is a location (also referred to as a point of effort) of the magnetic circuitry that contributes to switching between activated and non-activated states of the brake, and a brake contact surface **931***a* of a first flange portion **931**, which is a location (also referred to as a working point) that presses against a hub **916** and contributes to braking of a rotating portion, are physically separated from each other. Therefore, it is not always possible to obtain a strong braking force as in the above-described non-excitation actuation type electromagnetic braking device.

(11) (b) Since the armature **930** is a bobbin type, the first flange portion **931** and the second flange portion **932** serve to restrict the movement of each other. Therefore, when the brake contact surface **931***a* at the first flange portion **931** side is in contact with a friction member **913** in the brake activated state, it is necessary to secure an air gap **9***b* at the second flange portion **932** side, in between a surface **932***b* on the other side of the second flange portion **932** and the other end **962** of the stator magnetic circuit member **960**. An air gap **9***a* is also present on the opposite side, with the second flange portion **932** sandwiched therebetween. Therefore, a magnetic resistance in the magnetic circuit increases due to the air gaps **9***a* and **9***b*, and the magnetic flux that passes through them decreases accordingly, and as a result, a sufficient attracting force cannot always be obtained. Therefore, the strong braking force cannot always be obtained.

(12) (c) When the friction member **913** wears down, there is a possibility that the air gap **9***b* may decrease and eventually become 0 (zero). If this happens, then a pressing force against the hub **916** becomes weak, and the braking force cannot be stably exerted.

(13) (d) Since the armature **930** needs to move in a direction parallel to the central axis AX, it is necessary to secure a clearance **9***c* between a permanent magnet **933** and an end portion (not shown) of the second flange portion **932**. Note that reference numerals **934** indicated at both sides of the permanent magnet **933** are spacers, and do not function as yokes. When viewed from the permanent magnet **933**, the stator magnetic circuit member **960** and the second flange portion **932** are what function as yokes. Since the clearance **9***c* is required in this way, the magnetic resistance in the magnetic circuits increases, and the magnetic flux that passes through reduces accordingly, and as a result, the sufficient attracting force cannot always be obtained. Therefore, the strong braking force cannot always be obtained.

(14) The present invention takes the above-described circumstances into consideration, and an object thereof is to provide the electromagnetic braking device that stably exerts the strong braking force while saving power.

Means for Overcoming the Problems

(15) According to one aspect of the present invention, there is provided an electromagnetic braking device for braking movement of a rotation shaft of a braking target, the electromagnetic braking device is provided that includes a brake disk rotatable integrally with the rotation shaft and slidable along a central axis of the rotation shaft, a fixed disk disposed facing one side of, and coaxially with, the brake disk, an armature disposed facing another side of, and coaxial with, the brake disk, and slidable along the central axis, a biasing member for biasing the armature in a direction in which the brake disk is disposed, and a stator disposed with respect to the armature on a side opposite to a side where the brake disk is disposed, and capable of generating a magnetic force for attracting the armature in a direction away from the brake disk.

(16) Here, the stator includes a coil and a stator magnetic circuit member, which includes a first

yoke, a permanent magnet, and a second yoke. The stator magnetic circuit member has a substantial U shape that surrounds the coil in a cross-sectional view of a surface obtained by cutting by a plane including the central axis and is disposed so that one end surface on one end side, and another end surface on another end side, of the U shape face the armature. Elements of the stator magnetic circuit member are arranged, from one end to another end of the U shape, in the order of the first yoke, the permanent magnet, and the second yoke.
(17) The electromagnetic braking device is configured so that (i) in a rotatable state in which the rotation shaft is rotatable, the armature is held in contact with the one end surface and the other end surface of the stator magnetic circuit member even while energization to the coil is OFF, (ii) when, while in the rotatable state, a current of a predetermined magnitude in a first direction flows through the coil, the armature moves toward the brake disk and contacts the brake disk to shift to a rotation braking state in which rotation of the rotation shaft is braked, (iii) in the rotation braking state, the brake disk is held in a state of being sandwiched between the armature and the fixed disk while being in contact therewith even while energization of the coil is OFF, and (iv) when, while in the rotation braking state, a current having a predetermined magnitude flows through the coil in a second direction opposite to the first direction, the armature moves toward the stator, and the brake disk is released from contact between the armature and the fixed disk to shift to the rotatable state.
(18) According to another aspect of the present invention, the electromagnetic braking device is configured so that (a) in a rotatable state in which the rotation shaft is rotatable, a magnitude of a force attracting the armature by a magnetic circuit that uses the permanent magnet as a magnetomotive force source exceeds a magnitude of a force (biasing force) biasing the armature by a biasing member, (b) when transitioning from the rotatable state to a rotation braking state in which rotation of the rotation shaft is braked, the magnitude of the force attracting the armature by the magnetic circuit with the permanent magnet and the coil as the magnetomotive force source is smaller than the magnitude of the above-described biasing force, (c) in the rotation braking state, the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet as the magnetomotive force source is smaller than the magnitude of the biasing force, and (d) when transitioning from the rotation braking state to the rotatable state, the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet and the coil as the magnetomotive force source exceeds the magnitude of the above-described biasing force.
Effects of the Invention
(19) According to the present invention, it is possible to provide a power-saving electromagnetic braking device that stably exerts the strong braking force while saving power.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIGS. **1**A and **1**B are perspective views of an electromagnetic braking device **1** according to an embodiment.
(2) FIG. **2** is an A-A cross-sectional view of the electromagnetic braking device **1** according to the embodiment, when two virtual planes indicated by PL1 and PL2 in FIG. **1**A are developed and viewed along arrow A.
(3) FIGS. **3**A to **3**H are diagrams for explaining functions of the electromagnetic braking device **1** according to the embodiment.
(4) FIG. **4** is a graph showing a force (attracting force fsc) by a stator **100** that attracts an armature **300** and a force (spring force fsp) of a biasing member **200** that biases the armature **300**, in relation to the position of the armature **300**.
(5) FIG. **5** is an enlarged cross-sectional view of a main part of an electromagnetic braking device **2** according to a modification.

(6) FIG. **6** is a view showing configuration of an electromagnetic braking device **900** described in Patent Document 4.

EMBODIMENT OF INVENTION

(7) Hereinafter, an embodiment of an electromagnetic braking device according to the present invention will be described with reference to the drawings. Each drawing is a schematic diagram illustrating an example, and does not necessarily strictly reflect actual dimensions, ratios, and the like.

(8) 1. Configuration of Electromagnetic Braking Device **1** According to the Embodiment

(9) (1) Outline of Electromagnetic Braking Device **1**

(10) An electromagnetic braking device **1** according to the embodiment is an electromagnetic braking device that brakes movement of a rotation shaft (a shaft of a motor, a shaft of a wheel, or the like) of a braking target (a motor, various vehicles, or the like) which is not illustrated.

(11) FIGS. **1**A and **1**B are perspective views of the electromagnetic braking device **1** according to the embodiment. FIG. **1**A is a view showing an external appearance of the electromagnetic braking device **1**, and FIG. **1**B is a view when the electromagnetic braking device **1** is disassembled along a central axis AX of a rotation shaft (shaft **700**). In FIGS. **1**A and **1**B, lead wires are not shown. FIG. **2** is an A-A cross-sectional view of the electromagnetic braking device **1** according to the embodiment when two virtual planes indicated by PL1 and PL2 in FIG. **1**A (virtual planes including a bolt screw **630**, the central axis AX, and a coil spring **200**) are developed and viewed from arrows A. FIG. **2** shows a rotation braking state. Illustration of ribs, shafts, bearings and the like is omitted.

(12) As shown in FIGS. **1**A, **1**B and **2**, the electromagnetic braking device **1** includes a stator **100**, an armature **300**, a brake disk **400**, and a fixed disk **500**, which are arranged along the central axis AX of the rotation shaft (shaft **700**) in this order from the left side to the right side of the drawing. The coil springs **200** as a biasing member are disposed in spring holes **125** of the stator **100** (see FIGS. **1**B and **2**).

(13) The rotation shaft (shaft **700**) is not necessarily an essential component of the electromagnetic braking device **1**, but is shown together with other components in FIGS. **1**A and **1**B to facilitate understanding. Hereinafter, the shaft may be referred to as a rotation shaft **700**, and the rotation shaft may be referred to as a shaft **700**. Similarly, the coil springs may be referred to as a biasing member **200**, and the biasing member may be referred to as the coil springs **200**. These are interchangeable with each other.

(14) When the electromagnetic braking device **1** is used, for example, the stator **100** may be fixed to an appropriate fixing portion (such as a fixing section of the braking target), the shaft **700** of the braking target may be inserted into an opening **612** of a hub **610** (to be described later), and the shaft **700** may be fixed to the hub **610** by a bolt screw through a screw hole (not shown). Further, when the shaft **700** is inserted into the hub **610** of the electromagnetic braking device **1** in advance as shown in FIGS. **1**A and **1**B, the shaft **700** may be connected to the rotating portion of the braking target using a coupling or the like.

(15) Once the electromagnetic braking device **1** is fixed and connected to the braking target as described above, the armature **300** is set to move (details will be described later) when a current of a predetermined magnitude in an intended direction is supplied to a coil **150** (to be described later) from outside through a lead wire (not shown). “Fixed and connected” here may be fixed and connected directly or fixed and connected indirectly via another component.

(16) The brake disk **400** rotates together with the hub **610** integrally with the rotation shaft **700** about the central axis AX. When the armature **300** moves toward the fixed disk **500** and contacts the brake disk **400** while sandwiching the brake disk **400** with the fixed disk **500**, movement of the brake disk **400** is braked by frictional force between it and both the armature **300** and the fixed disk **500**. By this, movement of the rotation shaft **700** is also braked indirectly (rotation is decelerated, rotation is stopped, or movement in the rotation direction is restricted). On the other hand, when the

armature **300** moves toward the stator **100**, the brake disk **400** is released from the contact between the armature **300** and the fixed disk **500** and becomes rotatable. Accordingly, the rotation shaft **700** indirectly becomes rotatable.
(17) Hereinafter, detailed description of each component of the electromagnetic braking device **1** will continue with a focus on structure.
(18) (2) Brake Disk **400**
(19) The brake disk **400** is rotatable integrally with the rotation shaft **700** and is slidable along the central axis AX of the rotation shaft **700**. The brake disk **400** is substantially ring-shaped and has a friction surface on one side that contacts the fixed disk **500** and a friction surface on the other side that contacts the armature **300**.
(20) The brake disk **400** includes a spacer disk **410** and brake pads **420**, which are disposed on both surfaces of the spacer disk **410** so as to sandwich the spacer disk **410**.
(21) The brake pads **420** are formed in a ring shape having a constant width, one surface of each is intimately fixed to the spacer disk **410**, and the other surface (front surface) of each forms the above-described friction surfaces. It is desirable that the brake pads **420** be a material having a relatively high coefficient of friction and yet be highly durable. A width of the brake pads **420** is much smaller than a width of the spacer disk **410**. The spacer disk **410** is substantially ring-shaped, and has a substantially quadrangular opening **412** formed at the center thereof in conformity with the contour of the hub **610** (to be described later) (see FIG. **1**B). The spacer disk **410** may be made of either a non-magnetic material or a soft magnetic material.
(22) It should be noted that provision of the brake pads **420** may be omitted from the brake disk **400**, and the brake disk **400** may be constituted by only the spacer disk **410**.
(23) (3) Hub **610**
(24) The hub **610** has a central through hole and the shaft **700** can be inserted through an opening **612** of the central through hole. The inserted shaft **700** can be fixed to the hub **610** by a fixing screw (not shown).
(25) The outer shape of the hub **610** is a substantially quadrangular prism, but the four corners thereof are formed in contour shapes substantially equivalent to arcs centered on the central axis AX, which is the center of the central through hole (strictly speaking, they may not be perfect arcs, but may be shapes simply chamfered in straight lines), and align with the opening of the opening **412** in the spacer disk **410** described above. The outer dimension of the hub **610** having a substantially rectangular outline shape is set to be slightly smaller than the dimensions of the opening **412** of the spacer disk **410** so that the hub **610** can be fitted into the opening **412** of the spacer disk **410**.
(26) Since the spacer disk **410** (and thus the brake disk **400**) and the hub **610** have such a relationship, the brake disk **400** is restrained by the hub **610** in the rotational direction and rotates integrally with the hub **610** (and thus with the rotation shaft **700**). On the other hand, in the thrust direction, the brake disk **400** can slide along the central axis AX.
(27) (4) Fixed Disk **500**
(28) The fixed disk **500** is disposed facing one side of, and coaxial with, the brake disk **400**. The fixed disk **500** has a substantially ring shape with an opening at the center, and an opening **512** enables the shaft **700**, the hub **610**, and the like to pass through without interfering with them.
(29) The side of the fixed disk **500** on which the brake disk **400** is disposed has a friction surface (not shown) that comes into contact with the brake disk **400**. The fixed disk **500** is provided with three countersink holes **510** at intervals of 120°, and bolt screws **630** can be inserted into the countersink holes **510** from the side opposite to the side of the fixed disk **500** provided with the friction surface.
(30) The bolt screws **630** pass through inner holes **642** of cylindrical collars **640** and are screwed into screw holes **124** provided in the stator **100** (a second yoke **120** on the outer peripheral side), whereby the fixed disk **500** is fixed to the stator **100** while maintaining a separation distance

defined by the height of the collar **640**.
(31) (5) Armature **300**
(32) The armature **300** is disposed facing the other side of, and coaxial with, the brake disk **400**. The armature **300** is made of a soft magnetic material. The armature **300** has a substantial ring shape with an opening at the center, and an opening **312** enables the shaft **700**, the hub **610** and the like to pass through without interfering with them.
(33) The side of the armature **300** on which the brake disk **400** is disposed has a friction surface (not shown) that comes into contact with the brake disk **400**. The surface opposite to the surface on which the friction surface is provided has a contact surface that comes into contact with the yokes (**110**, **120**) of the stator **100** (to be described later), a surface that receives a biasing force of the coil springs **200** (to be described later), and the like.
(34) The outer peripheral edge of the armature **300** is provided with notches **320** at positions corresponding to the collars **640**. The collars **640** are loosely engaged in the notches **320**, and when the armature **300** is moved by the biasing force of the coil springs **200** or an attracting force of the stator **100** (details will be described later), the armature **300** is guided by the collars **640** via the notches **320** and can slide in the thrust direction along the central axis AX.
(35) (6) Coil Springs **200** (Biasing Member)
(36) The coil springs **200**, as a biasing member, are dropped into circular concave spring holes **125** provided in the second yoke **120** of the stator **100** (to be described later), one end of each is brought into contact with and regulated by spring walls **125***a*, which are the bottom of the spring holes **125**, and the other ends protrude from the spring holes **125** toward the armature **300** along the central axis AX and contact the armature **300** (see FIG. **2**).
(37) The other end side of the coil springs **200** can expand and contract along the central axis AX with movement of the armature **300**, toward and away from the side where the armature **300** is disposed.
(38) The coil springs **200**, as a biasing member, press the armature **300** in the direction in which the brake disk **400** is disposed. Note that in this specification, pressing the armature **300** in the direction in which the brake disk **400** is disposed is referred to as “biasing”, and this pressing force is referred to as “biasing force fsp or spring force fsp”.
(39) Although the coil springs **200** have been described as the biasing member in the embodiment, the biasing member is not limited thereto. For example, the biasing member may be realized by a leaf spring, an appropriate actuator, or the like.
(40) (7) Stator **100**
(41) The stator **100** is disposed with respect to the armature **300** on a side opposite to a side where the brake disk **400** is disposed, and can generate a magnetic force for attracting “the armature **300** in a direction away from the brake disk.” In this specification, the force for attracting the armature **300** is referred to as “attracting force fsc”. As shown in FIG. **2**, the stator **100** generally includes a coil **150** and a stator magnetic circuit member **105**, which includes a first yoke **110**, a permanent magnet **130**, and the second yoke **120**.
(42) (7-1) The coil **150** excites members constituting a magnetic circuit (details will be described later), such as the stator magnetic circuit member **105** and the armature **300**, by supplying and energizing a current of a predetermined magnitude in an intended direction from the outside via a lead wire (not shown). The coil **150** may be obtained by using a bobbin **140** and winding an electric wire around the central axis AX following a rail of the bobbin **140**. Note that the bobbin **140** is made of an insulating material.
(43) (7-2) The stator magnetic circuit member **105** has a substantial U shape that surrounds the coil **150** in a cross-sectional view of a surface obtained by cutting by a plane including the central axis AX (the state as shown in FIG. **2**), and is disposed so that one end surface **112** on one end side of the U shape and the other end surface **122** on the other end side face the armature **300**. The elements of the stator magnetic circuit member **105** are arranged, from one end (closer to the

rotation shaft) to the other end (farther from the rotation shaft) of the U shape described above, in the order of the first yoke **110** (inner circumferential yoke), the permanent magnet **130**, and the second yoke **120** (outer circumferential yoke).
(44) Note that it is desirable that the permanent magnet **130** is disposed to one side of the one end of the U shape close to the central axis AX of the rotation shaft **700** and at a position closer to the one end surface.
(45) Here, the cross-sectional shape of the stator magnetic circuit member **105** has the “substantial U shape” in the sense that the one end surface **112** on one end side and the other end surface **122** on the other end side face the armature **300**, and the member that connects the one end surface **112** and the other end surface **122** is closed and continuous without any particular air gap. In this sense, shapes that are near an approximate C shape or an approximate dog-leg shape are also included in the “substantial U shape” referred to here. Further, the “stator magnetic circuit member **105**” herein refers to a general member constituting a magnetic circuit (details will be described later), and is a concept including a permanent magnet in addition to yokes. The first yoke **110** and the second yoke **120** are made of a soft magnetic material.
(46) (7-3) Although the cross-sectional shape of the stator magnetic circuit member **105** is as described above, the stator magnetic circuit member **105** as a whole has a substantial ring shape or a substantial cylindrical shape with an opening at the center (see FIGS. **2** and **1**B). A ball bearing (not shown) is embedded in an opening **102** of the stator magnetic circuit member **105**, an outer ring of the ball bearing is fixed to the stator magnetic circuit member side, and an inner ring of the ball bearing is fixed to the shaft **700**.
(47) (7-4) Similarly, the second yoke **120** overall has a substantial ring shape or a substantially cylindrical shape having an opening at the center, and an annular recessed groove **121** having an opening at the armature **300** side is formed. An outer peripheral (in the RD direction) wall of the second yoke **120** that forms the annular recessed groove **121** constitutes the “other end” of the stator magnetic circuit member **105**, and a surface of the other end that faces the armature **300** is the “other end surface **122**” of the stator magnetic circuit member **105**. The other end surface **122** is the surface that contacts the armature **300**. A width of the other end surface **122** is set to be smaller (narrower) than a width of the second yoke **120** other than the other end surface **122** (the width of the wall closer to the outer periphery).
(48) The coil **150** is accommodated in the annular recessed groove **121** together with the bobbin **140**.
(49) The wall closer to the center (toward the—RD direction) that forms the annular recessed groove **121** is one step lower than the wall to the outer periphery (in the RD direction), the ring-shaped permanent magnet **130** is stacked in the lower step toward the center, and the ring-shaped first yoke **110** is further stacked so as to sandwich the permanent magnet **130** between itself and the second yoke **120**.
(50) The circular concave spring holes **125** are formed in the second yoke **120**. Further, the second yoke **120** is formed with the screw holes **124**, which can be screwed into by the bolt screws **630**.
(51) (7-5) The permanent magnet **130** has a slightly flattened ring shape, and for example, a permanent magnet that is magnetized so that one surface becomes an N pole and the other surface becomes an S pole can be employed.
(52) The permanent magnet **130** is disposed such that a magnetic axis connecting the positive magnetic pole (N pole) and the negative magnetic pole (S pole) of the permanent magnet **130** to each other coincides with a direction in which the first yoke **110**, the permanent magnet **130**, and the second yoke **120** are stacked (left-right direction in FIG. **2**). In the example of the embodiment, the permanent magnet **130** is arranged so that the positive magnetic pole (N pole) appears on the side where the fixed disk **500** is arranged (the side where the first yoke **110** is stacked to the right side in FIG. **2**) and the negative magnetic pole (S pole) appears on the opposite side (the side where the second yoke **120** is stacked to the left side in FIG. **2**). Note that the arrangement of the positive

magnetic pole and the negative magnetic pole may be reversed as long as the control of the energization to the coil **150** described later is matched.

(53) (7-6) The first yoke **110** as a whole has a substantially ring shape with an opening at the center, and has a substantially cup shape on the side facing the armature **300** with the portion closer to the center being one step lower than the edge closer to the outer periphery. The edge portion closer to the outer periphery constitutes “one end” of the stator magnetic circuit member **105**, and the end surface thereof constitutes “one end surface **112**” of the stator magnetic circuit member **105**. The one end surface **112** is the surface that contacts the armature **300**.

(54) (7-7) A width W2 of the one end surface **112** is set to be smaller (narrower) than an overall width (in this example, substantially the same as a width W1 of the permanent magnet **130**) of the first yoke **110** including the one end surface **112**.

(55) In addition, the electromagnetic braking device **1** is configured so that $W2<W1$, wherein, in a cross-sectional view of a surface obtained by cutting the electromagnetic braking device by a plane including the central axis, W1 is the width of the permanent magnet **130** in a direction perpendicular to the central axis AX and W2 is the width of the one end surface **112** of the first yoke **110**, or the other end surface **122** of the second yoke **120**, in the direction perpendicular to the central axis AX. It is further desirable that $W2<(W1/2)$.

(56) 2. Functions of the Electromagnetic Braking Device **1** According to the Embodiment

(57) Next, functions of the electromagnetic braking device **1** will be sequentially described with reference to FIGS. **3**A to **3**H and FIG. **4**.

(58) FIGS. **3**A to **3**H are diagrams for explaining functions of the electromagnetic braking device **1** according to the embodiment. FIGS. **3**A, **3**C, **3**E, and **3**G are enlarged cross-sectional views of main parts corresponding to a first phase to a fourth phase, respectively. Note that the components in this drawing are schematically shown, and therefore have different dimensions, ratios, and the like from those of FIGS. **1**A, **1**B and **2**. FIGS. **3**B, **3**D, **3**F, and **3**H are diagrams of magnetic circuits equivalent to the electromagnetic braking device **1** corresponding to the first phase to the fourth phase, respectively.

(59) (1) Magnetic Circuit Equivalent to Electromagnetic Braking Device **1**

(60) First, in describing functions of the electromagnetic braking device **1**, a magnetic circuit equivalent to the electromagnetic braking device **1** will be described first.

(61) Since the electromagnetic braking device **1** adopts the structure as described above, it constitutes one closed “magnetic circuit”.

(62) “Magnetic circuit” refers to a circuit formed by a path of an N pole of the permanent magnet **130**, the first yoke **110**, air gap AG between the one end surface **112** and the armature **300**, the armature **300**, the air gap AG between the armature **300** and the other end surface **122**, the second yoke **120**, and an S pole of the permanent magnet **130** using the permanent magnet **130** and the coil **150** as magnetomotive force sources. However, the orientation of the magnetic poles is based on the assumption of the magnetic pole arrangement of the permanent magnet exemplified above.

(63) Here, the magnetomotive force of the permanent magnet **130** is Fmg, the magnetomotive force of the coil is Fc, the magnetic resistance by the first yoke **110**, the armature **300**, and the second yoke **120** among the magnetic resistances of the paths constituting the magnetic circuit (that is, the same as the total resistance when the armature **300** is in contact with the one end surface **112** and the other end surface **122** of the stator magnetic circuit member **105**) is RCON, the magnetic resistance of the air gap AG portion when the armature **300** separates from the stator **100** even slightly is RAG, and a magnetic flux passing through the magnetic circuit is Φ (See FIG. **2** and FIGS. **3**A to **3**H, to be described later).

(64) In the present embodiment, it is assumed that Fmg is constant, Fc varies depending on the direction and magnitude of the current flowing through the coil, RCON is constant, RAG varies depending on the size of the air gap AG, and 0 (to which a number corresponding to the phase number is attached) can vary depending on the state.

(65) (1-1) Magnetic Circuit of First Phase
(66) As shown in FIG. **3**A, when the armature **300** is completely attracted to the stator **100**, the rotation shaft is rotatable. This state is referred to as a "rotatable state". An equivalent magnetic circuit when no current is supplied to the coil **150** in the rotatable state is as shown in FIG. **3**B, and the magnetomotive force is only Fmg from the permanent magnet **130** (the magnetic circuit that uses the permanent magnet as a magnetomotive force source). Since the air gap AG is 0 (zero), RAG is also 0 (zero), and the total magnetic resistance is only RCON. The magnetic flux at this time is Φ 1.
(67) (1-2) Magnetic Circuit of Second Phase
(68) As shown in FIG. **3**C, when a current having a predetermined magnitude flows through the coil **150** in a first direction (here, the direction from the front surface to the back surface of the drawing sheet) in the rotatable state of the first phase, the armature **300** starts to move toward the brake disk **400** (arrow B). The magnetic circuit equivalent to this state is as shown in FIG. **3**D. The magnetomotive force in this circuit is Fmg from the permanent magnet **130** and the magnetomotive force Fc from the coil **150** in the direction in which the magnetomotive force Fmg of the permanent magnet is reduced, and the total magnetomotive force obtained by combining these is Fmg-Fc (the magnetic circuit that uses the permanent magnet and the coil as the magnetomotive force source). Since the air gap AG appears, RAG also changes from a state of 0 (zero) to a state of having a value, and the total magnetic resistance becomes RCON+RAG. The magnetic flux at this time is Φ 2. The value of the magnetic flux Φ 2 at this time is smaller than the value of the magnetic flux Φ 1. Therefore, the attracting force fsc is weaker than that in the first phase. Generally, it is known that the larger the air gap in the magnetic circuit, the smaller the attracting force acting on the armature. This is because when an air gap is large, the magnetic resistance of the whole magnetic circuit becomes large, and accordingly, the magnetic flux that passes near the air gap AG is reduced and the attracting force is reduced.
(69) (1-3) Third Phase Magnetic Circuit
(70) As shown in FIG. **3**E, when the armature **300** presses the brake disk **400** and the brake disk **400** is completely sandwiched between the armature **300** and the fixed disk **500** while contacting them, the rotation of the rotation shaft is braked. This state is referred to as a "rotation braking state". The equivalent magnetic circuit when no current is supplied to the coil **150** during the rotation braking state is as shown in FIG. **3**F, and the magnetomotive force is only Fmg from the permanent magnet **130** (the magnetic circuit that uses the permanent magnet as the magnetomotive force source). The magnetic resistance RAG corresponding to the air gap AG becomes a value corresponding to the maximum value AGmax of the air gap, and the total magnetic resistance becomes RCON+RAG(AG=AGmax). The magnetic flux at this time is Φ 3. In general, $\Phi3 \leq \Phi2 \leq \Phi1$.
(71) (1-4) Fourth Phase Magnetic Circuit
(72) As shown in FIG. **3**G, in the rotation braking state of the third phase, when a current of a predetermined magnitude flows through the coil **150** in a second direction (here, the direction from the back surface to the front surface of the drawing sheet) opposite to the first direction, the armature **300** starts to move toward the stator **100** (arrow C). The magnetic circuit equivalent to this state is as shown in FIG. **3**H. The magnetomotive force in this circuit is Fmg from the permanent magnet **130** and the magnetomotive force Fc from the coil **150** in the direction in which it is added to the magnetomotive force Fmg of the permanent magnet, and the total magnetomotive force obtained by combining these is Fmg+Fc (the magnetic circuit that uses the permanent magnet and the coil as the magnetomotive force source). Since the air gap AG still remains although it is decreasing, RAG is also in a state of having a value, and the total magnetic resistance is RCON+RAG. The magnetic flux at this time is Φ 4. The value of the magnetic flux Φ 4 at this time is larger than the value of the magnetic flux Φ 3. Therefore, the attracting force fsc is stronger than that in the third phase. This is because, contrary to the case of the second phase, when the air gap

becomes smaller, the magnetic resistance of the overall magnetic circuit becomes smaller, and accordingly, the magnetic flux passing through the vicinity of the air gap AG becomes larger and the attracting force becomes stronger.
(73) (2) Specifications of the Electromagnetic Braking Device **1**
(74) As can be seen from the structure in the vicinity of the armature **300** (see FIG. **2** and FIGS. **3**A to **3**H), it can be understood that the behavior and state of the armature **300** are the combination of the “spring force fsp” of the coil springs **200** and the “attracting force fsc” of the magnetic flux Φ generated by the magnetic circuit (strictly speaking, the magnetic flux Φ passing between the armature **300** and the one end surface **112** and/or the other end surface **122** of the stator magnetic circuit member **105**).
(75) Here, “specifications” such as the strength of the spring (spring constant, arrangement position of the spring (contraction amount of the spring), magnetomotive force of the permanent magnet, magnetomotive force of the coil, permeability of the yoke, and maximum value AGmax of the air gap can be appropriately set as long as the operation and effects of the present invention are achieved, but in the present embodiment, the electromagnetic braking device **1** is configured to set these “specifications” so as to produce the spring force fsp and the attracting force fsc as shown in FIG. **4**, for example (details will be described below).
(76) (3) Relationship Between Spring Force Fsp and Attracting Force Fsc, and Movement of Armature **300**
(77) FIG. **4** is a graph showing the relationship between a force (the attracting force fsc) attracting the armature **300** by the stator **100** and a force (the spring force fsp) for biasing the armature **300** by the biasing member **200** on the vertical axis and the position of the armature **300** on the horizontal axis. A two dot chain line indicated by reference symbol D in the plus region of the vertical axis is a curve of “an absolute value |fsp| of the spring force” shown for comparing the magnitude of the spring force fsp and the magnitude of the attracting force fsc in states without a reference symbol. The arrows in the drawing indicate the direction of phase transition. The position of the armature **300** on the horizontal axis in the graph can be said to be the gap between the yokes (the first yoke **110** and the second yoke **120**) and the armature **300**, and specifically corresponds to the air gap AG between the surface of the armature **300** on the stator **100** side and the one end surface **112** and/or the other end surface **122** of the stator magnetic circuit member **105**.
(78) Hereinafter, the relationship between the spring force fsp and the attracting force fsc, and the movement of the armature **300**, in the electromagnetic braking device **1** will be described with reference to FIG. **4** (and also FIGS. **3**A to **3**H).
(79) (3-1) First Phase (Self-Maintaining Rotatable State)
(80) The first phase is a phase in which the rotatable state is self-maintaining.
(81) In the graph, when the electromagnetic braking device **1** is in the first phase (when AG=0), the coordinates (0, fsc1) taken by the attracting force are higher by Δf1 than the coordinates of the absolute value of the spring force indicated by the curve D. In other words, in the rotatable state in which the rotation shaft **700** is rotatable, the magnitude of the force (the attracting force) fsc1 that attracts the armature **300** by the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source exceeds the magnitude of the force (the spring force or the biasing force) fsp1 that the armature **300** is biased by the biasing member **200**.
(82) In the first phase, energization to the coil **150** is OFF. In the magnetic circuit of the first phase, the magnetomotive force source is only the permanent magnet **130**, and it would seem that the attracting force fsc cannot be sufficiently drawn out only by this. However, if the specifications are optimally set by making good use of the fact that the attracting force generally varies depending on the position of the armature (generally, the smaller the air gap AG is, the smaller the magnetic resistance RAG is and the larger the attracting force acting on the armature is), the attracting force fsc by the permanent magnet **130** alone can exceed the spring force fsp.
(83) As described above, the electromagnetic braking device **1** is configured such that in the first

phase the attracting force fsc always exceeds the spring force fsp even while the energization of the coil **150** is OFF (see FIGS. **3**A and **3**B), the armature **300** is always attracted toward the stator **100**, and the armature **300** is kept in contact with the one end surface **112** and the other end surface **122** of the stator magnetic circuit member **105**.
(84) (3-2) Second Phase (Transition from Rotatable State to Rotation Braking State)
(85) The second phase is a phase in the process transitioning from the first phase (rotatable state) to the third phase (rotation braking state).
(86) When the current of the predetermined magnitude in the first direction (see FIG. **3**C) flows through the coil **150** in the state of the first phase, as described above, the magnetomotive force Fc is generated by the coil **150** in a direction in which the magnetomotive force Fmg of the permanent magnet is reduced, the total magnetomotive force after combining becomes Fmg-Fc, and as a result, the attracting force fsc is weakened.
(87) When the phase shifts from the first phase to the second phase, the attracting force is weakened by the above-described principle, and the coordinates taken by the attracting force in the first phase temporarily shift from (0, fsc1) to (0, fsc2). At this time, since the absolute value |fsp1| of the spring force exceeds the attracting force fsc2 as shown in the graph, the armature **300** separates from the stator **100** (the air gap AG also increases accordingly). Since the attracting force changes depending on the position of the armature as described above, the attracting force fsc changes along the curve E of the graph as the armature **300** moves (as AG changes). On the other hand, since the spring force fsp changes in accordance with the contraction amount of the spring, the spring force fsp also changes along the straight line H of the graph as the armature **300** moves. Then, when the rotation braking state is established and the air gap is widened to a point where the armature **300** cannot move any more, the coordinates taken by the attracting force fsc become (AGmax, fsc3). During this time, the attracting force fsc (curve E) is always smaller than the absolute value of the spring force (curve D) of the spring force.
(88) That is, when transitioning from the rotatable state to the rotation braking state in which the rotation of the rotation shaft **700** is braked (second phase), the magnitude of the force (the attracting force fsc) attracting the armature **300** by the magnetic circuit with the permanent magnet **130** and the coil **150** as the magnetomotive force source is smaller than the magnitude of the biasing force (the spring force fsp).
(89) In other words, the electromagnetic braking device **1** is configured so that when the current of the predetermined magnitude in the first direction flows through the coil **150** while in the rotatable state, the armature **300** moves toward the brake disk **400** side and contacts the brake disk **400** to shift to the “rotation braking state” in which rotation of the rotation shaft **700** is braked.
(90) (3-3) Third Phase (Self-Maintaining Rotation Braking State)
(91) The third phase is a phase in which the rotation braking state is maintained.
(92) In the graph, when the electromagnetic braking device **1** is in the third phase (when AG=AGmax), the coordinate (AGmax, fsc4) taken by the attracting force is lower by an amount $\Delta f2$ than the coordinate of the absolute value of the spring force as indicated by the curve D. In other words, in the rotation braking state, the magnitude of the force (the attracting force) fsc4 attracting the armature **300** by the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source is smaller than the magnitude of the biasing force (the spring force) fsp2.
(93) As described above, the electromagnetic braking device **1** is configured such that in the third phase the spring force fsp is always greater than the attracting force fsc while the energization of the coil **150** is OFF (see FIGS. **3**E and **3**F), and the brake disk **400** is held in a state of being sandwiched between the armature **300** and the fixed disk **500** while being in contact therewith.
(94) (3-4) Fourth Phase (Transition from Rotation Braking State to Rotatable State)
(95) The fourth phase is a phase in the process of transitioning from the third phase (rotation braking state) to the first phase (rotatable state).

(96) When the current of the predetermined magnitude in the second direction (see FIG. **3**C) opposite from the first direction flows through the coil **150** while in the state of the third phase, as described above the magnetomotive force Fc is generated by the coil **150** in a direction in which it is added to the magnetomotive force Fmg of the permanent magnet, the total magnetomotive force after combining becomes Fmg+Fc, and as a result, the attracting force fsc is strengthened.
(97) When the phase shifts from the third phase to the fourth phase, the attracting force is increased by the above-described principle, and the coordinates taken by the attracting force in the first phase temporarily shift from (AGmax, fsc4) to (AGmax, fsc5). As shown in the graph, since the attracting force fsc5 exceeds the absolute value |fsp2| of the spring force at this time, the armature **300** approaches the stator **100** (and the air gap AG decreases accordingly). Since the attracting force varies depending on the position of the armature as described above, the attracting force fsc changes along the curve G of the graph as the armature **300** moves (as AG changes). On the other hand, since the spring force fsp changes in accordance with the contraction amount of the spring, the spring force fsp also changes along the straight line H of the graph as the armature **300** moves. Then, when the armature **300** completely comes into contact with the stator **100** and the air gap disappears to a point where the armature **101** cannot move any further, the coordinates of the attracting force fsc become (0, fsc6). During this time, the attracting force fsc (curve G) always exceeds the absolute value of the spring force (curve D) of the spring force.
(98) That is, when transitioning from the rotation braking state to the rotatable state in which the rotation of the rotation shaft **700** is rotatable (fourth phase), the magnitude of the force (the attracting force fsc) attracting the armature **300** by the magnetic circuit with the permanent magnet **130** and the coil **150** as the magnetomotive force source is higher than the magnitude of the biasing force (the spring force fsp).
(99) In other words, the electromagnetic braking device **1** is configured such that when the current having the predetermined magnitude flows through the coil **150** in the second direction opposite to the first direction while in the rotation braking state, the armature **300** moves toward the stator **100**, and the brake disk **400** is released from contact between the armature **300** and the fixed disk **500** to shift to the “rotatable state”.
(100) (3-5) In the electromagnetic braking device **1**, the magnetomotive force of the permanent magnet **130**, the spring coefficient of the biasing member **200**, and the displacement of the biasing member **200** are set such that Δf2>Δf1. Here, “the displacement of the biasing member **200** is set” can be said to mean that, for example, the magnitude of contraction of the coil springs **200** is set. Specifically, it means that the depth of the spring holes **125** and the dimension of AGmax are appropriately set.
(101) However, the difference in the rotatable state (first phase) between the magnitude |fsc1| of the force attracting the armature **300** from the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source and the magnitude |fsp1| of the force biasing the armature **300** from the biasing member **200** is Δf1, and the difference in the rotation braking state (third phase) between the magnitude |fsc4| of the force attracting the armature **300** from the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source and the magnitude |fsp2| of the force biasing the armature **300** by the biasing member **200** is Δf2 (see FIG. **4**).
(102) (3-6) As can be seen from FIG. **4**, the slope of the curve E (0, fsc2) to (AGmax, fsc3) or of the curve G (AGmax, fsc5) to (0, fsc6) of the attracting force fsc is greater than the slope of the curve H (0, fsp1) to (AGmax, fsp2) of the spring force fsp. That is, in the electromagnetic braking device **1**, with respect to displacement (horizontal axis) of the armature **200**, the specifications are set such that the rate of change of the attracting force fsc from the stator **100** is higher than the rate of change of the biasing force fsp from the biasing member **200**.
(103) As can be understood from the above description, in the electromagnetic braking device **1** according to the embodiment, the force applied to the armature **300** is roughly divided into two types of forces: the biasing force (the spring force fsp) from the biasing member **200** and the

attracting force (fsc) from the magnetic circuit around the stator **100**. Note that the attracting force (fsc) can be generated as an attracting force that uses the permanent magnet **130** as the magnetomotive force source and as an attracting force using the coil **150** as the magnetomotive force source.
(104) On the one hand, the magnetomotive force Fmg derived from the permanent magnet **130** is generated as a fixed bias (the attracting force derived from the permanent magnet **130** is always generated to some extent).
(105) On the other hand, with respect to the magnetomotive force Fc derived from the coil **150**, the manner of generating the magnetomotive force Fmg can be controlled as intended by appropriately controlling energization to the coil (energization/non-energization (OFF) control to the coil **150**, control of the direction of current flow such as the first direction/second direction when energization is performed, control of the magnitude of current, and the like).
(106) Thus, the electromagnetic braking device **1** according to the embodiment can perform self-maintaining by being configured so that the attracting force only by the permanent magnet **130** exceeds the spring force fsp while making use of the fact that the magnetic resistance RAG changes depending on the position of the armature **300** (depending on the size of the air gap AG) and also is configured so that, during the transition between the “rotatable state” and the “rotation braking state”, the attracting force fsc can exceed/fall below the biasing force fsp by increasing (adding)/decreasing the attracting force fsc by changing the direction of the current flowing through the coil **150**.
(107) 3. Effects of the Electromagnetic Braking Device **1** According to the Embodiment
(108) (1) The electromagnetic braking device **1** according to the embodiment includes the biasing member **200** that presses the armature **300** in the direction in which the brake disk **400** is disposed, and because it is configured as described above, in the rotation braking state, the biasing force primarily by the biasing member **200** contributes to braking. Therefore, as compared with a conventional self-maintaining type electromagnetic braking device, in which braking is performed by moving the armature relying only on the magnetomotive force of the permanent magnet (see Patent Document 4), a stronger braking force can be stably exerted.
(109) The electromagnetic braking device **1** further includes the permanent magnet **130** as the stator magnetic circuit member **105**, in addition to the yokes (the first yoke **110** and the second yoke **120**). In the rotatable state, the armature **300** can be held in contact with the one end surface **112** and the other end surface **122** of the stator magnetic circuit member **105** by the magnetic circuit that uses this permanent magnet **130** as the magnetomotive force source, even while energization of the coil **150** is OFF.
(110) Therefore, in the electromagnetic braking device of the present invention, it is not necessary to constantly supply the current to the coil in the rotatable state as in a conventional non-excitation actuation type electromagnetic braking device (see Patent Documents 1 to 3), and it is the electromagnetic braking device that is more power-saving than conventional.
(111) As described above, the electromagnetic braking device **1** according to the embodiment achieves power saving while stably exerting the strong braking force.
(112) (2) The electromagnetic braking device **1** according to the embodiment includes the above-described biasing member **200**, and also the stator **100** includes, in addition to the coil **150**, the permanent magnet **130** as a constituent element of the stator magnetic circuit member **105**. At this time, it is configured such that “in the rotatable state, the magnitude of the force attracting the armature **300** by the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source is greater than the magnitude of the force biasing the armature **300** by the biasing member **200**” and, “in the rotation braking state, the magnitude of the force attracting the armature **300** by the magnetic circuit that uses the permanent magnet **130** as the magnetomotive force source is less than the magnitude of the biasing force.”
(113) For this reason, the rotatable state and the rotation braking state can be maintained without

causing current to flow through the coil **150**, and it is a power-saving electromagnetic braking device.
(114) In addition, in the rotation braking state, the biasing force primarily by the biasing member **200** contributes to braking. Therefore, as compared with the conventional self-maintaining type electromagnetic braking device, in which braking is performed by moving the armature relying only on the magnetomotive force of the permanent magnet (see Patent Document 4), the stronger braking force can be stably exerted.
(115) The electromagnetic braking device **1** according to the embodiment is also configured such that "when transitioning from the rotatable state to the rotation braking state, the magnitude of the force attracting the armature **300** by the magnetic circuit that uses the permanent magnet **130** and the coil **150** as the magnetomotive force source falls below the magnitude of the biasing force" and "when transitioning from the rotation braking state to the rotatable state, the magnitude of the force attracting the armature **300** by the magnetic circuit that uses the permanent magnet **130** and the coil **150** as the magnetomotive force source exceeds the magnitude of the biasing force".
(116) Therefore, the armature can be moved to the brake disk side or to the stator side using the magnetomotive force of the coil like a lever, and the armature can be arbitrarily moved back and forth between the rotatable state and the rotation braking state.
(117) As described above, the electromagnetic braking device **1** according to the embodiment is power saving while stably exerting the strong braking force.
(118) (3) The permanent magnet **130** is disposed to one side of the one end of the U shape close to the central axis AX of the rotation shaft **700** (to the side of the first yoke **110**) and at a position closer to the one end surface **112**.
(119) In this way, by arranging the permanent magnet **130** as a magnetic force source at a position close to the central axis AX, it can be expected that the strong attracting force is generated at a position closer to the rotation shaft **700**, and more stable braking can be obtained. Further, by disposing the permanent magnet **130** at the position closer to the one end surface **112**, it can be expected that a relatively large magnetic flux will be generated at a position close to the surface (the one end surface **112**) that is in contact with the armature **300**, and the armature can be attracted efficiently.
(120) (4) It is configured so that $W2<W1$, wherein W1 is the width of the permanent magnet **130** in the direction perpendicular to the central axis AX and W2 is the width of the one end surface **112** of the first yoke **110**, or the other end surface **122** of the second yoke **120**, in the direction perpendicular to the central axis AX. Therefore, since the width W2 of the one end surface **112** or the other end surface **122** through which the magnetic flux passes to the armature **300** side is narrower than the width W1 of the permanent magnet **130** as the magnetomotive force source, the magnetic flux Φ can be induced in a narrow width to increase the density of the magnetic flux, thereby efficiently attracting the armature. Furthermore, this effect can be further enhanced by making it so that $W2<(W½)$.
(121) (5) Assuming that the difference between |fsc1| and |fsp1| is Δf1 and the difference between |fsc4| and |fsp2| is Δf2, then the magnetomotive force of the permanent magnet **130**, the spring coefficient of the biasing member **200**, and the displacement of the biasing member **200** are set such that $\Delta f2>\Delta f1$. In other words, the force Δf2 with which the armature contacts against the brake disk in the rotation braking state is set to be larger than the force Δf1 with which the armature contacts against the first yoke and/or the second yoke in the rotatable state. Therefore, the electromagnetic braking device **1** according to the embodiment can stably exert the even stronger braking force.
(122) (6) The brake disk **400** includes the spacer disk **410** and brake pads **420** disposed on both surfaces of the spacer disk **410** so as to sandwich the spacer disk **410**.
(123) The brake pads **420** may be omitted from the brake disk **400**, and the brake disk **400** may be constituted only by the spacer disk **410**, but in this case, contact between the brake disk **400** and the

armature **300** and between the brake disk **400** and the fixed disk **500** become metal-to-metal contact. For this reason, when the armature **300** hits the brake disk **400** in order to brake rotation, the friction surface may be irregularly abraded, and accordingly, the state of friction is likely to fluctuate, and stable friction might not be obtained. On the other hand, when the brake pads **420** are disposed on both surfaces of the spacer disk **410** as in the embodiment, stable friction can be obtained without causing the above-described problem.
(124) Although the present invention has been described based on the above embodiments, the present invention is not limited to the above embodiments. The present invention can be implemented in various aspects without departing from the gist thereof, and for example, the following modifications are also possible.
(125) (1) The number, material, shape, position, size, and the like of the components described in the above-described embodiment are examples, and can be changed within a range not impairing the effects of the present invention.
(126) (2) In the example described in the embodiment, it was described that the permanent magnet **130** is disposed to one side of the one end of the U shape closer to the central axis AX of the rotation shaft **700** and at the position closer to the one end surface **112**. However, the present invention is not limited thereto. For example, as shown in FIG. **5**, the permanent magnet **130′** may be disposed to the side of the other end of the U shape far from the central axis AX of the rotation shaft (not shown) and at a position close to the other end surface. FIG. **5** is an enlarged cross-sectional view of main portions of an electromagnetic braking device **2** according to a modification, and corresponds to FIG. **3**A.

Claims

1. An electromagnetic braking device for braking movement of a rotation shaft of a braking target, the electromagnetic braking device comprising: a brake disk rotatable integrally with the rotation shaft and slidable along a central axis of the rotation shaft; a fixed disk disposed facing one side of, and coaxially with, the brake disk; an armature disposed facing another side of, and coaxial with, the brake disk, and slidable along the central axis; a biasing member for biasing the armature in a direction in which the brake disk is disposed; and a stator disposed with respect to the armature on a side opposite to a side where the brake disk is disposed, and capable of generating a magnetic force for attracting the armature in a direction away from the brake disk, wherein the stator includes a coil and a stator magnetic circuit member, which includes a first yoke, a permanent magnet, and a second yoke, the stator magnetic circuit member has a substantial U shape that surrounds the coil in a cross-sectional view of a surface obtained by cutting by a plane including the central axis, and is disposed so that one end surface on one end side, and another end surface on another end side, of the U shape face the armature, elements of the stator magnetic circuit member are arranged, from one end to another end of the U shape, in order of the first yoke, the permanent magnet, and the second yoke, at least one of the one end side and the another end side of the U shape stator magnetic circuit member includes a first portion having a first width and a second portion having a second width which is narrower than the first width of the first portion when viewed in the cross-sectional view of the surface obtained by cutting by the plane including the central axis of the stator, a portion between the first portion and the second portion of the stator magnetic circuit member is stepped on a portion closer to the armature than a center of the coil, the permanent magnet is in the first portion, and the electromagnetic braking device is configured so that in a rotatable state in which the rotation shaft is rotatable, the armature is held in contact with the one end surface and the other end surface of the stator magnetic circuit member even while energization to the coil is OFF, when, while in the rotatable state, a current of a predetermined magnitude in a first direction flows through the coil, the armature moves toward the brake disk and contacts the brake disk to shift to a rotation braking state in which rotation of the rotation shaft is

braked, in the rotation braking state, the brake disk is held in a state of being sandwiched between the armature and the fixed disk while being in contact therewith even while energization of the coil is OFF, and when, while in the rotation braking state, a current having a predetermined magnitude flows through the coil in a second direction opposite to the first direction, the armature moves toward the stator, and the brake disk is released from contact between the armature and the fixed disk to shift to the rotatable state.

2. The electromagnetic braking device according to claim 1, wherein in the rotatable state, $\Delta f1$ is a difference between a magnitude of a force attracting the armature by a magnetic circuit that uses the permanent magnet as a magnetomotive force source and a magnitude of a biasing force biasing the armature by the biasing member, in the rotation braking state, $\Delta f2$ is a difference between the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet as the magnetomotive force source and the magnitude of the biasing force biasing the armature by the biasing member, and a magnetomotive force of the permanent magnet, a spring coefficient of the biasing member, and displacement of the biasing member are set such that $\Delta f2>\Delta f1$.

3. The electromagnetic braking device according to claim 1, wherein the permanent magnet is disposed to the one end side of the U shape close to the central axis of the rotation shaft and at a position closer to the one end surface.

4. The electromagnetic braking device according to claim 1, wherein $W2<W1$, wherein, in a cross-sectional view of a surface obtained by cutting the electromagnetic braking device by a plane including the central axis, W1 is a width of the permanent magnet in a direction perpendicular to the central axis and W2 is a width of the one end surface of the first yoke, or the other end surface of the second yoke, in the direction perpendicular to the central axis.

5. The electromagnetic braking device according to claim 4, wherein $W2<(W1/2)$.

6. An electromagnetic braking device for braking movement of a rotation shaft of a braking target, the electromagnetic braking device comprising: a brake disk rotatable integrally with the rotation shaft and slidable along a central axis of the rotation shaft; a fixed disk disposed facing one side of, and coaxially with, the brake disk; an armature disposed facing another side of, and coaxial with, the brake disk, and slidable along the central axis; a biasing member for biasing the armature in a direction in which the brake disk is disposed; and a stator disposed with respect to the armature on a side opposite to a side where the brake disk is disposed, and capable of generating a magnetic force for attracting the armature in a direction away from the brake disk, wherein the stator includes a coil and a stator magnetic circuit member, which includes a first yoke, a permanent magnet, and a second yoke, the stator magnetic circuit member has a substantial U shape that surrounds the coil in a cross-sectional view of a surface obtained by cutting by a plane including the central axis, and is disposed so that one end surface on one end side, and another end surface on another end side, of the U shape face the armature, elements of the stator magnetic circuit member are arranged, from one end to another end of the U shape, in order of the first yoke, the permanent magnet, and the second yoke, at least one of the one end side and the another end side of the U shape stator magnetic circuit member includes a first portion having a first width and a second portion having a second width which is narrower than the first width of the first portion when viewed in the cross-sectional view of the surface obtained by cutting by the plane including the central axis of the stator, a portion between the first portion and the second portion of the stator magnetic circuit member is stepped on a portion closer to the armature than a center of the coil, the permanent magnet is in the first portion, and the electromagnetic braking device is configured so that in a rotatable state in which the rotation shaft is rotatable, a magnitude of a force attracting the armature by a magnetic circuit that uses the permanent magnet as a magnetomotive force source exceeds a magnitude of a biasing force biasing the armature by the biasing member, when transitioning from the rotatable state to a rotation braking state in which rotation of the rotation shaft is braked, the magnitude of the force attracting the armature by the magnetic circuit with the

permanent magnet and the coil as the magnetomotive force source is smaller than the magnitude of the biasing force, in the rotation braking state, the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet as the magnetomotive force source is smaller than the magnitude of the biasing force, and when transitioning from the rotation braking state to the rotatable state, the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet and the coil as the magnetomotive force source exceeds the magnitude of the biasing force.

7. The electromagnetic braking device according to claim 6, wherein in the rotatable state, $\Delta f1$ is a difference between the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet as the magnetomotive force source and the magnitude of the biasing force biasing the armature by the biasing member, in the rotation braking state, $\Delta f2$ is a difference between the magnitude of the force attracting the armature by the magnetic circuit that uses the permanent magnet as the magnetomotive force source and the magnitude of the biasing force biasing the armature by the biasing member, and the magnetomotive force of the permanent magnet, a spring coefficient of the biasing member, and displacement of the biasing member are set such that $\Delta f2>\Delta f1$.

8. The electromagnetic braking device according to claim 6, wherein the permanent magnet is disposed to the one end side of the U shape close to the central axis of the rotation shaft and at a position closer to the one end surface.

9. The electromagnetic braking device according to claim 6, wherein $W2<W1$, wherein, in a cross-sectional view of a surface obtained by cutting the electromagnetic braking device by a plane including the central axis, W1 is a width of the permanent magnet in a direction perpendicular to the central axis and W2 is a width of the one end surface of the first yoke, or the other end surface of the second yoke, in the direction perpendicular to the central axis.

10. The electromagnetic braking device according to claim 9, wherein $W2<(W1/2)$.