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(54) **PROXIMITY SENSOR**

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(57) **ABSTRACT**

Provided is a proximity sensor capable of sufficiently extending a detection distance by suppressing an influence of embedded metal. A coil of a proximity sensor includes a first coil and a second coil. The second coil is disposed concentrically with the first coil. The proximity sensor detects a detection object on the basis of a change in voltage or current generated in each of the first coil and the second coil. The coil wire of the first coil is electrically connected to the in-head substrate through direct bonding.

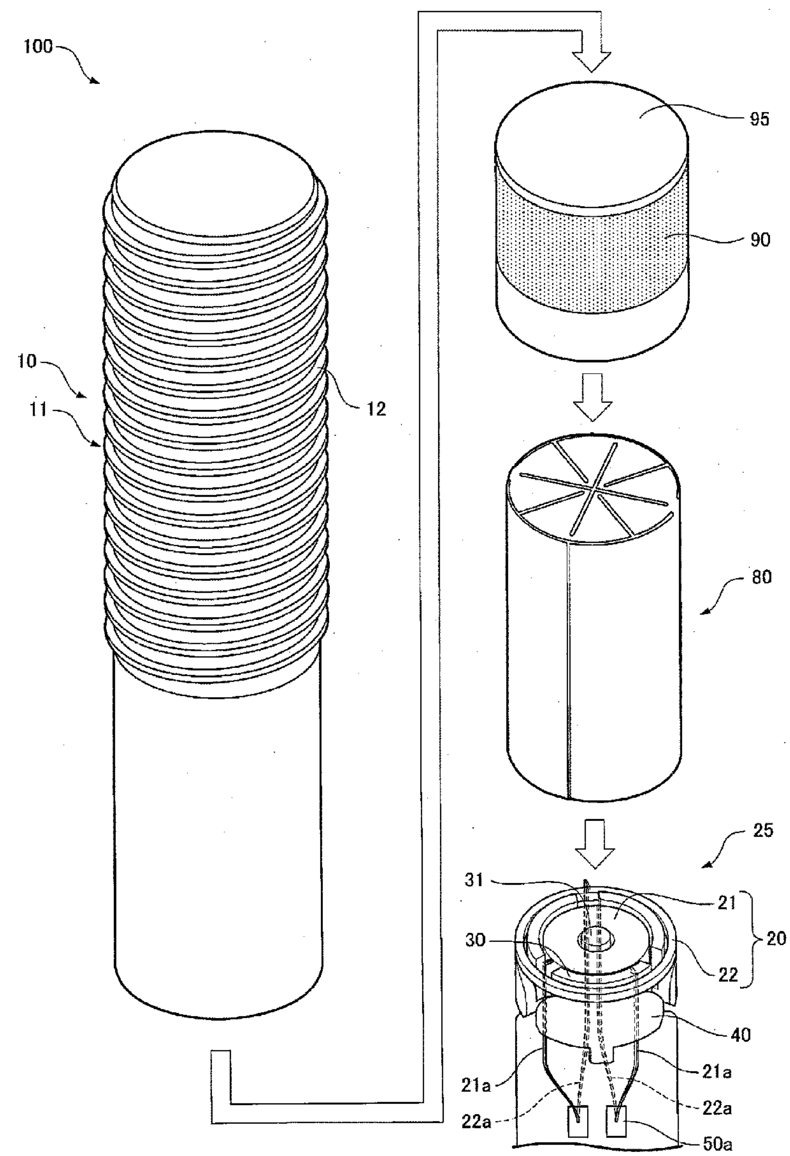


FIG. 1

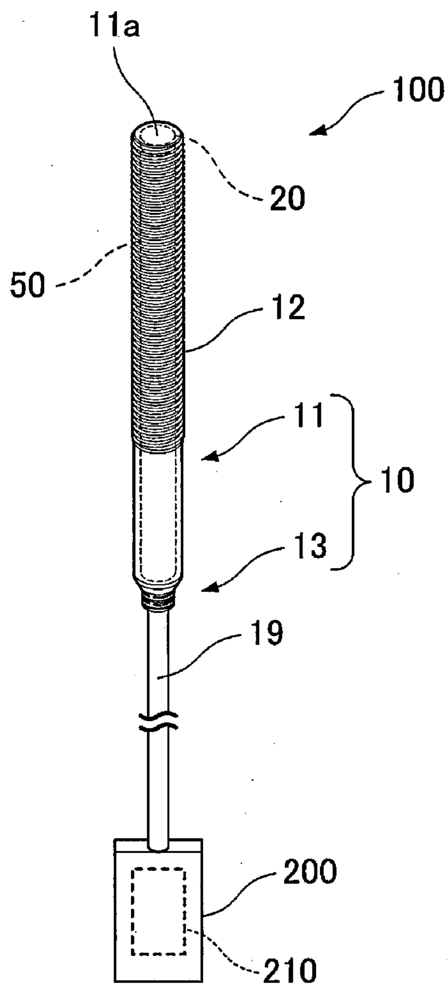
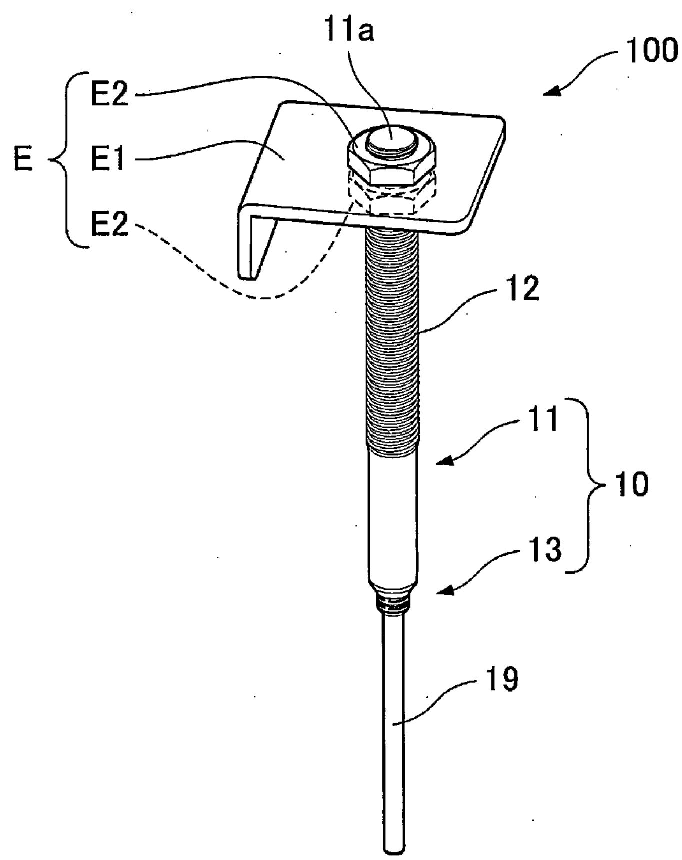


FIG. 2



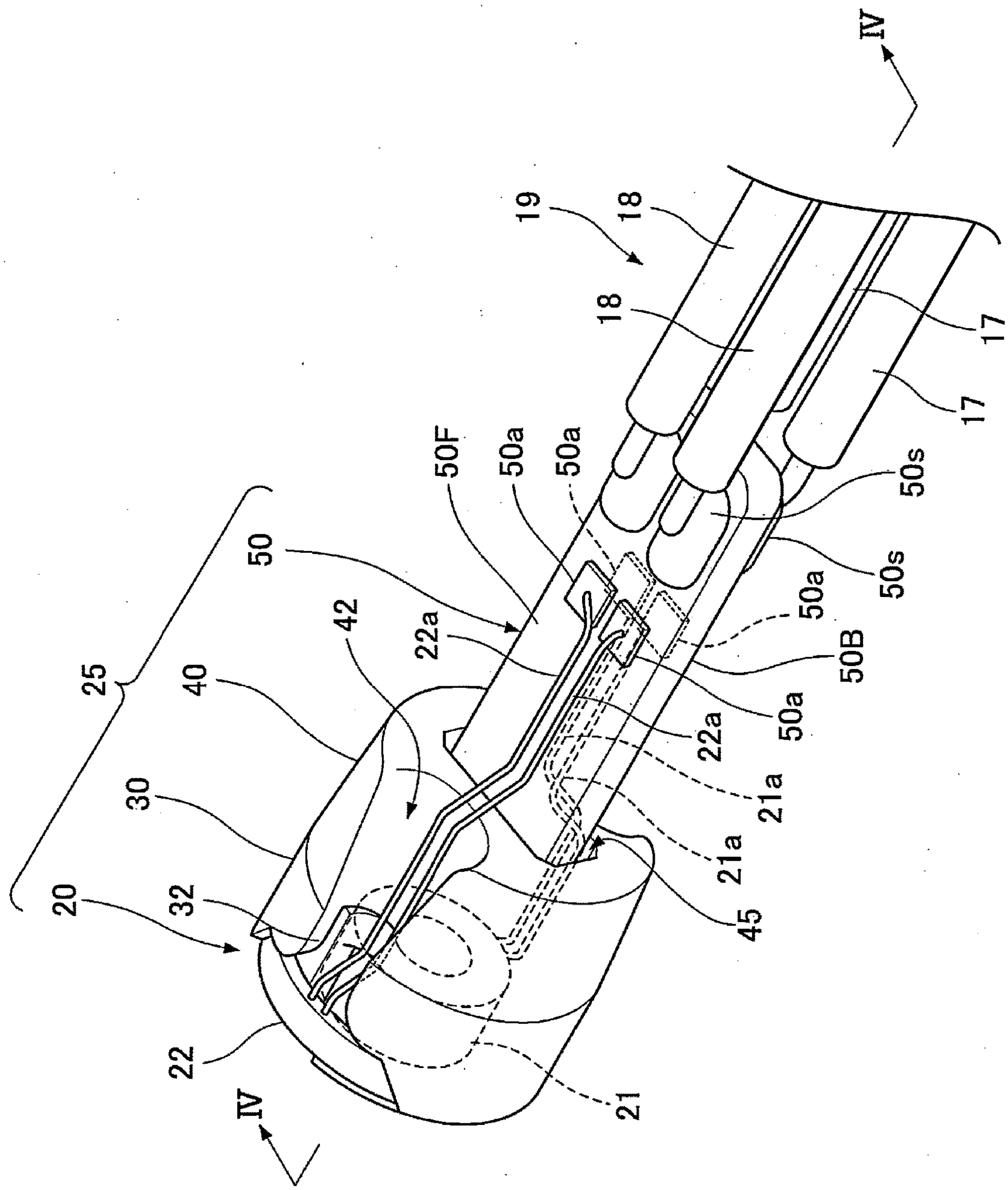

IV
19
18
18
17
17
50F
50a
50a
50s
50s
50
50a
50B
50a
42
22a
22a
21a
21a
25
40
30
32
20
45
22
21
IV

FIG. 3

FIG. 4

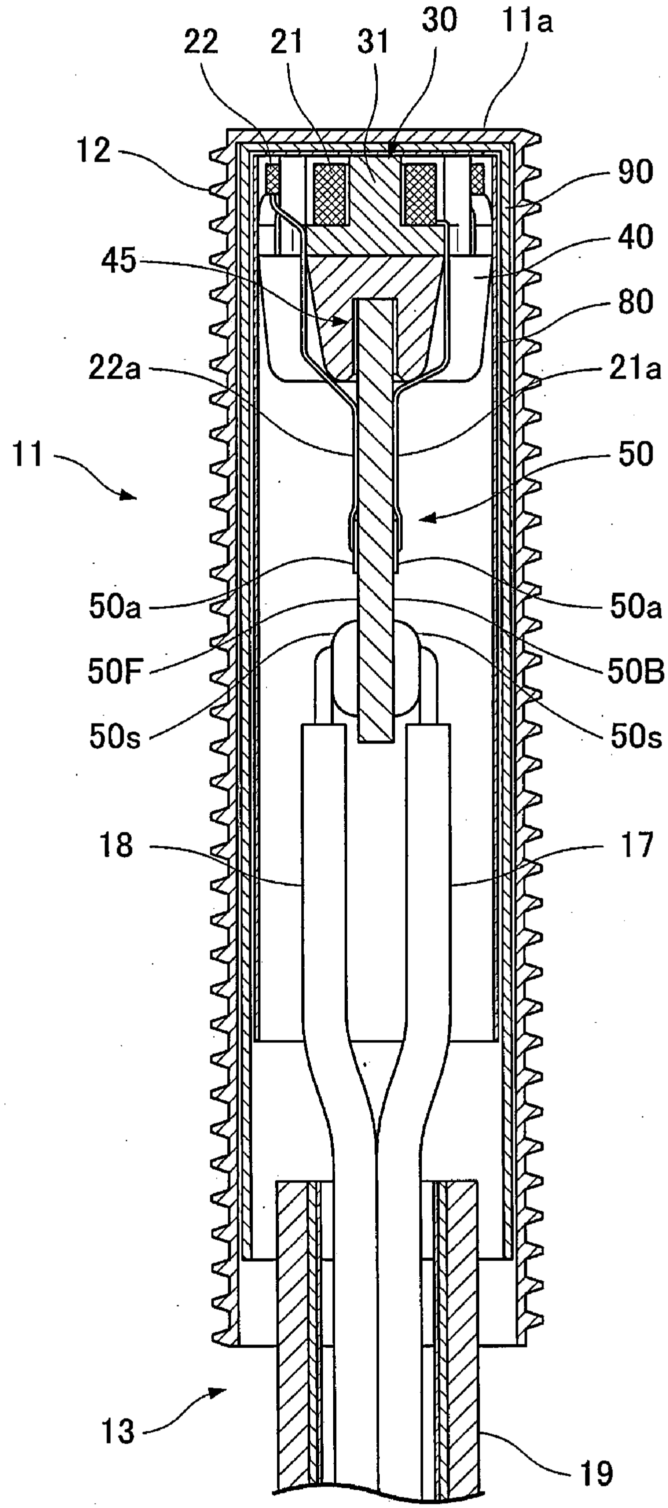

22
21
31
30
11a
12
90
40
45
80
22a
21a
11
50
50a
50a
50F
50B
50s
50s
18
17
13
19

FIG. 5

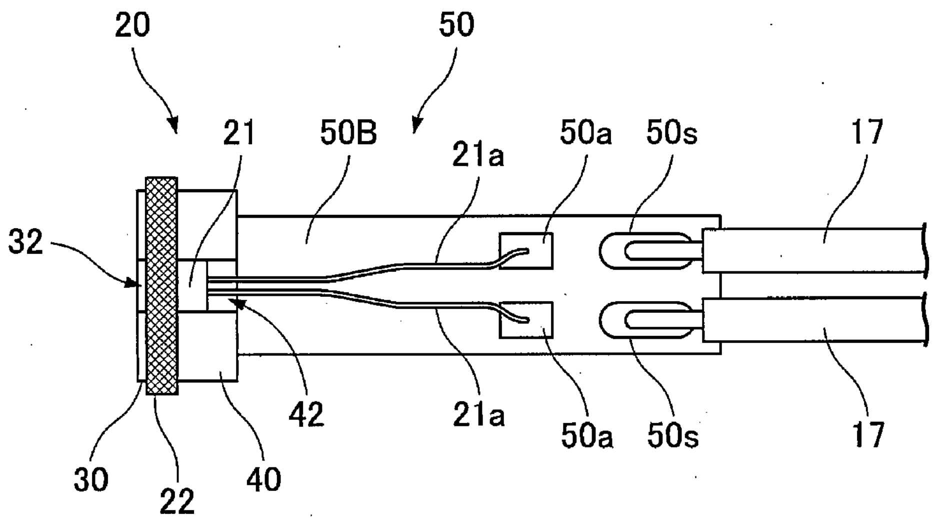

20
50
21
50B
21a
50a
50s
17
32
42
21a
50a
50s
17
30
22
40

FIG. 6

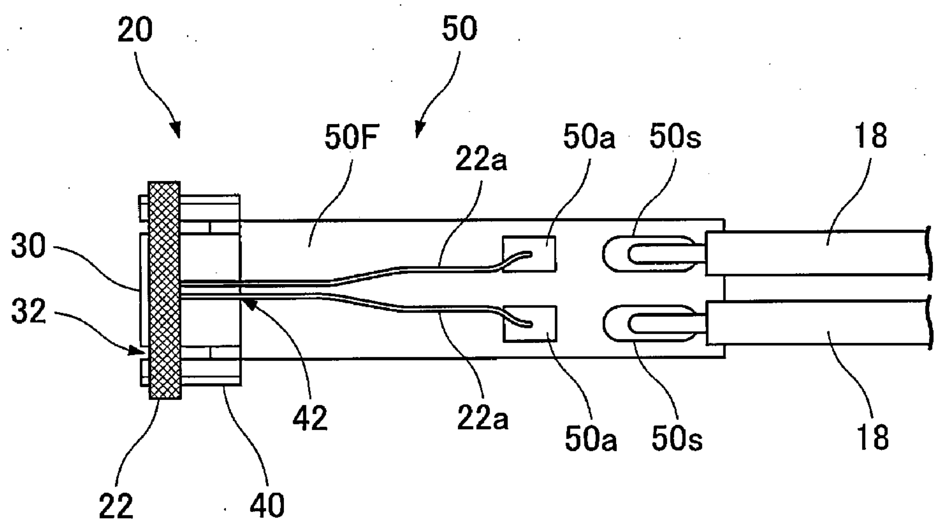

20
50
50F
22a
50a
50s
18
30
32
42
22a
50a
50s
18
22
40

FIG. 7

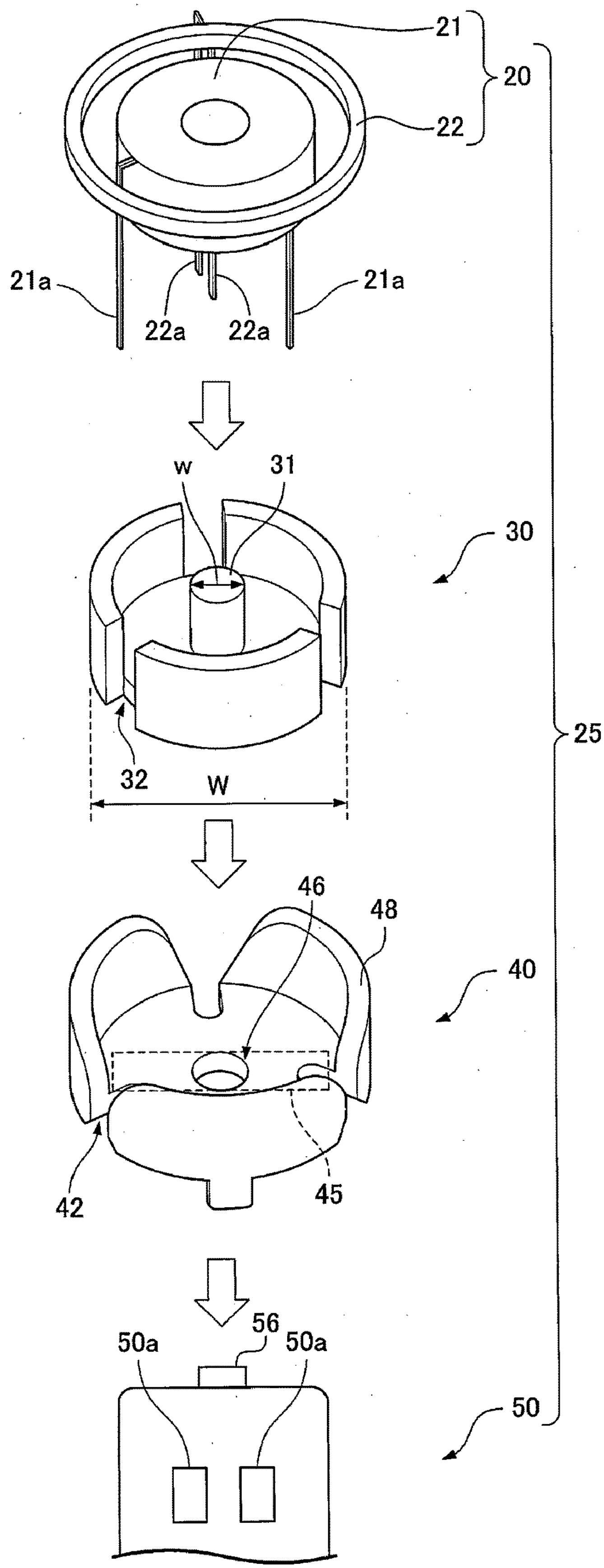


FIG. 8

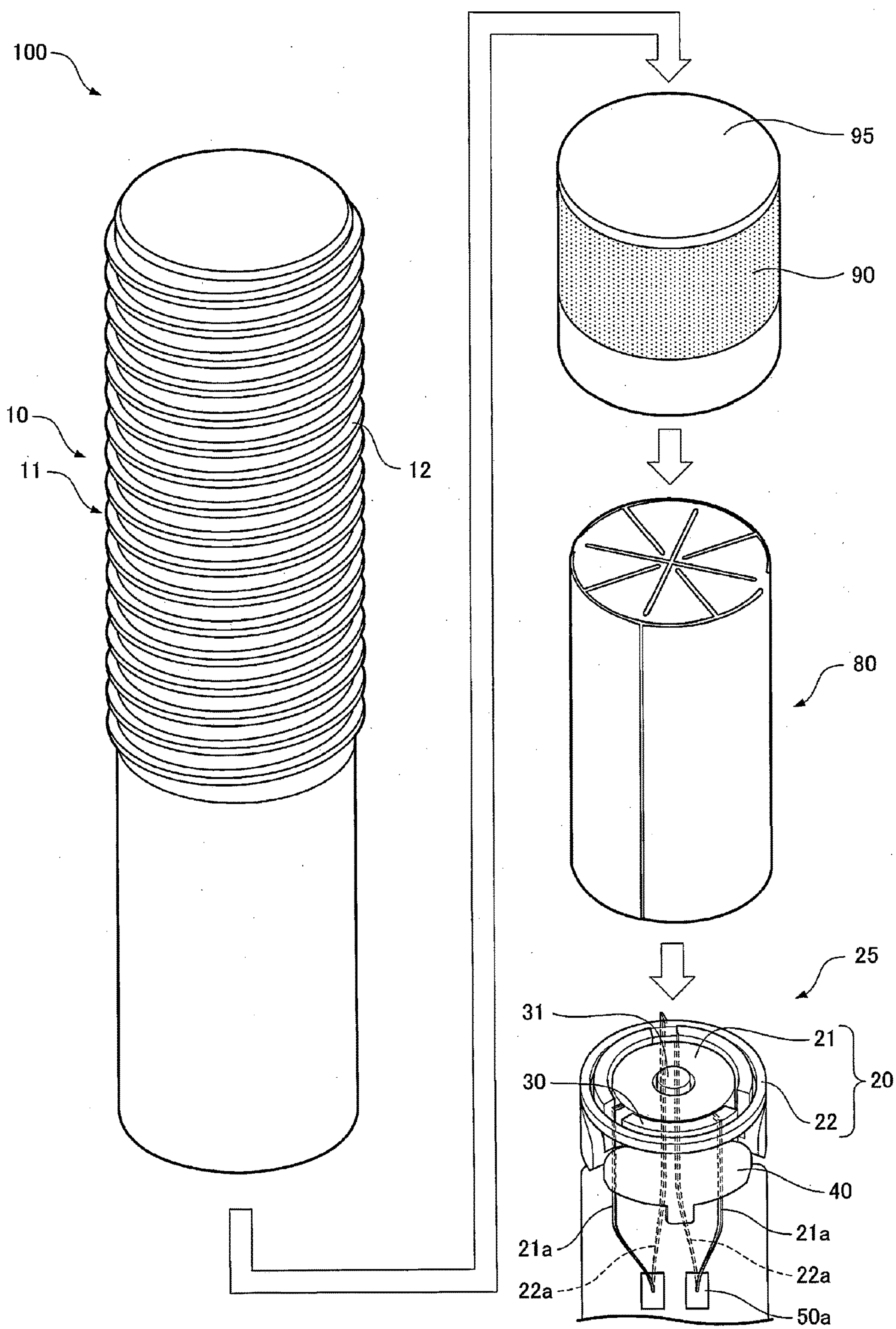


FIG. 9

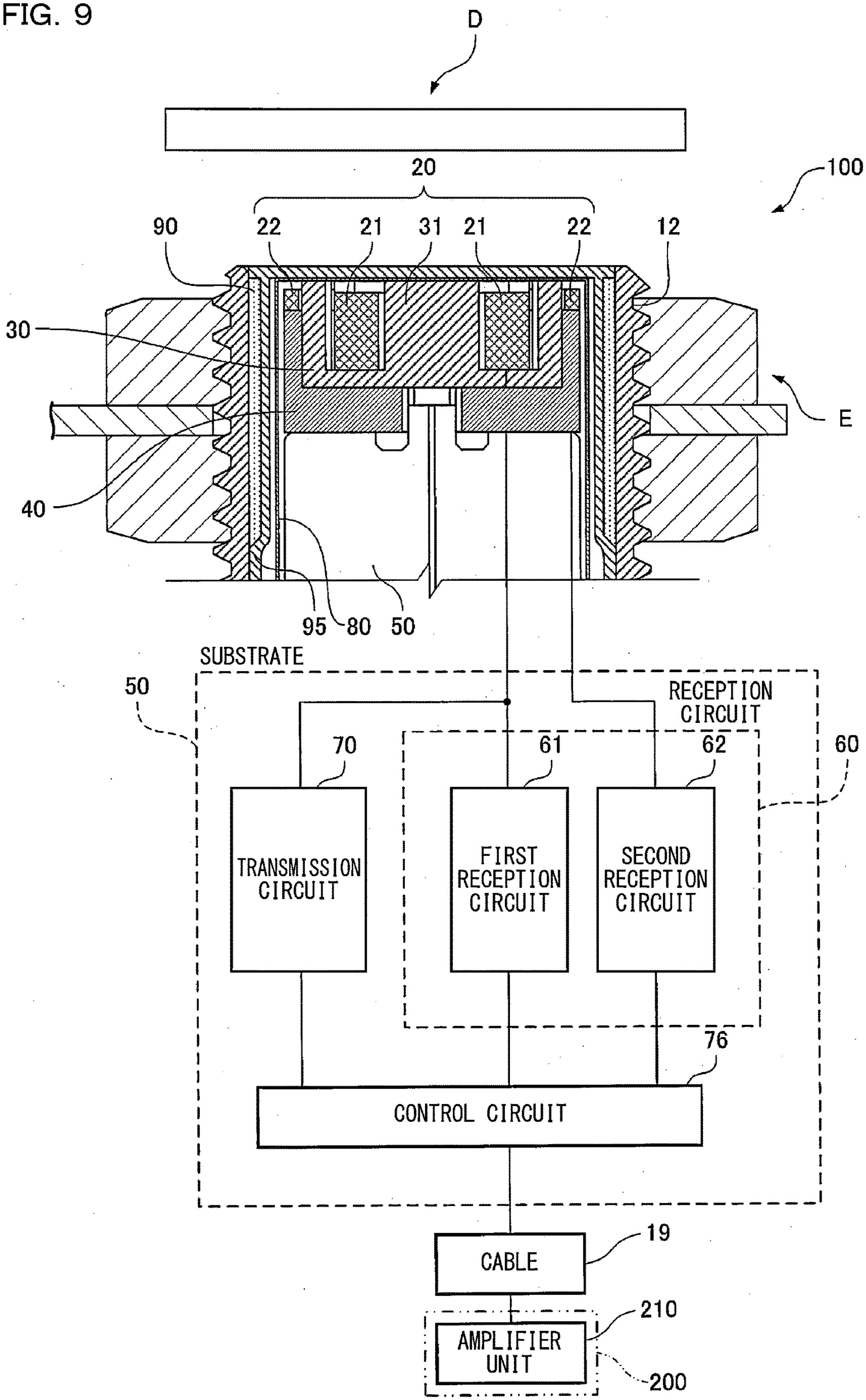

D
20
100
90
22
21
31
21
22
12
30
E
40
95
80
50
SUBSTRATE
50
RECEPTION CIRCUIT
70
61
62
60
TRANSMISSION CIRCUIT
FIRST RECEPTION CIRCUIT
SECOND RECEPTION CIRCUIT
76
CONTROL CIRCUIT
CABLE
19
210
AMPLIFIER UNIT
200

FIG. 10

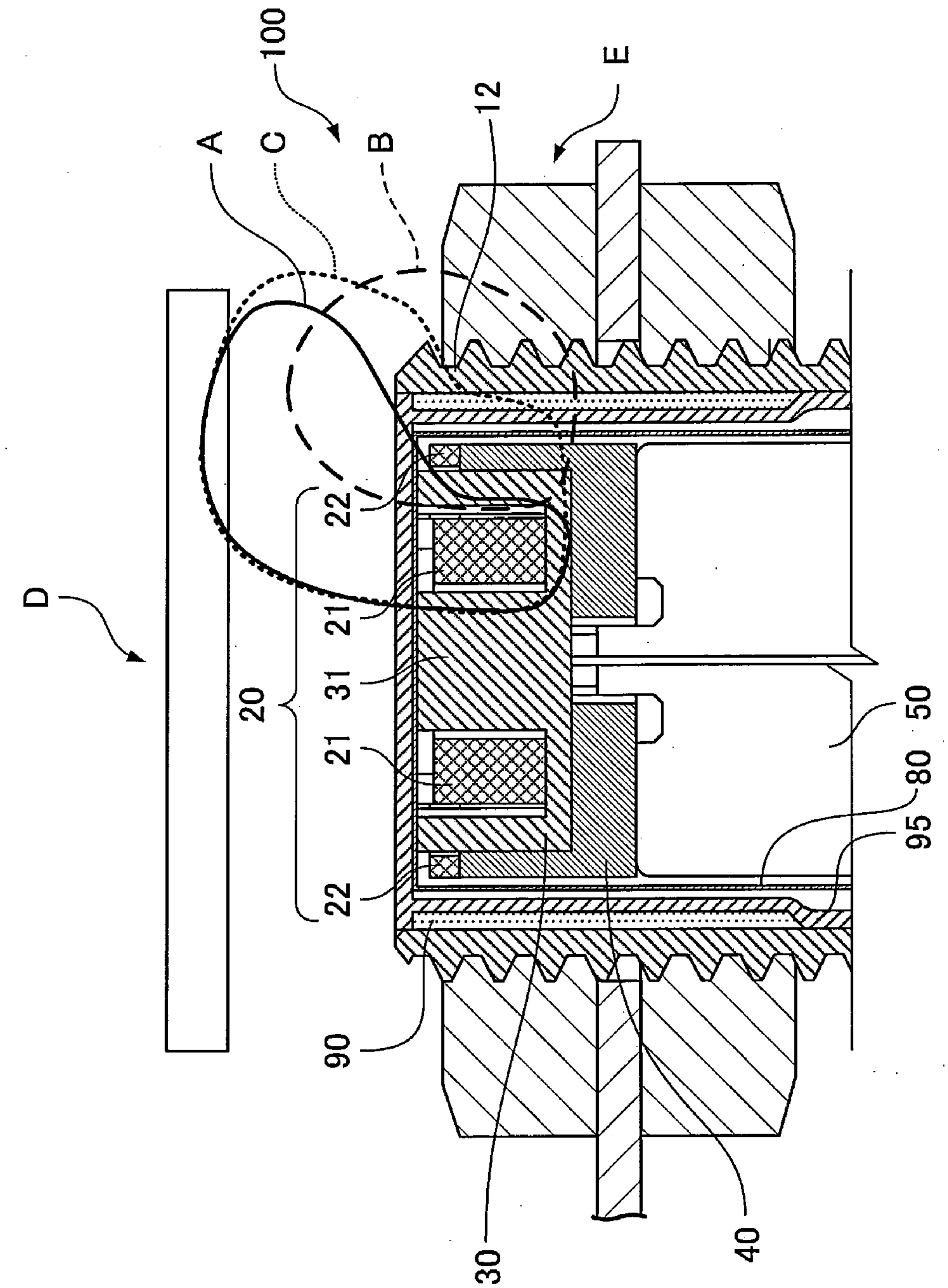


FIG. 11

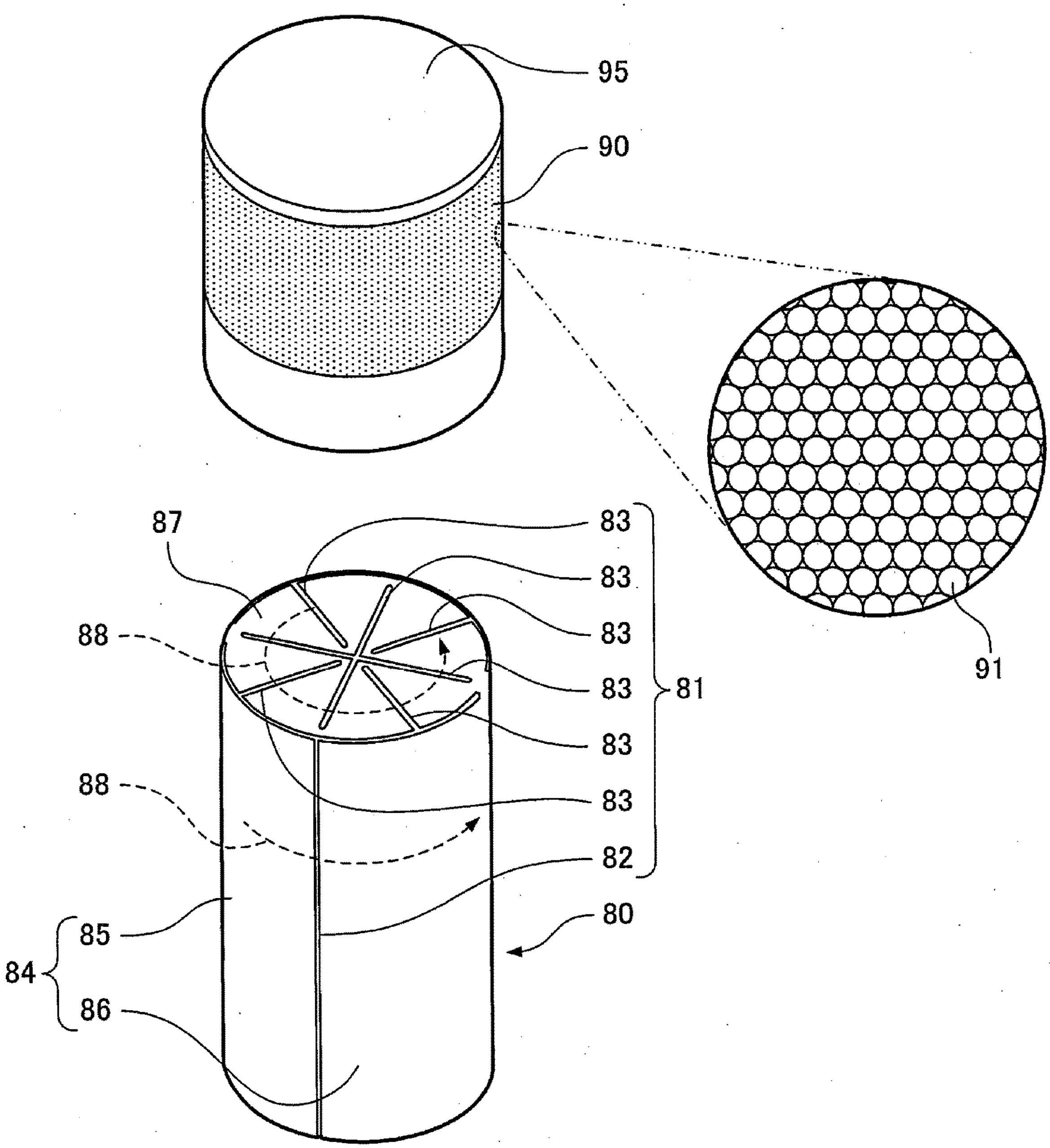
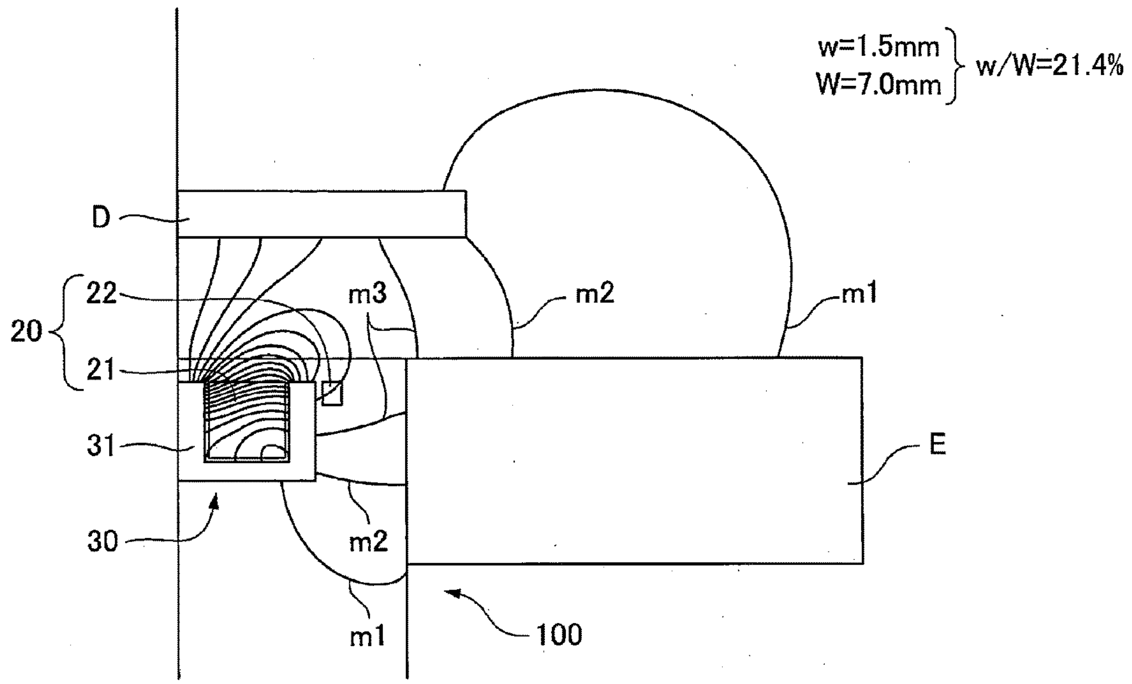


FIG. 12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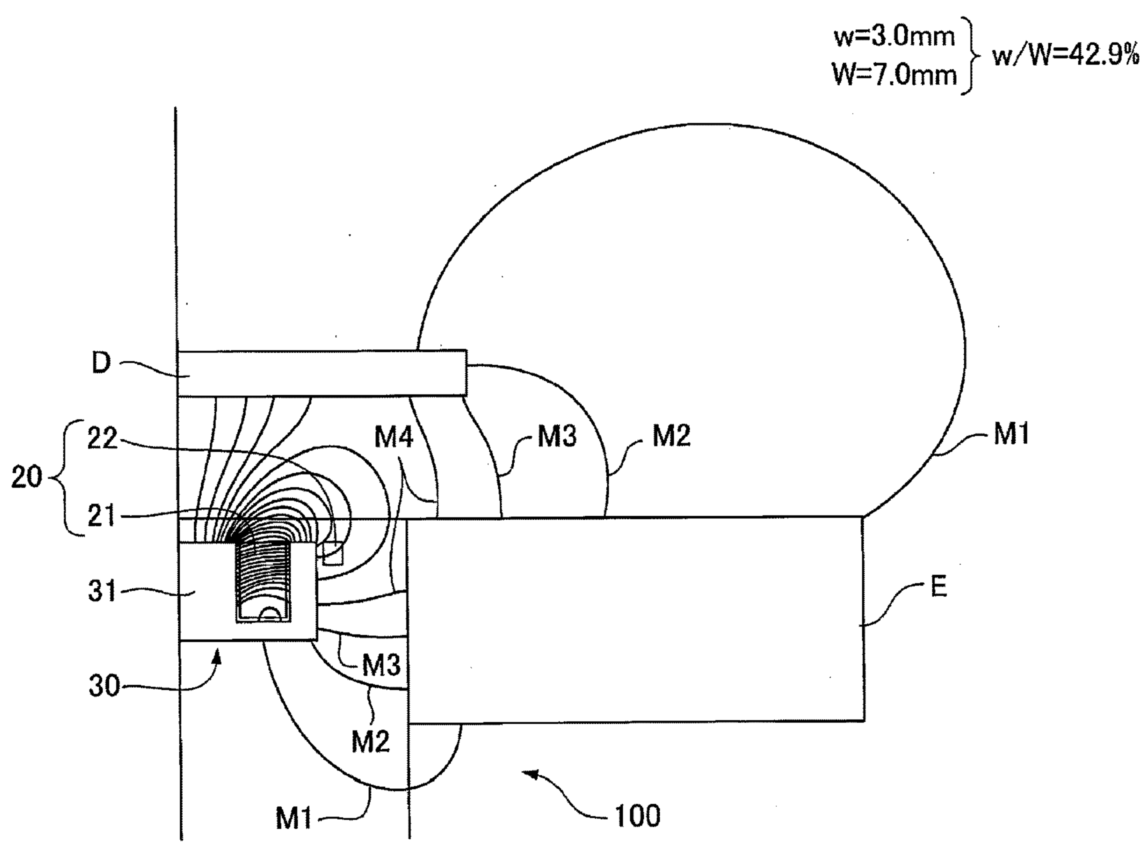
w/W=21.4%
D
20
22
21
31
30
m3
m2
m1
E
m2
m1
100

FIG. 13


w=3.0mm
W=7.0mm
w/W=42.9%
D
20
22
21
31
30
M4
M3
M2
M1
E
M3
M2
M1
100

# PROXIMITY SENSOR

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims foreign priority based on Japanese Patent Application No. 2024-022088, filed Feb. 16, 2024, the contents of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1. Technical Field

**[0002]** The invention relates to a proximity sensor.

### 2. Description of the Related Art

**[0003]** JP 2018-152320 A discloses a proximity sensor. The proximity sensor described in JP 2018-152320 A reduces an influence of a change in coil characteristics and the like.

**[0004]** As illustrated in FIG. **3** of JP 2018-152320 A, the proximity sensor of JP 2018-152320 A is used by being embedded in nuts and washers of reference numerals 7 to 9.

## SUMMARY OF THE INVENTION

**[0005]** Meanwhile, the proximity sensor may fail if it comes into contact with an object to be detected (hereinafter, the detection object) and its peripheral members. For this reason, the proximity sensor is required to extend a distance to be detected (hereinafter, the detection distance) in order to avoid contact with the detection object or the like.

**[0006]** In order to extend the detection distance, the proximity sensor also needs to detect a weak change in the reception waveform. However, since the proximity sensor described in JP 2018-152320 A cannot detect a weak change in the reception waveform due to the influence of an embedded nut, a washer, or the like (hereinafter, an embedded metal), the detection distance cannot be sufficiently extended.

**[0007]** The invention has been made in view of the above problems, and an object thereof is to provide a proximity sensor capable of sufficiently extending a detection distance by suppressing an influence of embedded metal.

**[0008]** According to one aspect of the invention, a proximity sensor includes a coil, a ferrite core, a head housing, and an in-head substrate. The coil generates a magnetic field by an excitation current. The ferrite core guides a magnetic field generated from the coil. The head housing accommodates the coil and the ferrite core. The in-head substrate is accommodated in the head housing. The coil includes a first coil and a second coil. The second coil is disposed concentrically with the first coil. The proximity sensor further includes a transmission circuit, a reception circuit, and a control circuit. The transmission circuit periodically applies a pulsed excitation current to the coil. The reception circuit detects a voltage or a current generated in each of the first coil and the second coil by the magnetic field which is changed by the detection object. The control circuit detects the detection object on the basis of the change in the voltage or the current generated in at least one of the first coil and the second coil detected by the reception circuit. The coil wire of the first coil is electrically connected to the in-head substrate through direct bonding.

**[0009]** According to another aspect of the invention, a proximity sensor includes a coil, a ferrite core, a head housing, a cable, and an amplifier housing. The coil generates a magnetic field by an excitation current. The ferrite core guides a magnetic field generated from the coil. The head housing accommodates the coil and the ferrite core. The cable extends from the head housing. The amplifier housing is connected to the head housing via a cable. The coil includes a first coil and a second coil. The second coil is disposed concentrically with the first coil. The proximity sensor further includes a transmission circuit, a reception circuit, and a control circuit. The transmission circuit periodically applies a pulsed excitation current to the coil. The reception circuit detects a voltage or a current generated in at least one of the first coil and the second coil by the magnetic field which is changed by the detection object. The control circuit detects the detection object on the basis of the change in the voltage or the current generated in each of the first coil and the second coil detected by the reception circuit. The coil wire of the first coil is electrically connected to the cable through direct bonding.

**[0010]** According to still another aspect of the invention, a proximity sensor includes a coil, a ferrite core, and a head housing. The coil generates a magnetic field by an excitation current. The ferrite core guides a magnetic field generated from the coil. The head housing accommodates the coil and the ferrite core. The coil includes a first coil and a second coil. The second coil is disposed outside the first coil in the radial direction. The proximity sensor further includes a transmission circuit, a reception circuit, and a control circuit. The transmission circuit periodically applies a pulsed excitation current to the coil. The reception circuit detects a voltage or a current generated in each of the first coil and the second coil by the magnetic field which is changed by the detection object. The control circuit detects the detection object on the basis of the change in the voltage or the current generated in at least one of the first coil and the second coil detected by the reception circuit. In the head housing, a diameter of a surface facing the detection object is less than 8 mm. The number of windings of the first coil is 100 or more.

**[0011]** According to the proximity sensor of the invention, the detection distance can be sufficiently extended by suppressing the influence of the embedded metal.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** FIG. **1** is an external view of a proximity sensor;

**[0013]** FIG. **2** is an external view of the proximity sensor in a used state;

**[0014]** FIG. **3** is a perspective view illustrating a bonding state between a coil wire and a substrate electrode;

**[0015]** FIG. **4** is a sectional view taken along line IV-IV of FIG. **3**;

**[0016]** FIG. **5** is a view illustrating wiring of a coil wire from a first coil to a substrate electrode;

**[0017]** FIG. **6** is a view illustrating wiring of a coil wire from a second coil to a substrate electrode;

**[0018]** FIG. **7** is an exploded perspective view from a coil constituting the proximity sensor to an in-head substrate;

**[0019]** FIG. **8** is an exploded perspective view of components accommodated in a head housing of the proximity sensor;

**[0020]** FIG. **9** is a block diagram for explaining a main circuit configuration of the proximity sensor;

**[0021]** FIG. **10** is a diagram schematically illustrating magnetic flux lines around a first coil and a second coil;

**[0022]** FIG. **11** is an exploded perspective view for explaining the electric shield and the magnetic shield in detail;

**[0023]** FIG. **12** is a magnetic flux diagram in a case where the shaft body of the ferrite core is thin; and

**[0024]** FIG. **13** is a magnetic flux diagram in a case where the shaft body of the ferrite core is not thin.

## DETAILED DESCRIPTION

**[0025]** Hereinafter, embodiments of the invention will be described with reference to the drawings. Note that, in the drawings, the same or corresponding portions are denoted by the same reference numerals, and the description thereof will not be repeated. In the following description, terms meaning a position or a direction such as "upper", "lower", "left", and "right" may be used. These terms are used for convenience to facilitate understanding of the embodiments, and are not related to the direction in which they are actually implemented unless otherwise expressly stated.

**[0026]** Hereinafter, a proximity sensor **100** according to an embodiment of the invention will be described with reference to the drawings.

**[0027]** First, a situation in which a proximity sensor **100** is used will be described with reference to FIGS. **1** and **2**. FIG. **1** is an external view of the proximity sensor **100**. FIG. **2** is an external view of the proximity sensor **100** in a used state.

**[0028]** As illustrated in FIG. **1**, the proximity sensor **100** has a shape (shield type) that can be fixed by a nut or the like by forming an outer screw **12** on a side surface. The outer screw **12** is formed on an outer surface of a housing body **11** of a head housing **10** disposed near the detection object. The head housing **10** is made of metal, and a head front surface portion **11***a* (the upper end portion in FIG. **1**) facing the detection object is also made of metal. If the head front surface portion **11***a* is made of metal, the proximity sensor **100** is less likely to be damaged even if the head front surface portion **11***a* comes into contact with an object in the surrounding environment such as a detection object.

**[0029]** In the present embodiment, the head housing **10** has a cylindrical shape, and the head front surface portion **11***a* has a circular shape. The diameter of the head housing **10** of the present embodiment is small (small diameter). For example, the diameter of the head front surface portion **11***a* (a surface facing the detection object) is less than 8 mm.

**[0030]** Inside the head housing **10**, a coil **20** for generating a magnetic field and an in-head substrate **50** electrically connected to the coil **20** are disposed. The proximity sensor **100** of the present embodiment uses metal as a detection object. An eddy current is induced in the metal detection object by receiving the magnetic field generated from the coil **20**. The proximity sensor **100** detects a magnetic field (magnetic flux) generated from an eddy current generated in the detection object.

**[0031]** The in-head substrate **50** is electrically connected to the cable **19**. The cable **19** extends from the inside of the head housing **10** to the outside of the head housing **10** through a head base end **13**. The cable **19** is connected to an amplifier housing **200**. The amplifier housing **200** accommodates an amplifier unit **210**. The amplifier unit **210** amplifies the electric signal transmitted from the coil **20** through the cable **19** and transmits the amplified electric signal to an external device (such as a computer). In addition, the amplifier unit **210** supplies power for operating the coil **20** to the coil **20** through the cable **19**.

**[0032]** As illustrated in FIG. **2**, the proximity sensor **100** is fixed to a mounting bracket E**1** with a double nut E**2**, for example. That is, the proximity sensor **100** is embedded in the mounting bracket E**1** and the double nut E**2**. In this state, the proximity sensor **100** detects an embedded metal E such as the mounting bracket E**1** and the double nut E**2** which are not originally detected. Therefore, the proximity sensor **100** according to the embodiment of the invention is configured to suppress the influence of the embedded metal E in order to sufficiently extend the detection distance.

**[0033]** Hereinafter, configurations of the coil **20** and the in-head substrate **50** will be described with reference to FIGS. **3**, **4**, **5**, and **6**. FIG. **3** is a perspective view illustrating a bonding state between coil wires **21***a* and **22***a* and a substrate electrode **50***a*. FIG. **4** is a sectional view taken along line IV-IV of FIG. **3**. FIG. **5** is a view illustrating wiring of the coil wire **21***a* from the first coil **21** to the substrate electrode **50***a*. FIG. **6** is a view illustrating wiring of the coil wire **22***a* from the second coil **22** to the substrate electrode **50***a*. Note that FIG. **5** illustrates one surface **50**B of the in-head substrate **50**, and FIG. **6** illustrates the other surface **50**F of the in-head substrate **50**.

**[0034]** FIGS. **3**, **4**, **5**, and **6** illustrate the coil **20** and the in-head substrate **50** accommodated in the head housing **10** of the proximity sensor **100** in FIG. **1**. The proximity sensor **100** includes a coil **20**, a ferrite core **30**, a core holder **40**, and an in-head substrate **50**. The coil **20**, the ferrite core **30**, the core holder **40**, and the in-head substrate **50** are all accommodated in the head housing **10**. Hereinafter, the coil **20**, the ferrite core **30**, the core holder **40**, and the in-head substrate **50** may be collectively referred to as a sensor unit **25**.

**[0035]** The coil **20** generates a magnetic field by an excitation current. The ferrite core **30** guides the magnetic field generated from the coil **20**. The coil **20** includes a first coil **21** and a second coil **22**. The second coil **22** is disposed outside the first coil **21** in the radial direction. The second coil **22** may be disposed concentrically with the first coil **21**. In the present example, "disposed concentrically" indicates an arrangement relationship in which the circles are not limited to the objects on the same plane, and thus, in a case where the second coil **22** is disposed concentrically with respect to the first coil **21**, the second coil **22** may be disposed on the side where a detection object D is detected (or the opposite side) with respect to the first coil **21**. The first coil **21** is configured by winding the coil wire **21***a*. The second coil **22** is configured by winding the coil wire **22***a*. The magnetic field generated from the coil **20** is preferably guided toward the detection object. Since the ferrite core **30** includes the shaft body **31** and the shaft body **31** is directed to the detection object, the magnetic field generated near the shaft body **31** is easily guided to the detection object. Therefore, it is preferable that the first coil **21** configured to be closer to the shaft body **31** than the second coil **22** generates a magnetic field by the excitation current. Note that the ferrite core **30** in the present embodiment has the shaft body **31** around which the first coil **21** is wound and the peripheral wall (outer peripheral portion) that is located between the first coil **21** and the second coil **22** and is made of a magnetic material, but the ferrite core **30** may have only the shaft body **31**. In addition, the shaft body **31** made of a magnetic material other than ferrite may be disposed. In addition, since the magnetic field itself is generated even without the ferrite core **30**, the proximity sensor **100** may have a configuration without the ferrite core **30**.

**[0036]** In order to ensure sufficient inductance, the number of windings of the first coil **21** is preferably 100 or more, and preferably 200 or more. When the number of windings of the first coil **21** is sufficiently large, the influence of the magnetic field generated from the first coil **21** by the pulsed excitation current passes through the head front surface portion **11***a* and reaches the distant detection object. Therefore, even if the surface of the head housing **10** facing the detection object is made of metal, the detection distance of the proximity sensor **100** becomes sufficiently large. When the linear shape of the coil wire **21***a* of the first coil **21** is sufficiently thin, for example, 0.02 mm or less, even if the diameter of the head front surface portion **11***a* of the head housing **10** is less than 8 mm, the first coil **21** having 200 or more turns can be accommodated in the head housing **10**.

**[0037]** The core holder **40** holds the ferrite core **30**. The core holder **40** positions the second coil **22** and fixes the ferrite core **30** to the in-head substrate **50**. A substrate receiving portion **45** is formed in the core holder **40**. When the end of the in-head substrate **50** is inserted into the substrate receiving portion **45**, the in-head substrate **50** is fixed to the core holder **40**. When the core holder **40** holds the ferrite core **30**, the core holder **40** fixes the ferrite core **30** to the in-head substrate **50**.

**[0038]** A slit **32** extending in the axial direction is formed in a part of the outer periphery of the ferrite core **30**. A slit **42** extending in the axial direction is also formed in a part of the outer periphery of the core holder **40**. The coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** are drawn out to the in-head substrate **50** through the slit **32** of the ferrite core **30** and the slit **42** of the core holder **40**.

**[0039]** The substrate electrode **50***a* is disposed on each of one surface **50**B and the other surface **50**F of the in-head substrate **50**. In FIGS. **3**, **4**, **5**, and **6**, two substrate electrodes **50***a* are disposed on each of one surface **50**B and the other surface **50**F.

**[0040]** At least the coil wire **21***a* of the first coil **21** is preferably electrically connected to the in-head substrate **50** through direct bonding. In the present embodiment, both the coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** are directly bonded to the substrate electrode **50***a* on the in-head substrate **50**.

**[0041]** Direct bonding means that members to be bonded are directly bonded to each other without interposing a brazing material such as solder. For example, the coil wire **21***a* and the coil wire **22***a* are bonded to the substrate electrode **50***a* by a method such as resistance welding, pressure welding, ultrasonic bonding, or friction stir welding, whereby direct bonding is performed.

**[0042]** By performing the direct bonding, the problem of copper erosion in which copper of the conductive wire is dissolved in the solder is avoided even for the thin coil wire **21***a* and the thin coil wire **22***a* (for example, 0.02 mm or less). In addition, soldering the thin coil wire **21***a* and the thin coil wire **22***a* to the substrate electrode **50***a* has a high degree of difficulty in work, but the degree of difficulty in work is often lower in direct bonding than in soldering.

**[0043]** For example, in resistance welding, it is possible to perform direct bonding only by applying a current in a state where the coil wire **21***a* and the coil wire **22***a* are in contact with the substrate electrode **50***a*, and work is easier than soldering in which soldering needs to be performed by soldering.

**[0044]** An intermediary member may be interposed between the coil wire **21***a* of the first coil **21** (or the coil wire **22***a* of the second coil **22**) and the in-head substrate **50**. Even in a case where the coil wire **21***a* or the coil wire **22***a* and the intermediary member are directly bonded and the intermediary member is electrically connected to the in-head substrate **50**, it can be said that the coil wire **21***a* or the coil wire **22***a* is electrically connected to the in-head substrate **50** through direct bonding.

**[0045]** When the coil wire **21***a* or the coil wire **22***a* is electrically connected to the in-head substrate **50** through direct bonding, the first coil **21** and the second coil **22** can be configured by the thin coil wire **21***a* and the thin coil wire **22***a* (for example, 0.02 mm or less). When the first coil **21** and the second coil **22** are constituted by the thin coil wire **21***a* and the thin coil wire **22***a*, even if the number of windings of the first coil **21** and the second coil **22** is large (for example, 100 or more, or 200 or more), the diameter dimension of the coil **20** becomes small. When the diameter dimension of the coil **20** is small, the proximity sensor **100** can have a small diameter (for example, the diameter of the head front surface portion **11***a* is less than 8 mm). If the number of windings of the first coil **21** is sufficiently large, the detection distance becomes sufficiently large even if the head front surface portion **11***a* is made of metal.

**[0046]** The coil wire **21***a* and the coil wire **22***a* are electrically connected to the cable **19** via the substrate electrode **50***a* and wiring (not illustrated) on the in-head substrate **50**. The cable **19** includes a plurality of cable wires. In FIGS. **3**, **4**, **5**, and **6**, two first cable wires **17** electrically connected to the coil wire **21***a* of the first coil **21** and two second cable wires **18** electrically connected to the coil wire **22***a* of the second coil **22** are included in the cable **19**.

**[0047]** The first cable wire **17** is connected to one surface **50**B of the in-head substrate **50**. The second cable wire **18** is connected to the other surface **50**F of the in-head substrate **50**. Connection between the first cable wire **17** and the second cable wire **18** and the in-head substrate **50** may be performed by soldering using solder **50***s*.

**[0048]** Since the first cable wire **17** and the second cable wire **18** are separately disposed on one surface **50**B and the other surface **50**F, respectively, the first coil **21** and the second coil **22** can be electrically connected to the cable **19** even if the dimension of the in-head substrate **50** is small. Therefore, even if the head housing **10** has a small diameter (for example, the diameter of the head front surface portion **11***a* is less than 8 mm), the dimension of the in-head substrate **50** can be set to a dimension capable of being accommodated in the head housing **10**. One of the two first cable wires **17** may be electrically connected to one of the two coil wires **21***a* of the first coil **21**, and the other one of the first cable wires **17** may be electrically connected to one of the two coil wires **22***a* of the second coil **22**. In this case, the remaining one of the coil wires **21***a* of the first coil **21** and the remaining one of the coil wires **22***a* of the second coil **22** are connected to each of the two second cable wires **18**. That is, the first cable wire **17** connected to the one surface **50**B is not limited to being electrically connected to the coil wire **21***a* of the first coil **21**, and the first cable wire **17** is preferably electrically connected to either the coil wire **21***a* of the first coil **21** or the coil wire **22***a* of the second coil

22. Similarly, the second cable wire **18** connected to the other surface **50**F is preferably electrically connected to either the coil wire **21***a* of the first coil **21** or the coil wire **22***a* of the second coil **22**.

**[0049]** Note that the coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** may be electrically connected to the cable **19** via direct bonding without interposing the in-head substrate **50**. For example, the coil wire **21***a* of the first coil **21** may be directly bonded to the first cable wire **17** without using the solder **50***s*. In addition, an intermediary member may be interposed between the coil wire **21***a* of the first coil **21** (or the coil wire **22***a* of the second coil **22**) and the cable **19**. Even in a case where the coil wire **21***a* or the coil wire **22***a* and the intermediary member are directly bonded and the intermediary member is electrically connected to the cable **19**, it can be said that the coil wire **21***a* or the coil wire **22***a* is electrically connected to the cable **19** through direct bonding.

**[0050]** Next, configurations of the coil **20**, the ferrite core **30**, the core holder **40**, and the in-head substrate **50** will be described with reference to FIG. **7**. FIG. **7** is an exploded perspective view from the coil **20** constituting the proximity sensor **100** to the in-head substrate **50**.

**[0051]** As illustrated in FIG. **7**, the first coil **21** and the second coil **22** are concentrically disposed, and the second coil **22** is disposed outside the first coil **21** in the radial direction. In addition, the second coil **22** is shorter than the first coil **21** in a direction (axial direction) orthogonal to the radial direction thereof. That is, the axial dimension of the second coil is smaller than that of the first coil **21**. With such a configuration, the second coil **22** has a lower sensitivity to the magnetic flux with respect to the first coil **21**. For example, in a case where the first coil **21** is used to detect the detection object and the second coil **22** is used to detect the embedded metal E, it is preferable to reduce the influence of the magnetic flux passing through both the detection object and the embedded metal E on the detection result of the second coil **22**. By reducing the sensitivity of the second coil **22** to the magnetic flux with respect to the first coil **21**, the influence of the magnetic flux passing through both the detection object and the embedded metal E is reduced.

**[0052]** As illustrated in FIG. **7**, the ferrite core **30** has a shaft body **31**. The shaft body **31** passes through the hollow portion of the first coil **21**. Hereinafter, in the radial direction, the ratio of the width w of the shaft body **31** to the entire width W of the ferrite core **30** may be referred to as a relative shaft width w/W.

**[0053]** A slit **32** extending in the axial direction is formed in a part of the outer periphery of the ferrite core **30**. In FIG. **7**, three slits **32** are formed. The coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** pass through the slit **32**. In FIG. **7**, two of the coil wires **21***a* of the first coil **21** pass through the two slits **32** on the front side in the drawing, and two of the coil wires **22***a* of the second coil **22** pass through one slit **32** on the back side.

**[0054]** The core holder **40** is made of resin, for example. The slit **42** extending in the axial direction is formed in a part of the outer periphery of the core holder **40**. In FIG. **7**, three slits **42** are formed. The coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** pass through the slit **42**. In FIG. **7**, two of the coil wires **21***a* of the first coil **21** pass through the two slits **42** on the front side in the drawing, and two of the coil wires **22***a* of the second coil **22** pass through one slit **42** on the back side.

**[0055]** The core holder **40** fixes the ferrite core **30** to the in-head substrate **50** by receiving the in-head substrate **50** with the recessed substrate receiving portion **45** formed on the lower surface while holding the ferrite core **30**. Note that a holder hole **46** is formed at the center of the substrate receiving portion **45**, and a substrate protrusion **56** formed at the tip of the in-head substrate **50** is inserted into the holder hole **46**, whereby the in-head substrate **50** is fixed to the core holder **40**. When the core holder **40** fixes the in-head substrate **50**, positioning accuracy between the in-head substrate **50** and the coil **20** is enhanced, and the proximity sensor **100** can be manufactured in a space-saving manner.

**[0056]** An upper surface **48** of the circumferential edge portion of the core holder **40** supports the second coil **22**. Since the upper surface **48** of the circumferential edge portion supports the second coil **22**, the core holder **40** positions the second coil **22**.

**[0057]** Next, the arrangement of the electric shield **80** and the magnetic shield **90** used for the proximity sensor **100** will be described with reference to FIG. **8**. FIG. **8** is an exploded perspective view of components housed in the head housing **10** of the proximity sensor **100**.

**[0058]** In addition to the sensor unit **25**, an electric shield **80** and a magnetic shield **90** are further accommodated in the head housing **10** of the proximity sensor **100**.

**[0059]** The electric shield **80** covers the sensor unit **25**. The electric shield **80** completely covers the coil **20**, the ferrite core **30**, and the core holder **40** in the sensor unit **25**, and partially covers the in-head substrate **50**.

**[0060]** The magnetic shield **90** covers the sensor unit **25** together with the electric shield **80**. The magnetic shield **90** partially covers the electric shield **80**. The magnetic shield **90** completely covers the coil **20**, the ferrite core **30**, and the core holder **40** in the sensor unit **25**, and partially covers the in-head substrate **50**.

**[0061]** The head housing **10** has a housing body **11** in which an outer screw **12** is formed. As illustrated in FIG. **8**, the housing body **11** completely covers the magnetic shield **90**, the electric shield **80**, and the sensor unit **25**.

**[0062]** Hereinafter, a main circuit configuration of the proximity sensor **100** will be described with reference to FIG. **9**. FIG. **9** is a block diagram for explaining a main circuit configuration of the proximity sensor **100**.

**[0063]** As illustrated in FIG. **9**, the proximity sensor **100** further includes a transmission circuit **70**, a reception circuit **60**, and a control circuit **76** as main circuit configurations.

**[0064]** The transmission circuit **70** periodically applies a pulsed excitation current to the coil **20**. The coil **20** generates a magnetic field by periodically flowing a pulsed excitation current. The coil **20** includes a first coil **21** and a second coil **22**. The second coil **22** is disposed outside the first coil **21** in the radial direction. The transmission circuit **70** may include, for example, an excitation circuit that generates a pulsed excitation current on the basis of a signal from the control circuit **76** and causes the pulsed excitation current to flow to the first coil **21**. As illustrated in FIG. **9**, a part (outer peripheral portion) of the ferrite core **30** is located between the first coil **21** and the second coil **22**, but a magnetic material different from the ferrite core **30** may be located between the first coil **21** and the second coil **22**. In any case, since the magnetic material is disposed between the first coil **21** and the second coil **22**, the size (diameter dimension) of the entire coil **20** includes not only the sizes of the first coil **21** and the second coil **22** but also the size of the magnetic material. However, in the present embodiment, since the coil wire **21***a* of the first coil **21** and the coil wire **22***a* of the second coil **22** are thin, even if the number of windings is 100 or more (or 200 or more), the first coil **21** and the second coil **22** are small, and the entire coil **20** can be accommodated in a small head housing **10** having a diameter of less than 8 mm.

**[0065]** In a case where the detection object D is within the detection range, an eddy current is generated in the detection object D by the magnetic field generated from the coil **20**. A magnetic field is generated from the detection object D by the eddy current of the detection object D. Here, since the excitation current flowing through the coil **20** is pulsed, the magnetic field generated from the coil **20** is rapidly weakened. Therefore, the eddy current of the detection object D also weakens, and accordingly, the magnetic field generated from the detection object D also weakens. In order to prevent the weakening of the magnetic field generated from the detection object D, a voltage or a current is generated in the coil **20**.

**[0066]** The reception circuit **60** detects a voltage or a current generated in each of the first coil **21** and the second coil **22**. Since the first coil **21** and the second coil **22** have different arrangements, characteristics of the generated voltage or current are also different. By detecting voltages or currents having different characteristics, an arithmetic operation for suppressing the influence of the embedded metal E becomes efficient. The reception circuit **60** may include, for example, a braking resistor that adjusts the current flowing from the coil **20**, a filter circuit that performs filtering processing on the analog signal of the reception waveform, an amplifier circuit that amplifies the filtered analog signal, and an A/D conversion circuit that converts the amplified analog signal into a digital signal. Note that the reception circuit **60** may be configured to detect a voltage or a current generated in at least one of the first coil **21** and the second coil **22**.

**[0067]** The control circuit **76** detects the detection object D on the basis of the change in the voltage or the current detected by the reception circuit **60**. Preferably, the control circuit **76** detects the detection object D on the basis of a change in the voltage or the current generated in each of the first coil **21** and the second coil **22**. As a result, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E. The control circuit **76** is connected to the amplifier unit **210** of the amplifier housing **200** via the cable **19**. The control circuit **76** may include, for example, an arithmetic circuit that performs an arithmetic operation for detecting the detection object D on the basis of at least one of the first reception waveform and the second reception waveform, and an output circuit that outputs a result of the arithmetic operation of the arithmetic circuit to the outside (such as the amplifier unit **210**) via the cable **19**.

**[0068]** In the example illustrated in FIG. **9**, the first coil **21** generates a magnetic field by periodically flowing a pulsed excitation current from the transmission circuit **70**. In the present embodiment, only the first coil **21** generates the magnetic field by the excitation current, but the coil **20** that generates the magnetic field by the excitation current may be only the second coil **22**, or may be both the first coil **21** and the second coil **22**. In a case where an excitation current is applied to only one of the first coil **21** and the second coil **22** to generate a magnetic field, it is preferable to apply an excitation current only to the first coil **21** to generate a magnetic field. As described above, the detection result by the first coil **21** is different from the detection result by the second coil **22**, but in order to extend the detection distance, it is preferable that both detection results are easily affected by the detection object D. In a case where the magnetic field generated from the coil **20** is directed to a range in which the detection object D can be located, that is, a detection range, the detection result by the coil **20** is easily affected by the detection object D. The coil **20** through which the excitation current flows is preferably a coil wound close to a shaft body **31** of the ferrite core **30** to generate a magnetic field by causing the excitation current to flow through the first coil **21** since the generated magnetic field is easily directed to the detection range. In addition, in a case where an excitation current is caused to flow through both the first coil **21** and the second coil **22** to generate a magnetic field, for example, by directing the direction of the magnetic field of the first coil **21** to the detection object D and directing the direction of the magnetic field of the second coil **22** to the embedded metal E, it is possible to obtain a detection result in which the magnetic field of the first coil **21** and the magnetic field of the second coil **22** interfere with each other and the influence of the embedded metal E is reduced.

**[0069]** In the example illustrated in FIG. **9**, the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** are provided on the in-head substrate **50**. By providing the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** on the in-head substrate **50**, the circuit configuration is stabilized. The transmission circuit **70**, the reception circuit **60**, and the control circuit **76** are not limited to being provided on the in-head substrate **50**. For example, the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** may be provided in another member, for example, the amplifier housing **200**. Furthermore, any one or two of the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** may be provided on the in-head substrate **50**, and other circuits may be provided on another substrate (a substrate disposed inside or outside the head housing **10**, for example, a substrate in the amplifier housing **200**).

**[0070]** The reception circuit **60** includes a first reception circuit **61** and a second reception circuit **62**. The first reception circuit **61** detects a voltage or a current generated in the first coil **21**. The second reception circuit **62** detects a voltage or a current generated in the second coil **22**. Hereinafter, the temporal change of the voltage or the current detected by the reception circuit **60** may be referred to as a reception waveform. The temporal changes of the voltage or the current detected by the first reception circuit **61** and the second reception circuit **62** may be referred to as a first reception waveform and a second reception waveform, respectively.

**[0071]** Since the reception circuit **60** includes the first reception circuit **61** and the second reception circuit **62**, it is not necessary to switch the reception circuit **60** between the case of detecting the voltage or the current generated in the first coil **21** and the case of detecting the voltage or the current generated in the second coil **22**. That is, since the reception circuit **60** includes the first reception circuit **61** and the second reception circuit **62**, it is possible to simultaneously detect a voltage or a current generated in the first coil **21** and a voltage or a current generated in the second coil **22**.

Therefore, the proximity sensor **100** can sufficiently extend the detection distance by improving the detection accuracy.

**[0072]** Hereinafter, a magnetic field and a magnetic flux line thereof will be described with reference to FIG. **10**. FIG. **10** is a diagram schematically illustrating magnetic flux lines around the first coil **21** and the second coil **22**.

**[0073]** As illustrated in FIG. **10**, the core holder **40** holds the ferrite core **30** and positions the second coil **22**. When the core holder **40** positions the second coil **22**, the arrangement of the second coil **22** is stabilized regardless of the ferrite core **30**. As the arrangement of the second coil **22** is stabilized, the second reception waveform is stably detected. Therefore, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E.

**[0074]** In addition, since the axial dimension of the second coil **22** is smaller than the axial dimension of the first coil **21**, the magnetic flux lines passing through the embedded metal E are reduced. Therefore, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E.

**[0075]** The second coil **22** is located on the side (distal end side) where the detection object D is detected with respect to the first coil **21**. Since the second coil **22** is located on the distal end side of the first coil **21**, the magnetic flux lines passing through the embedded metal E are reduced. Therefore, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E.

**[0076]** The second coil **22** is preferably located on the distal end side. This is because the magnetic flux lines passing through the embedded metal E decrease as the second coil **22** is located on the more distal end side. Therefore, it is more preferable that the second coil **22** abuts on a member on the most distal end side of the proximity sensor **100**.

**[0077]** In FIG. **10**, the magnetic flux line received only by the first coil **21** is indicated by a thick line of a symbol A, the magnetic flux line received only by the second coil **22** is indicated by a broken line of a symbol B, and the magnetic flux lines received by both the first coil **21** and the second coil **22** are indicated by a dotted line of a symbol C.

**[0078]** The magnetic flux line (thick line: symbol A) received only by the first coil **21** has a high rate of generating a reception waveform based on the detection object D. The magnetic flux line (broken line: symbol B) received only by the second coil **22** has a high rate of generating a reception waveform based on the embedded metal E. The magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** have a high rate of generating a reception waveform based on both the detection object D and the embedded metal E.

**[0079]** Therefore, by reducing the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22**, the respective ratios of the reception waveform based on the detection object D and the reception waveform based on the embedded metal E relatively increase. When the ratio between the reception waveform based on the detection object D and the reception waveform based on the embedded metal E increases, the reception waveform based on the embedded metal E can be easily grasped, leading to reduction of the influence of the embedded metal E.

**[0080]** As compared with FIG. **10**, the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** form a path avoiding the embedded metal E. In order to achieve the state illustrated in FIG. **10**, the magnetic shield **90** and the ferrite core **30** are appropriately provided.

**[0081]** As illustrated in FIG. **10**, by appropriately arranging the magnetic shield **90**, the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** form a path that further avoid the embedded metal E. This is because the magnetic shield **90** guides the magnetic flux lines with relative magnetic permeability of a certain degree or more.

**[0082]** By forming the ferrite core **30** into an appropriate shape, the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** form a path that further avoids the embedded metal E. This is because the shape of the ferrite core **30** causes the magnetic flux lines to further face the distal end side.

**[0083]** Hereinafter, the magnetic shield **90** will be described in detail with reference to FIGS. **10** and **11**. FIG. **11** is an exploded perspective view for explaining the electric shield **80** and the magnetic shield **90** in detail.

**[0084]** As illustrated in FIG. **10**, the magnetic shield **90** is disposed outside the second coil **22** in the radial direction. With this arrangement, the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** are guided along the magnetic shield **90**, so that a path that further avoids the embedded metal E is obtained. Therefore, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E.

**[0085]** In the proximity sensor **100**, the magnetic shield **90** is more preferable toward the outer side in the radial direction. This is because the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** are guided in a direction to further avoid the embedded metal E. For example, the magnetic shield **90** is disposed outside the electric shield **80** (and inside the head housing **10**) in the radial direction. The magnetic shield **90** may constitute the head housing **10**.

**[0086]** As illustrated in FIG. **11**, the magnetic shield **90** includes a sheet member kneaded with ferromagnetic powder **91** (for example, metal powder). Since the magnetic shield **90** is formed of a sheet member kneaded with the ferromagnetic powder **91**, the magnetic shield has a relative magnetic permeability higher (to some extent or more) than air and a low electric conductivity. The sheet member may be formed by compacting the ferromagnetic powder **91**. The magnetic shield **90** appropriately guides the magnetic flux lines with relative magnetic permeability higher than air. The magnetic shield **90** has a low electrical conductivity, so that an eddy current loop in the magnetic shield **90** can be suppressed without performing insulation treatment. By suppressing the eddy current loop, noise to the reception waveform is suppressed. Therefore, the proximity sensor **100** including such a magnetic shield **90** can sufficiently extend the detection distance by improving the detection accuracy.

**[0087]** The ferromagnetic powder **91** constituting the magnetic shield **90** is, for example, iron powder. Since the magnetic shield **90** is formed of a sheet member kneaded with iron powder, the magnetic shield has a relatively high relative magnetic permeability (about 200 to 300). The sheet member kneaded with iron powder is, for example, an electromagnetic wave absorbing sheet. In this example, a sheet member kneaded with the ferromagnetic powder **91** is used as the magnetic shield **90**, but the entire magnetic shield **90** may be an amorphous ferromagnetic member. For example, it may be amorphous.

**[0088]** Note that a permalloy sheet, a cobalt sheet, or the like is not suitable as the magnetic shield **90**. This is because a permalloy sheet, a cobalt sheet, or the like has a high relative magnetic permeability (about 1000 to several tens of thousands) but has a high electrical conductivity. The high electrical conductivity leads to the generation of the eddy current loop.

**[0089]** The magnetic shield **90** is wound around an outer periphery of a resin cap **95** having a bottomed cylindrical shape. The resin cap **95** has a function of protecting a member accommodated inside the resin cap **95**. The magnetic shield **90** is wound around the outer periphery of the resin cap **95**, whereby the arrangement on the outer side in the radial direction is stabilized. Instead of the resin cap **95** made of resin, a cap other than resin may be used. The magnetic shield **90** is disposed outside the cap regardless of whether or not the cap is made of resin.

**[0090]** Hereinafter, details of the electric shield **80** will be described with reference to FIG. **11**. The electric shield **80** is a bottomed cylindrical metal body that protects the coil **20** and the ferrite core **30** from external noise.

**[0091]** As illustrated in FIG. **11**, the electric shield **80** is disposed outside the second coil **22** in the radial direction. A cut **81** is formed in the electric shield **80**. The cut **81** is transverse to a direction **88** around the axis of the electric shield **80**. Specifically, the longitudinal direction of the cut **81** intersects (preferably is orthogonal to) the direction **88** around the axis.

**[0092]** By the cut **81** intersecting the direction **88** around the axis of the electric shield **80**, a loop of an eddy current which is a current around the axis is suppressed in the electric shield **80**. By suppressing the eddy current loop, noise to the reception waveform is suppressed. Therefore, the proximity sensor **100** including such an electric shield **80** can sufficiently extend the detection distance by improving the detection accuracy.

**[0093]** The electric shield **80** includes a peripheral portion **84** and a detection surface portion **87**. The peripheral portion **84** covers the second coil **22** from the outside in the radial direction. The detection surface portion **87** closes the distal end side which is one end of the peripheral portion **84**. The detection surface portion **87** is located on the side where the detection object D is detected.

**[0094]** The cut **81** has a peripheral cut **82** and a detection surface cut **83**. The peripheral cut **82** is formed in the peripheral portion **84**. The detection surface cut **83** is formed in the detection surface portion **87**.

**[0095]** By the peripheral cut **82**, an eddy current loop is suppressed in the peripheral portion **84**. The peripheral cut **82** facilitates the manufacture of the electric shield **80**. The detection surface cut **83** efficiently suppresses the eddy current loop in the detection surface portion **87**.

**[0096]** The electric shield **80** has a sheet metal configuration. That is, the electric shield **80** is obtained by bending a thin metal plate. Since the electric shield **80** has the sheet metal configuration, the shape is stabilized even if the strength is reduced due to the cut **81**. The thin metal plate before being bent as the electric shield **80** may be punched out. The electric shield **80** has a bottomed cylindrical three-dimensional shape by pressing the punched thin metal plate. That is, the electric shield **80** may be a press-molded product of a punched thin metal plate. The shape of such an electric shield **80** is further stabilized even if the strength is reduced by the cut **81**. The thin metal plate constituting the electric shield **80** may be, for example, copper foil or brass foil. The electric shield **80** is not limited to the sheet metal configuration. For example, the electric shield **80** may be a coating molded product or a vapor deposition molded product. The coating molded product or the vapor deposition molded product is molded by applying or vapor depositing a conductive material on a bottomed cylindrical resin mold. Since a current flows through the electric shield **80**, the electric shield **80** is preferably electrically connected to the ground (GND, reference potential). In the present embodiment, for example, a shielded cable (not illustrated) serving as a reference potential is included in the first cable wire **17**, and the shielded cable is electrically connected to the electric shield **80**.

**[0097]** Hereinafter, the ferrite core **30** will be described in detail with reference to FIGS. **12** and **13**. FIG. **12** is a magnetic flux diagram in a case where the shaft body **31** of the ferrite core **30** is thin. FIG. **13** is a magnetic flux diagram in a case where the shaft body **31** of the ferrite core **30** is not thin. FIG. **12** illustrates magnetic flux lines in a case where the width w of the shaft body **31** in the radial direction is **1.5** mm in the electromagnetic field simulation, and FIG. **13** illustrates magnetic flux lines in a case where the width w of the shaft body **31** in the radial direction is 3 mm in the electromagnetic field simulation.

**[0098]** In the example illustrated in FIG. **12**, the width w of the shaft body **31** is 1.5 mm and the width W of the entire ferrite core **30** is 7 mm in the radial direction, and the relative shaft width w/W is 21.4%. That is, the relative shaft width w/W is 30% or less. As illustrated in FIG. **12**, three magnetic flux lines m**1** to m**3** pass through the embedded metal E.

**[0099]** On the other hand, in the example illustrated in FIG. **13**, the width w of the shaft body **31** is 3 mm and the width W of the entire ferrite core **30** is 7 mm in the radial direction, and the relative shaft width w/W is 42.9%. That is, the relative shaft width w/W is more than 30%. As illustrated in FIG. **13**, four magnetic flux lines M**1** to M**4** pass through the embedded metal E.

**[0100]** As is clear from the comparison between FIGS. **12** and **13**, in FIG. **12** in which the relative shaft width w/W has been 30% or less, the number of magnetic flux lines passing through the embedded metal E has been as small as 3, and in FIG. **13** in which the relative shaft width w/W has been more than 30%, the number of magnetic flux lines passing through the embedded metal E has been as large as 4. Therefore, it is found that the influence of the embedded metal E is suppressed when the relative shaft width w/W is 30% or less.

**[0101]** When the relative shaft width w/W is less than 15%, it is difficult to manufacture the ferrite core **30**. Therefore, it can be said that the relative shaft width w/W is preferably 30% or less, and more preferably 15% or more and 30% or less.

**[0102]** The embodiment is illustrative in all respects and is not restrictive. The scope of the invention is indicated not by the above description but by the claims, and it is intended that meanings equivalent to the claims and all modifications within the scope are included. Among the configurations described in the embodiment, configurations other than the configuration described as one aspect of the invention in "means for solving problems" are arbitrary configurations, and can be appropriately deleted and changed.

**[0103]** (1) In the embodiment, the magnetic shield **90** and the electric shield **80** are illustrated as cylindrical shapes, but may have other shapes such as a square tube shape.

**[0104]** (2) Although the mounting bracket E**1** and the double nut E**2** have been described as the embedded metal E in which the proximity sensor **100** is embedded, other metals may be used. The other metal is a single nut, a metal block on which an inner screw is formed, or the like. The embedded metal E is merely metal in which the proximity sensor **100** is embedded, and is not a configuration of the proximity sensor **100** itself.

**[0105]** (3) In the embodiment, the transmission circuit **70** is illustrated as one, but the transmission circuit **70** may include a first transmission circuit and a second transmission circuit. The first transmission circuit periodically applies a pulsed excitation current to the first coil **21**, and the second transmission circuit periodically applies a pulsed excitation current to the second coil **22**.

**[0106]** The invention provides a proximity sensor, and has industrial applicability.

What is claimed is:

**1**. A proximity sensor comprising:

a coil that generates a magnetic field by an excitation current;

a ferrite core that guides the magnetic field generated from the coil;

a head housing that accommodates the coil and the ferrite core; and

an in-head substrate that is accommodated in the head housing, wherein

the coil includes:

a first coil; and

a second coil disposed concentrically with the first coil,

the proximity sensor further comprises:

a transmission circuit that periodically applies a pulsed excitation current to the coil;

a reception circuit that detects a voltage or a current generated in at least one of the first coil and the second coil by the magnetic field which is changed by a detection object; and

a control circuit that detects the detection object on a basis of a change in the voltage or the current detected by the reception circuit, and

a coil wire of the first coil is electrically connected to the in-head substrate via direct bonding.

**2**. The proximity sensor according to claim **1**, wherein the transmission circuit, the reception circuit, and the control circuit are provided on the in-head substrate.

**3**. The proximity sensor according to claim **1**, further comprising:

a cable that extends from the head housing; and

an amplifier housing that is connected to the head housing via the cable, wherein

the transmission circuit, the reception circuit, and the control circuit are provided in the amplifier housing.

**4**. The proximity sensor according to claim **1**, wherein the reception circuit includes:

a first reception circuit that detects a voltage or a current generated in the first coil; and

a second reception circuit that detects a voltage or a current generated in the second coil, wherein

the control circuit detects the detection object on a basis of a difference between the voltage or the current detected by the first reception circuit and the voltage or the current ditected by the second reception circuit.

**5**. The proximity sensor according to claim **1**, wherein the second coil is shorter than the first coil in a direction orthogonal to a radial direction of the second coil.

**6**. The proximity sensor according to claim **5**, wherein the second coil is disposed outside the first coil in the radial direction.

**7**. The proximity sensor according to claim **1**, wherein the second coil is located closer to a side where the detection object is detected than the first coil.

**8**. The proximity sensor according to claim **1**, further comprising

a core holder that holds the ferrite core, wherein

the core holder positions the second coil and fixes the ferrite core to the in-head substrate.

**9**. The proximity sensor according to claim **1**, further comprising a magnetic shield that is disposed outside the second coil in a radial direction, wherein

the magnetic shield includes a sheet member kneaded with ferromagnetic powder.

**10**. The proximity sensor of claim **1**, further comprising

an electric shield that is disposed outside the second coil in a radial direction, wherein

the electrical shield is formed with a cut across a direction around an axis of the electric shield.

**11**. The proximity sensor according to claim **10**, wherein the electric shield includes:

a peripheral portion covering the second coil from an outside of the second coil in the radial direction; and

a detection surface portion located on a side where the detection object is detected,

the cut is formed in the detection surface portion, and

the electrical shield is a press-molded product of a punched thin metal plate.

**12**. The proximity sensor according to claim **11**, wherein the cut is formed in the peripheral portion.

**13**. The proximity sensor according to claim **1**, wherein

the ferrite core has a shaft body passing through a hollow portion of the first coil, and

a ratio of a width of the shaft body to an entire width of the ferrite core in a radial direction of the first coil is 30% or less.

**14**. The proximity sensor according to claim **13**, wherein a ratio of a width of the shaft body to an entire width of the ferrite core in a radial direction of the first coil is 15% or more.

**15**. The proximity sensor according to claim **1**, wherein

the cable includes a first cable wire electrically connected to either a coil wire of the first coil or a coil wire of the second coil, and a second cable wire electrically connected to either a coil wire of the first coil or a coil wire of the second coil,

the first cable wire is connected to one surface of the in-head substrate, and the second cable wire is connected to another surface of the in-head substrate.

**16**. A proximity sensor comprising:

a coil that generates a magnetic field by an excitation current;

a ferrite core that guides the magnetic field generated from the coil;

a head housing that accommodates the coil and the ferrite core; and

a cable that extends from the head housing, wherein

the coil includes:

a first coil; and

a second coil disposed concentrically with the first coil,

the proximity sensor further comprises:

a transmission circuit that periodically applies a pulsed excitation current to the coil;

a reception circuit that detects a voltage or a current generated in at least one of the first coil and the second coil by the magnetic field which is changed by a detection object; and

a control circuit that detects the detection object on a basis of a change in the voltage or the current detected by the reception circuit, and

a coil wire of the first coil is electrically connected to the cable via direct bonding.

**17**. A proximity sensor comprising:

a coil that generates a magnetic field by an excitation current;

a ferrite core that guides the magnetic field generated from the coil; and

a head housing that accommodates the coil and the ferrite core, wherein

the coil includes:

a first coil;

a second coil disposed outside the first coil in a radial direction; and

a magnetic material that is located between the first coil and the second coil,

the proximity sensor further comprises:

a transmission circuit that periodically applies a pulsed excitation current to the coil;

a reception circuit that detects a voltage or a current generated in at least one of the first coil and the second coil by the magnetic field which is changed by a detection object; and

a control circuit that detects the detection object on a basis of a change in the voltage or the current detected by the reception circuit,

a diameter of a surface of the head housing capable of facing the detection object is less than 8 mm, and

a number of windings of the first coil is 100 or more.

**18**. The proximity sensor according to claim **17**, wherein a surface of the head housing capable of facing the detection object is made of metal.

**19**. The proximity sensor according to claim **17**, wherein a wire diameter of a coil wire of the first coil is 0.02 mm or less.

**20**. The proximity sensor according to claim **17**. further comprising

an in-head substrate that is accommodated in the head housing, wherein

a coil wire of the first coil is electrically connected to the in-head substrate via direct bonding.

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